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Morteza Ghobakhloo

Mohammad Iranmanesh
Edith Cowan University

Manuel E. Morales

Mehrbakhsh Nilashi

Azlan Amran

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Actions and approaches for enabling Industry 5.0-driven sustainable industrial transformation: A strategy roadmap

Morteza Ghobakhloo[1,2] | Mohammad Iranmanesh[3] | Manuel E. Morales[1] | Mehrbakhsh Nilashi[4] | Azlan Amran[5]

[1]School of Economics and Business, Kaunas University of Technology, Kaunas, Lithuania
[2]Division of Industrial Engineering and Management, Uppsala University, Uppsala, Sweden
[3]School of Business and Law, Edith Cowan University, Joondalup, Western Australia, Australia
[4]UCSI Graduate Business School, UCSI University, Kuala Lumpur, Malaysia
[5]Graduate School of Business, Universiti Sains Malaysia, Penang, Malaysia

Correspondence
Morteza Ghobakhloo, School of Economics and Business, Kaunas University of Technology, Kaunas, Lithuania.
Email: morteza_ghobakhloo@yahoo.com; morteza.ghobakhloo@ktu.lt

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Abstract

Although Industry 4.0 was believed to promote sustainable development, it has ignored or misunderstood many prevailing sustainability concerns, which led to the emergence of the Industry 5.0 agenda. While the desirable sustainability values of Industry 5.0 are widely acknowledged, the knowledge of how this agenda can deliver sustainable transformation is lacking. The present study addresses this knowledge gap, explaining how Industry 5.0 transformation should be managed to facilitate sustainable development. Therefore, this study strives to model the underlying mechanism for enabling such transformation. The study conducted a content-centric review of the literature and identified 11 actions and approaches that serve as enablers of Industry 5.0 transformation. The study further conducted the interpretive structural modeling and structured the enablers as an interpretive model explaining steps needed for enabling Industry 5.0. Finally, the study developed the strategy roadmap for enabling Industry 5.0 transformation and sustainable development. Results emphasized stakeholder salience, highlighting the enabling role of stakeholder integration and collaboration in Industry 5.0 transformation. Proactive governmental support is the most driving enabler of Industry 5.0, whereas eco-innovation and sustainable value network reformation are among the most complex and hard-to-develop enablers. Results offer several implications for policymakers and practitioners, explaining the functionality of each approach and strategy necessary for Industry 5.0 transformation. The roadmap determines the sequential relationships among these approaches and strategies and identifies their optimal development sequence for enabling Industry 5.0 transformation synergistically. Results further identify the codependences among the Industry 5.0 transition enablers and highlight their interactions and complementarities.

KEYWORDS
digital technology, environmental sustainability, human-centricity, Industry 5.0, resilience, sustainable industrial transformation

1 | INTRODUCTION

Even though the so-called Industry 4.0 paradigm is young and unfolding, academia and major European policy bodies are promoting a new wave of digital transformation known as Industry 5.0 (Ivanov, 2022). The unprecedented emergence of Industry 5.0 calls for exploring the emerging drivers of this new paradigm and explaining how it is positioned against prevailing socio-environmental concerns. Indeed, the economic and socio-environmental crises and challenges, such as social inequality, environmental degradation, and disruption caused by Covid 19 pandemic or the Ukraine–Russia conflict, require a deep systemic transformation that allows humans to live in peace, prosperity, and harmony with mother earth (Renda et al., 2022). Many believed that Industry 4.0 would provide such transformational power. Indeed, there has been much hype supporting the sustainable development implications of Industry 4.0 (Ng et al., 2022). However, a more realistic review of this phenomenon showed that while Industry 4.0 supports several aspects of sustainability at the micro-organizational level, it ignores or even misunderstands many micro and macro sustainability concerns such as employment disruption, workplace autonomy, digital divide, social exclusion, overconsumption, and unequal regional development (Ghobakhloo, Fathi, et al., 2021; Nara et al., 2021). The development of the new Industry 4.0 reality corresponded with the maturation of the Industry 5.0 concept. Industry 5.0 was initially introduced as the chronological continuation of Industry 4.0, which is pushed by the advancement of man–machine integration technologies (Longo et al., 2020; Nahavandi, 2019). Nevertheless, recent views introduce Industry 5.0 as a transformational movement complementary to Industry 4.0 that emphasizes sustainable development (Xu et al., 2021). Indeed, European Commission, in its recent policy brief, announced that Industry 4.0 could no longer serve as the appropriate framework for sustainable industrial transformation and alleviating contemporary socio-environmental crises. It is argued that Industry 4.0 lacks the necessary features to integrate circularity to value chains, promote social well-being, and prevent environmental degradation (Renda et al., 2022).

Industry 4.0 is only a decade old, and the hasty introduction of the Industry 5.0 concept has caused two notable controversies (Müller, 2020). First, industrial revolutions have always revolved around technological innovations, and the pulling power of the environmental and societal values of Industry 5.0 disrupts this tradition (Ghobakhloo, 2020). The most recent contributions to operationalizing the Industry 5.0 concept have addressed this controversy to a large extent. The latest academic and public views define Industry 5.0 as a technopolitical phenomenon (Sindhwani et al., 2022; Xu et al., 2021). Industry 5.0 is technological, as it still draws on technological capabilities to deliver the envisioned values (Lu et al., 2022). Industry 5.0 is also political, given that it draws on the regulatory and governance power of public actors and social groups to steer the industrial transformation toward human and environmental values (Breque et al., 2021). Second, Industry 4.0 is still unfolding and has yet to reach its full potential (Agrawal et al., 2022). The complete Industry 4.0 digital transformation has been primarily exclusive to industry leaders, and smaller businesses and classic supply chains have been struggling with the desirable implementation of Industry 4.0 technologies (Ghobakhloo et al., 2022). Correspondingly, the current understanding of the mechanism for the large-scale enabling of Industry 4.0 digital transformation is still under development (Chari et al., 2022). The circumstances are much worse when explaining how Industry 5.0 transformation can be facilitated since this novel phenomenon is more complex and transformative yet understudied. In other words, we know what sustainability values should be gained due to the Industry 5.0 transformation. However, the current understanding of how such desirable transformation under Industry 5.0 can be enabled is considerably lacking (Elangovan, 2022; Saniuk et al., 2022). Even though the literature has recently shown interest in introducing approaches that may play an enabling role, these contributions identified are somewhat sporadic, lacking cohesion and objectivity. For example, although Sindhwani et al. (2022) provided valuable insights into governing human-centric technology development to support Industry 5.0, the European Commission framework clearly outlines that technology governance could only be one of the many enabling mechanisms for Industry 5.0 transformation (Renda et al., 2022). The lack of a synoptic overview of how digital industrial transformation should be managed under Industry 5.0 would diminish the objectivity and cohesion needed by this forward-looking agenda to address the prevailing environmental crises and critical social tensions.

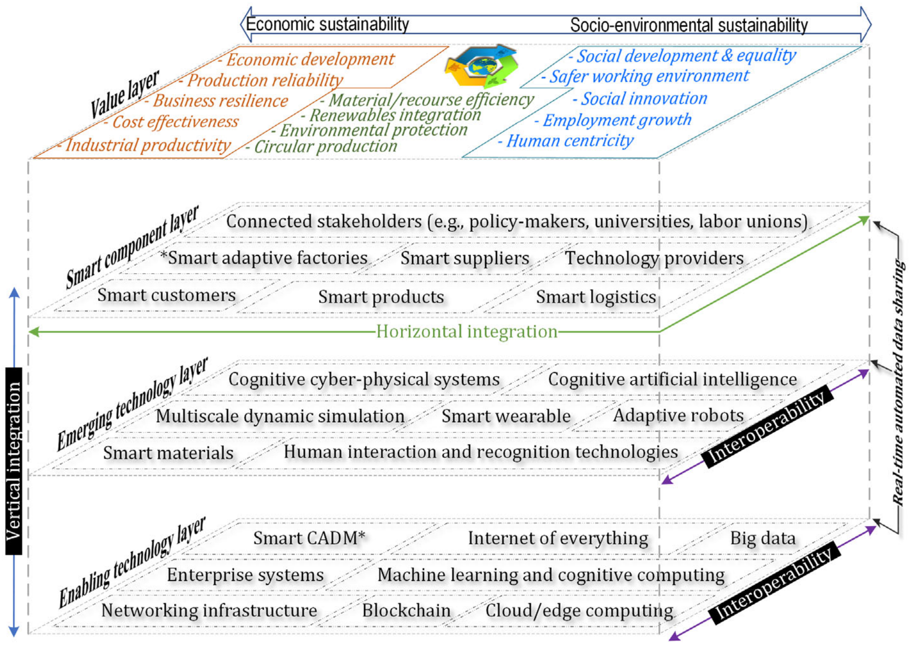
The present study strives to address this critical knowledge gap and provide a holistic overview of the process through which the large-scale transformation needed by Industry 5.0 objectives could be facilitated. Therefore, the core objective of this study involves developing a strategy roadmap that outlines how the enablers of Industry 5.0 should be managed and leveraged to promote the sustainability objectives of this paradigm. The study devises and implements a comprehensive roadmapping methodology to fulfill this core objective. First, the study conducts a content-centric review of the extant literature and identifies actions and approaches that have been reported to enable the Industry 5.0 transformation. Second, the study draws on the interpretive structural modeling (ISM) technique and experts' opinions to identify the sequential relationships among the enablers identified and develop an interpretive model of Industry 5.0 transformation. Third, the study draws on expert judgment to interpret the contextual relationships identified among enablers and develop the strategy roadmap that visualizes strategic actions and approaches essential to enabling Industry 5.0-driven sustainable industrial transformation. The study is among the first to address the strategic management of Industry 5.0 transformation. We believe the strategy roadmap and the underlying results would offer important implications for scholars, industrialists, social actors, and governments, as it provides a comprehensive definition of enablers, their functionality for Industry 5.0, and the sequence in which these enablers should be developed to maximize their synergetic enabling values. By doing so, the study could empower Industry 5.0 stakeholders to sustainably govern the digital transformation of industry and impartially prioritize economic growth objectives and socio-environmental values.

TABLE 1 A comparative review of previous studies contributing to the conceptualization of Industry 5.0.

Scholars	Type of research	Industry 5.0 conceptualization	Major findings and contributions
Özdemir and Hekim (2018)	Conceptual	Industry 5.0 is evolutionary and incremental, which builds on Industry 4.0 concept	Industry 5.0 uses digital technologies such as big data and IoT to democratize knowledge, leading society to a sustainable innovation ecosystem
Nahavandi (2019)	Conceptual	Industry 5.0 is an evolutionary step toward man–machine symbiosis	Industry 5.0 aims to address the human-centricity aspect of sustainability, where collaborate robots collaborate with operators instead of competing
Longo et al. (2020)	Empirical	Industry 5.0 represents a new revolution where cyber-physical manufacturing systems and human operators are integrated to realize CPPS and human agents to create the symbiotic factory concept	The value-oriented and ethical technology engineering is among the critical aspects of Industry 5.0
Xu et al. (2021)	Conceptual	Industry 5.0 is an evolutionary paradigm that complements Industry 4.0 by driving innovation to promote environmental and social values	Technologies that enable virtualization and man–machine integration are critical to Industry 5.0. Achieving the promised sustainability goals of Industry 5.0 might be challenging
Ivanov (2022)	Conceptual	Industry 5.0 is a multifaced phenomenon that draws on technological innovations, organizational principles, and managerial practices to promote sustainability	The scope of Industry 5.0 comprises corporations, supply networks, and society. It values value creation resilience, human-centricity, and societal needs
Ghobakhloo et al. (2022)	Empirical	Industry 5.0 represents a complementary exercise to industry 4.0 that draws on the role of society and industry to promote sustainability	Industry 5.0 can promote sustainable development via a complex mechanism involving several sustainability functions, such as value network integration
Huang et al. (2022)	Conceptual	Industry 5.0 is a futuristic paradigm that applies adaptable and flexible technological innovation to promote industry growth and socio-environmental preservation	Industry 5.0 and society 5.0 overlap and share several sustainability objectives. Human-CPS, employment, virtualization, and man–machine integration are the points of opportunity and challenge for Industry 5.0
Leng et al. (2022)	Conceptual	Industry 5.0 is a dynamic and evolving paradigm that pursues the vision of co-creative and shareholder-driven industrial development	Industry 5.0 sits at the intersection of Industry 4.0, Society 5.0, and Operator 5.0 concepts. Industry 5.0 is a holistic paradigm involving various industries and business sectors.
Maddikunta et al. (2022)	Conceptual	Industry 5.0 is evolutionary in the sense that it will use the creative outcome of man–machine symbiosis	Industry 5.0 is fundamentally technology-driven. Mass personalization is among the most critical goals of Industry 5.0. This work also describes the underlying technologies of Industry 5.0
Sharma et al. (2022)	Empirical	Industry 5.0 represent a revolutionary and disruptive innovation that reshapes the manufacturing paradigm, pushing a transition from a linear economic model to a circular economy	Industry 5.0 transformation can be impacted by a variety of technical enabling solutions and barriers such as costs, system interoperability, and falsified information
Sindhwani et al. (2022)	Empirical	Industry 5.0 is an extension of Industry 4.0, focusing on human-robot collaboration, digital technologies, and regulatory policies to develop a digital bioeconomy that promotes sustainability	Industry 5.0 relies on various technical enablers, such as bionics, virtual reality, digital twining, and IoT

2 | LITERATURE REVIEW

Industry 5.0 literature is young, and scholars have recently turned their attention to this phenomenon. Nevertheless, the definition of this phenomenon has evolved several times during the past few years. Table 1 compares previous studies offering essential contributions to the Industry 5.0 background. As one of the earlier contributions, Özdemir and Hekim (2018) argued that Industry 4.0 is excessively dependent on integration and hyperconnectivity. They proposed that Industry 5.0 draws on global technology governance to offer cyber resilience and develop hyperconnected digital networks that lead society to a sustainable innovation ecosystem. Scholars such as



Notes:
*CADM: Computer-aided design and manufacturing technologies such as 3D printers.
**Smart factories could be replaced with other smart entities depending on the industrial context. For example, smart hospitals would be a component of Industry 5.0 within the healthcare industry.

FIGURE 1 The reference model for Industry 5.0 (adapted from Ghobakhloo et al., 2022) [Colour figure can be viewed at wileyonlinelibrary.com]

Nahavandi (2019) and Demir et al. (2019) conceptualized Industry 5.0 as the revolution in man–machine symbiosis, arguing that this phenomenon would increase process efficiency by enhancing synergies among the human workforce and smart machines. In fact, a significant portion of the literature limited the scope of Industry 5.0 to man–machine symbiosis and associated issues such as ethical technology engineering (Longo et al., 2020), artificial intelligence-driven personal healthcare (Sung et al., 2020), and harmonization of human-technology union for resilience (Romero & Stahre, 2021). Overall, Table 1 implies that Industry 5.0 is embryonic, and the majority of contributions in the discipline have been at the theoretical/conceptual level. Previous studies offer various, and sometimes conflicting, perspectives on the conceptualization of Industry 5.0 and defining its core objectives. While early contributions offer invaluable insights into the enablers of Industry 5.0, most of the contributions are at the conceptual level, and the literature somewhat falls short in holistically describing the ecosystem under which Industry 5.0 would deliver its sustainability values.

The recent literature inclines toward a more holistic conceptualization of this phenomenon (Sindhwani et al., 2022; Xu et al., 2021). In particular, the European Commission took the initiative to formalize the Industry 5.0 framework in 2021. According to this framework, Industry 5.0 cannot be considered the chronological evolution of Industry 4.0. Instead, it complements and extends the advantages of Industry 4.0 by introducing environmental protection, human-centricity, and resilience as the core objectives (Breque et al., 2021). It took less than a year for the European Commission to extend its 2021 conceptualization of the phenomenon. Their policy brief explained that Industry 5.0 should move beyond the technology-driven growth of contemporary economic models of production and consumption. Instead, Industry 5.0 should steer industry transformation toward sustainable development and contribute to social development and well-being (Renda et al., 2022).

Following the European Commission's agenda, we define Industry 5.0 as a paradigm shift in the management of digital industrial transformation to achieve sustainable economic and socio-environmental development. Although the European Commission initiative has led to a consensus on the definition of Industry 5.0, the literature falls short in operationalizing this concept. Industry 5.0 is still a technological phenomenon because it relies on technological innovation to deliver its values (Müller, 2020). As shown in Figure 1, the technological constituents of Industry 5.0 consist of various classic (enabling) and emerging (disruptive) technologies that collectively drive the digital industrial transformation. The classic technologies pertain to information and digital technologies (IDT) and operations technologies (OT) that have become widely commercialized and accessible over the past few decades (ElFar et al., 2021). Although these technologies, such as enterprise resource planning or computer-aided design tools, have been around since the third industrial revolution, they continually evolve to meet the current business needs and play a critical role in propelling Industry 5.0 transformation (Martynov et al., 2019). Emerging technologies of Industry 5.0 refer to the latest disruptive technologies such as cognitive cyber-physical systems (CCPS), cognitive artificial intelligence (CAI), smart materials, internet of everything (IoE), or adaptive robots that reshape the models of value creation, production, and consumption (Xu et al., 2021). Under Industry 5.0, classic and emerging technologies combine to develop complex systems that facilitate the integration of Industry 5.0 components into hyperconnected and data-driven business ecosystems (Müller, 2020).

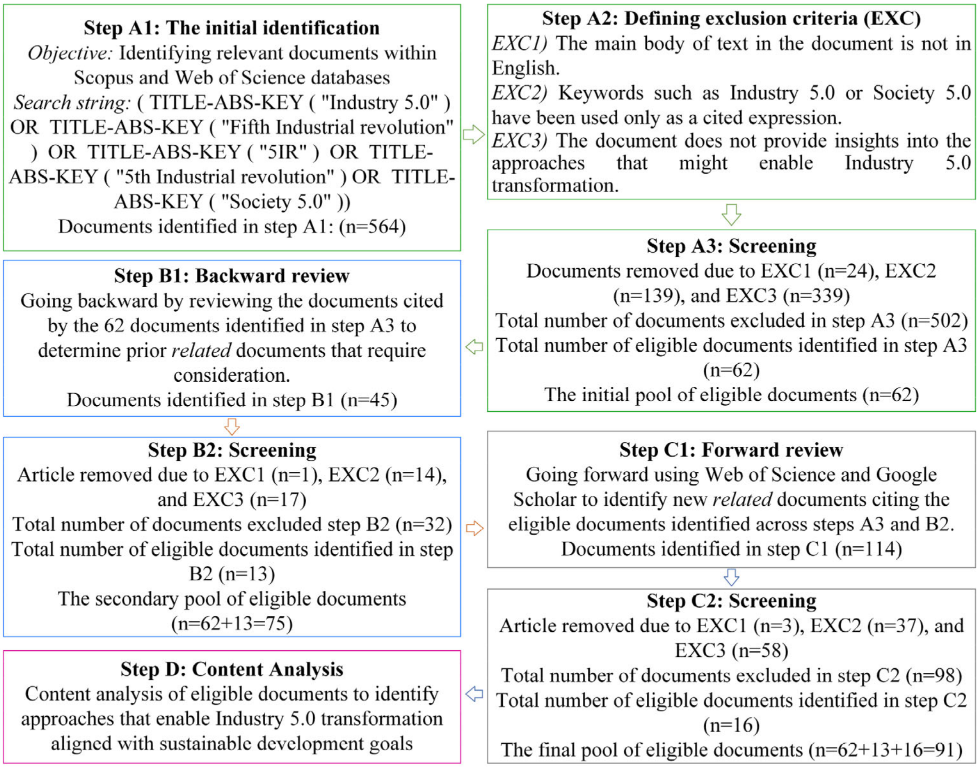


FIGURE 2 Steps performed for performing the content-centric review of the literature [Colour figure can be viewed at wileyonlinelibrary.com]

The business ecosystems of Industry 5.0 comprise many components, given that the digital transformational scope of this phenomenon expands beyond corporations (Alexa et al., 2022). The components of Industry 5.0 would be unique to the particular industrial contexts (Bulc et al., 2022; Martos et al., 2021). Smart factories, distributors, technology developers, consumers, suppliers, and products can be considered the smart components of the Industry 5.0 ecosystem within the manufacturing context (Lu et al., 2022; Xu et al., 2021). Contrary to Industry 4.0, which prioritizes shareholder value and short-term profitability, Industry 5.0 emphasizes stakeholder value and long-term socio-environmental sustainability (Breque et al., 2021). This fundamental difference in the functionality of the two concepts is comparatively evident in Figure 1. The literature widely acknowledges that Industry 4.0 is a productivity-driven phenomenon pushed by the rapid advancement of technological innovations (Grybauskas et al., 2022). It is why maximizing the shareholders' profitability is the primary objective of Industry 4.0 transformation among businesses (Huang et al., 2022). While Industry 4.0 positively impacts a variety of environmental sustainability indices, such as resource efficiency or emission reduction at the micro-operational level (Ng et al., 2022), these sustainability implications are somewhat inadvertent, achieved along with the productivity maximization goal of Industry 4.0. Nonetheless, as shown in Industry 5.0 reference model (Figure 1), stakeholders are among the fundamental components of Industry 5.0 since societal needs pull this phenomenon (Ghobakhloo et al., 2022). The value layer in Figure 1 reveals that Industry 5.0 equally prioritizes the three pillars of sustainability, attempting to strike a balance between economic growth and preserving socio-environmental values. Industry 5.0 agenda consistently recognizes that stakeholders' involvement in the management and governance of digital industrial transformation is indispensable to realizing the sustainability objectives (Renda et al., 2022).

The current Industry 5.0 framework publicized by the European Commission deeply aligns with the United Nation's sustainable development agenda, as it systematically pursues economic resilience, social development, environmental protection, human-centricity, and healthier distribution of wealth (Renda et al., 2022). Indeed, Industry 5.0 promises ambitious sustainability values, which require a profound transformation of business models, value structures, consumption norms, and public engagement (Sindhwani et al., 2022). The literature provides valuable insights into processes for enabling such transformations, albeit piecemeal (Sharma et al., 2022). The following sections address these enablers and their functionality.

2.1 | Identifying enablers of Industry 5.0

We followed the existing guidelines (Watson & Webster, 2020; Webster & Watson, 2002) and exemplars (Xiao & Watson, 2019) to perform a content-centric review of Industry 5.0 literature and identify enablers that support the industrial transformation needed for sustainable development goals of this phenomenon. This content-centric literature review process involved four main steps, as explained in Figure 2. In step A1 of the review process, we defined the search string and identified 564 potentially related documents. The search string also included the term "Society 5.0," given that Industry 5.0, primarily as defined by the European Commission, shares many features with the Society 5.0 concept (Breque et al., 2021;

Carayannis & Morawska-Jancelewicz, 2022). Step A2 involved defining the exclusion criteria. The screening of documents identified in step A1 was performed in step A3, in which we subjected the documents to the three exclusion criteria. This process resulted in excluding 502 documents and assigning 62 documents to the initial pool of eligible documents. In step B1, we conducted the backward review process and identified 45 new documents worthy of consideration. The exclusion criteria were applied to these new documents in step B2, recognizing 32 documents as ineligible. Thus, we recognized 13 new documents as eligible for content analysis and developed a secondary pool of 75 (62 + 13) eligible documents. As explained in Figure 2, we performed the forward review process in step C1 and identified 114 new documents. By applying the exclusion criteria to them, we removed 98 ineligible documents and shortlisted 16 new eligible documents. Step C2 led to the final pool of 91 (62 + 13 + 16) eligible documents.

Step D of the review process involved conducting the conceptual content analysis of eligible articles. Following the widely accepted guidelines (Krippendorff, 2018; Neuendorf, 2017), we developed and implemented a comprehensive content analysis framework to ensure the reliability (e.g., coder stability or classification accuracy) and validity of outcomes. The framework detailed all the necessary steps for performing the conceptual content analysis, such as analysis levels (e.g., concepts vs. themes), interactivity of the coding scheme, coding system goals, coding rules, pattern identification rules, and denoising procedure for distinguishability and applicability. Two content assessors independently performed the qualitative assessment of eligible documents to minimize assessor bias. Content assessors were ensured to have the necessary expertise on the topic, understand the research questions, and adhere to the content analysis framework. After completing the initial individual content analysis, the content assessors shared their findings in a series of meetings, collaboratively tracked the disagreements, and reached a shared consensus on the enablers of Industry 5.0 transformation as perceived by the literature. Overall, step D identified 11 enablers of driven sustainable industrial transformation under Industry 5.0. The 11 enablers include digital transformation competency, eco-innovation, proactive governmental support, resource availability and capabilities, stakeholder collaboration, stakeholder integration, sustainability orientation and thinking, sustainability performance management, sustainable corporate governance, sustainable value network reformation, and technology governance. Each of these enablers will be explained under the ISM methodology.

3 | METHODS

The present study draws on the methodology recommended by Ghobakhloo, Iranmanesh, et al. (2021); Ghobakhloo et al. (2022) to develop the strategy roadmap for enabling Industry 5.0-driven sustainable industrial transformation. At the macro policy scale, a strategy roadmap denotes a reference agenda for actors and stakeholders involved in developing a transformation framework. Such a roadmap should clearly explain the organization of the agenda, particular activities, and the needed interactions to fulfill the intended objectives. To bridge this gap between vision and actions, a roadmap should provide the stakeholders with a visual representation of how to execute a strategy and describe vital results that could be sequentially achieved. Accordingly, for the promised strategy roadmap in this study, the *actions* component of the strategy roadmap would refer to enablers of Industry 5.0 transformation. The *interaction identification* component of the strategy roadmap would entail identifying contextual precedence relationships among the enablers. Finally, explaining the *'how'* question regarding the interactions of the enablers involves describing the functionality of each contextual relationship. The study draws on the ISM technique to identify the contextual relationships among the enablers of Industry 5.0 transformation and develop the model of Industry 5.0-driven sustainable industrial transformation. ISM is a widely acknowledged decision support technique to explore complex issues in a structured manner (Chauhan et al., 2022). The underlying mechanism for enabling Industry 5.0 transformation is largely unexplored, and ISM can serve the present study as a valuable technique for the exploratory analysis of this phenomenon. Compared to other decision analytics and support techniques such as *analytic hierarchy process* or *decision-making trial and evaluation laboratory*, ISM provides the following advantages that best serve the present study:

1. The primary goal of this study is to offer a strategy roadmap that explains the order in which enablers of Industry 5.0 should be developed and leveraged. ISM excels in satisfying this objective as it identifies such order in terms of determining the relative importance of each enabler. Furthermore, the ISM identifies the precedence relationships among the enabler and explains the complexity of existing contextual relationships.
2. Another fundamental aspect of strategy roadmapping is to explain the 'how' question related to the role of each enabler. While ISM is inherently limited to interpreting notes and struggles with describing the functionality of each contextual relationship, it supports the integration of the interpretive model with the results of MICMAC analysis as well as the interpretive logic-knowledge base (ILB). This feature satisfies this particular requirement of strategy roadmapping.

Our decision to employ ISM is in line with comparable recent studies that have used this technique to explore the implications of Industry 4.0 for energy sustainability (Ghobakhloo & Fathi, 2021), circular economy (Kumar et al., 2021), or sustainable manufacturing (Ng et al., 2022). Steps undertaken for performing ISM in the study are visually demonstrated in Figure 3. These steps have been widely acknowledged and used within the ISM literature (e.g., Ghobakhloo, Iranmanesh, et al., 2021; Krishnan et al., 2021).

3.1 | Enablers of Industry 5.0

As explained in section 2.1, the content-centric review of Industry 5.0 literature in this study led to identifying 11 enablers for Industry 5.0 transformation. Each of the enablers is briefly elaborated on in the following.

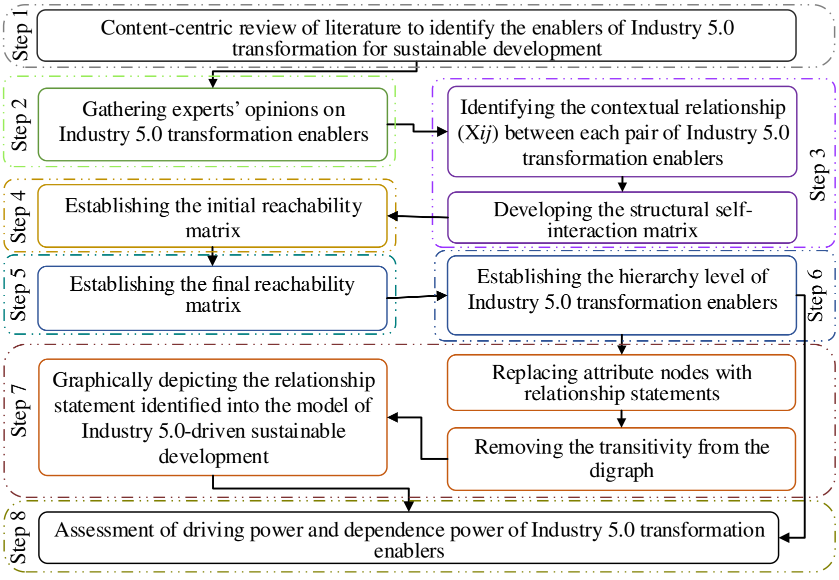


FIGURE 3 Steps applied for performing interpretive structural modeling technique [Colour figure can be viewed at wileyonlinelibrary.com]

3.1.1 | Digital transformation competency

Industry 5.0 is a technopolitical phenomenon requiring value network members to implement emerging technological innovations and become an integrated part of the hyper-connected value network (Cillo et al., 2021). Thus, businesses should have the necessary competency to implement and integrate the technological constituents of Industry 5.0, such as blockchain, CAI, adaptive robots, or digital twins (Müller, 2020; Xu et al., 2021). More importantly, businesses should be competent in developing the functional design principles of Industry 5.0, such as real-time capability, vertical or horizontal integration, and decentralization. Digital transformation competency (DTC) involves various digitalization competencies, including knowledge, technical, and strategic management (Lu et al., 2022). Knowledge competency refers to the availability of digitalization specialists and the adequacy of expertise in various information and operations technology (IT/OT) disciplines, such as user interface design, process automation, software engineering, data science, robotics engineering, and networking architecture (Ghobakhloo & Iranmanesh, 2021). The technical competency aspect of DTC entails back-end system integration readiness, IT/OT standardization, infrastructure integrability, and cybersecurity readiness (Ghobakhloo et al., 2022; Müller, 2020). Strategic management competency involves businesses having the necessary competencies to develop an Industry 5.0 transformation roadmap, manage the underlying technological transformation, and develop digitalization risk management capability (Aslam et al., 2020).

3.1.2 | Eco-innovation

As a critical enabler of Industry 5.0, eco-innovation (EOI) entails new approaches that promote sustainable development goals (Aslam et al., 2020). Environmental innovation and social innovation are the two constituents of EOI. Environmental innovation refers to implementing novel solutions and changes that allow business products, processes, and services contribute to a more environmentally sustainable economy (Ghobakhloo, Iranmanesh, et al., 2021). Social innovation entails improving society's well-being, welfare, and social needs by introducing and implementing innovative solutions that propel the necessary changes in the products, processes, business models, and collaborations (Terstriep et al., 2020). The enabling role of EOI involves allowing Industry 5.0 stakeholders to strike a balance between economic productivity and socio-environmental sustainability (Nahavandi, 2019). EOI can serve the economic resilience objective of Industry 5.0 by allowing businesses to identify novel growth opportunities, improve brand image, reduce operational costs, and proactively respond to market dynamics (Breque et al., 2021). EOI further allows value networks to reduce the impact of production and consumption modes on the environment and promote the circular economy (ElFar et al., 2021). Alternatively, the enabling role of EOI for social values of Industry 5.0 involves smartification of the work environment, improving customer satisfaction, and creating business modes that promote value chain inclusivity (Nahavandi, 2019; Sindhwani et al., 2022).

3.1.3 | Proactive governmental support

Industry 4.0 historical data has shown that public sectors, primarily governments, have not successfully regulated the pace or direction of digital transformation across various industries and regions (Ghobakhloo et al., 2022). Indeed, the ongoing digital transformation has been criticized for its adverse effects on socio-economic challenges, such as political instability, unbalanced regional development, and inequitable pace of digitalization among regions, industries, companies, and even individuals (Potočan et al., 2021). Learning from the Industry 4.0 phenomenon, Industry 5.0 requires a new form of government support to ensure that future industries can empower sustainable development. Proactive governmental support (PGS) can enable Industry 5.0 by synchronizing public policies with the pace of digitalization, improving the alignment between the public and private sectors (Renda et al., 2022). The regulating aspect of PGS for Industry 5.0 may involve various initiatives, from redefining policy processes or readjusting policy designs and structures to enforcing private actors to new socio-environmental compliance processes (OECD, 2019). The supportive part of PGS may involve new research and innovation funding or incentives to streamline the development of new economic models, industrial ecosystems, or market dynamics that support core values of Industry 5.0, such as job creation, open innovation, carbon neutrality, and value chain inclusivity (Datta & Nwankpa, 2021).

3.1.4 | Resource availability and capabilities

Corporate digitalization under Industry 5.0 is expectedly resource-intensive, requiring considerable investment in the acquisition, development, and implementation of underlying technologies and digital capabilities (Fraga-Lamas et al., 2021). Corporate digitalization and transformation under Industry 5.0 would be continuous and dynamic, given that the innovation cycles are progressively shortening (Maddikunta et al., 2022). The transition toward Industry 5.0 requires businesses to allocate the necessary resources continuously, a major upfront financing, and longer payback periods, which highlights a need and opportunity for strategically shifting away from conventional expectations regarding return on investment and payback periods (Jabbour et al., 2019). Thus, resource availability and capabilities (RAC) involves the availability of financial capital to support technology acquisition, Industry 5.0 research & development, and training or acquiring digitalization expertise (Ghobakhloo et al., 2022). More importantly, RAC also involves matching the capability of available resources to the requirements of Industry 5.0 digital transformation operations. For example, Industry 5.0 transformation requires inter-functional and interdepartmental collaboration within and among corporations (Renda et al., 2022). Time, human resources, and communication technologies are raw resources needed for enabling such collaboration (Ghobakhloo & Iranmanesh, 2021). Nonetheless, resources should be combined to match the required mechanism for collaboration, such as mutual trust, decision processes, or commitment (Köhler et al., 2022). Therefore, RAC also involves the organizational ability to combine or integrate resources, draw on their complementarities, and develop capabilities and further competencies that empower corporate digital transformation under Industry 5.0 (Orji, 2019).

3.1.5 | Stakeholder collaboration

The scope of Industry 5.0 expands beyond the digital transformation of individual corporations (Xu et al., 2021). Industry 5.0 requires the transformation of business processes, reconfiguration of supply chains, circularization of consumption modes, and synchronization of the public sector (Elangovan, 2022). Indeed, Industry 5.0 stakeholders need to align with the systemic transformation agenda of Industry 5.0 and collaboratively develop the culture of social dialog (Breque et al., 2021). Therefore, stakeholder collaboration (STC) involves enabling processes that allow Industry 5.0 stakeholders, including corporations, government, communities, and labor unions, to transparently communicate their needs, expectations, and conflicts of interest to collaboratively shape the direction of industrial transformation to meet Industry 5.0 core sustainable development objectives (Renda et al., 2022). Accordingly, STC involves Industry 5.0 stakeholders working together to design and implement the necessary legal frameworks, industry policies, innovation, and job creation & upskilling/reskilling initiatives (Saniuk et al., 2022; Sindhwani et al., 2022).

3.1.6 | Stakeholder integration

Horizontal and vertical integrations are familiar terms from the Industry 4.0 framework (Ng et al., 2022). Vertical integration denotes connecting and integrating all micro-components of an organization, establishing seamless data interchange across various business units, from warehousing to smart production systems (Tabim et al., 2021). While the enabling role of vertical integration remains unchanged for Industry 5.0, the scope and implication of horizontal integration extend to stakeholder integration under this phenomenon (Alexa et al., 2022). Contrary to Industry 4.0 that focuses on horizontal integration of all supply chain modules, Industry 5.0 entails the horizontal integration of the underlying smart components and stakeholders for a given value network, including smart business units (e.g., adaptive smart factories), customers, distributors, suppliers, technology providers, government bodies, local communities, and labor unions (Akundi et al., 2022; Renda et al., 2022). Stakeholder integration (STI) is critical to achieving Industry 5.0 sustainablity values as it promotes data transparency, environmental accountability, open innovation, skill development, infrastructural development, and systemic green transformation of Industries (Breque et al., 2021; Frederico, 2021).

3.1.7 | Sustainability orientation and thinking

This enabler concerns the capacity of individuals, corporations, supply chains, and stakeholders to value environmental protection and societal development (Carayannis & Morawska-Jancelewicz, 2022). Sustainability orientation and thinking (SUO) can ensure that Industry 5.0 actors have the capacity and willingness to engage with economic disruptions and prevailing socio-environmental challenges (Saniuk et al., 2022). For this to happen, Industry 5.0 actors should understand the complex interactions among cultural, political, economic, societal, and environmental ecosystems, allowing them to predict the impact of their decisions on sustainability and develop a sense of responsibility for the future generation's well-being (Renda et al., 2022). The scope of SUO drastically changes according to the particularity of Industry 5.0 actors. For example, SUO for smart consumers may involve developing more sustainable consumption behavior such as paying more for green products, preventing waste, or prolonging products' life (Torres-Ruiz et al., 2018). For corporations, SUO can entail developing the core competencies for integrating cleaner technologies, implementing corporate social responsibility, or creating shared value to ensure competitiveness while positively impacting the environment and society (Winans et al., 2021). Overall, the comprehensive development of SUO among Industry 5.0 actors is crucial to many sustainability micro-objectives of this phenomenon, such as supply chain resilience, renewable integration, product circularity, employee well-being, and waste reduction.

3.1.8 | Sustainability performance management

Industry 5.0 ambitiously aims for a wide variety of micro and macro sustainability objectives (Sindhwani et al., 2022). Therefore, new sustainability performance management (SPM) systems should be introduced to realistically measure the progress toward what matters under Industry 5.0 (Akundi et al., 2022). The SPM for Industry 5.0 should evolve from traditional financial metrics and industrial profit-centricity and introduce adaptive sustainability metrics idiosyncratic to each industrial ecosystem (Renda et al., 2022; Sharma et al., 2022). For example, SPM can promote the circularity objective of Industry 5.0 by setting new targets or indicators, such as 'material recycling rate' and 'trade in recyclable raw materials,' that monitor the transitioning of industrial sectors toward the circular economy (Rincón-Moreno et al., 2021). SPM enables Industry 5.0 by allowing regulatory bodies to track the progress toward sustainable development objectives, make data-driven decisions on the sustainability trajectory of this phenomenon, and take a proactive leading role in developing the necessary managerial best practices or policy tools for steering industry transformation toward sustainability (Fraga-Lamas et al., 2021; Shanmugam et al., 2022).

3.1.9 | Sustainable corporate governance

Corporate governance denotes the system of governing, controlling, managing, and strategizing corporate goals and directions (Manita et al., 2020). Good corporate governance is indispensable to sustainability as it facilitates supporting conditions such as transparency, business integrity, and accountability (Alkaraan et al., 2022). Nowadays, most corporations follow the 'shareholder primacy' corporate governance model, prioritizing shareholder interests, mainly manifested in the incentive scheme and short-term value gains (Zaman et al., 2022). Indeed, there is no strong evidence suggesting that Industry 4.0 has pushed the transition from the shareholder capitalism model toward the stakeholders model with more sustainable corporate governance (Renda et al., 2022). Corporations are at the center of the systemic transformation needed by Industry 5.0. Businesses need to incorporate more sustainable models of corporate governance to adjust and align their actions with the core objectives of Industry 5.0, such as human-centricity, resilience, and environmental protection (Breque et al., 2021). Sustainable corporate governance (SCG) enables Industry 5.0 by requiring corporations to integrate sustainability goals into their corporate and business strategies and implement time-bound and measurable metrics to monitor progress toward Industry 5.0 goals (Renda et al., 2022). SCG would empower businesses to align the benefits and interests of shareholders, stakeholders, the environment, and society, allowing them to pursue sustainable value creation (Zhang, Chen, et al., 2021).

3.1.10 | Sustainable value network reformation

The transition from neoliberal capitalism economic models toward stakeholder primacy under Industry 5.0 involves de-risking value networks and building value chains that are more resilient, circular, and environmentally sustainable (Carraresi & Bröring, 2021). Sustainable value network reformation (SVR) entails developing digital supply networks that are more modular, decentralized, and adaptive (Maddikunta et al., 2022). Under SVR, modularization involves addressing the ever-increasing complexity of contemporary supply chains by transforming their linear designs into more circular and dynamic designs (Tseng et al., 2022). Modularization uses modern technologies to digitalize supply chain notes (e.g., production facilities or distribution channels) and transfer them into reconfigurable modules to develop interconnected dynamic supply networks that create new business models and profit tools (Ghobakhloo, Iranmanesh, et al., 2021). Decentralization allows value network modules to operate autonomously and make decentralized decisions. The adaptability aspect of SVR entails leveraging modularity and decentralization capabilities to adjust the value network's design to ongoing or imminent structural shifts in the markets (Toktaş-Palut, 2022). SVR is indispensable to Industry 5.0 objectives as its underlying mechanisms facilitate supply chain agility, product adaptation, renewable integration, circular production, and sustainable business models (Zhang, Wang, et al., 2021).

3.1.11 | Technology governance

Similar to Industry 4.0, technological advancement and innovation are the primary drivers of industrial transformation and the resulting economic productivity and human well-being promised by Industry 5.0 (Thakur & Kumar Sehgal, 2021). Nonetheless, the Collingridge dilemma would still hold for Industry 5.0, implying that the development of disruptive technological innovations in the area of AI, robotics, simulation, virtualization, and man–machine symbiosis may very well cause a double-bind problem: (1) the unpredictability of the scope and extent of impacts until Industry 5.0 technological innovations are diffused extensively, and (2) difficulty to control and change technologies when they have become entrenched (OECD, 2022; Özdemir, 2018). Although the diffusion of novel technologies has been consistently associated with major socio-economic drawbacks such as the digital divide or social exclusion, the problems do not necessarily lie within the technology advancement per se. The lack of technology governance has been a significant barrier to the contribution of technology to sustainability goals (Corsi et al., 2020). Indeed, the Industry 4.0 experience showcased how technological innovation outpaced the legal systems due to improper or inadequate technology governance (Tay et al., 2021). Therefore, the enabling role of technology governance (TGV) involves integrating administrative, sociopolitical, economic, and environmental authority into the design, diffusion, implementation, and operation of Industry 5.0 technologies in societies and industries (Nelson & Gorichanaz, 2019). TGV can regulate the pace of the digital technological revolution via numerous mechanisms, such as integrating accountability routines into research and development agendas or promoting public engagement in developing necessary practical and design standards for new technologies (Xu et al., 2021; Yang et al., 2022).

3.2 | Gathering expert opinion

Figure 3 explains that the second step in performing ISM involves gathering experts' opinions. The research team followed the existing guides (e.g., Hertzum, 2014, 2017) and developed a robust expert identification and selection protocol to ensure the validity of outcomes and avoid potential bias. Following the protocol, the research team collaborated with the partner network and identified 19 European experts potentially eligible to take part in identifying the relationships among the enablers. The study focused on European experts for two primary motives. First, the present study was supported by an H2020 ERA Chair program funded by the European Commission, allowing us to draw on the existing resources and connections to approach experts and have their participation agreement. Second, Industry 5.0, as perceived in the present study, is primarily a European framework, rendering European experts more eligible to participate. The study approached the 19 experts, inviting them to participate in the preliminary eligibility assessment step. This preliminary step involved experts answering a few self-assessment questions to measure their familiarity and experience with the Industry 5.0 phenomenon. Out of the 19 experts, 16 agreed to participate in the self-assessment step, out of whom 12 were identified as eligible to attend the expert panel meetings. Two eligible experts could not participate in the expert panel meeting due to personal issues. As a result, 10 experts participated in the expert panel meeting step. The experts comprised four females and six males, all academicians with experience collaborating with various European Union research programs in related research contexts such as sustainable development, digital transformation, resilient smart economy, or circular economy.

Experts' opinions on the enablers of Industry 5.0 transformations were collected across four online meetings. The nominal group technique (NGT) was used as the primary approach for idea generation and decision-making across the expert panel meetings. NGT offers various advantages, such as encouraging and offering fair opportunities for contributions from all experts, and its application has been widely acknowledged within prior ISM-based studies (e.g., Ghobakhloo, 2020). Following the widely accepted NGT methodology (e.g., Ng et al., 2022), each NGT-based expert panel meeting involved five stages, namely (1) introduction, (2) silent idea generation, (3) idea sharing, (4) group discussion, and (5) voting and decision making. The *introduction* stage involved the moderator explaining the purpose of the meeting and the underlying procedures to follow. In the *silent idea generation* stage, each participant was provided with a standardized online note sheet so that they could record their ideas concerning a given topic. The *idea-sharing* stage involved the mediator inviting each expert to share ideas they generated. The moderator recorded all the ideas generated within the electronic flip chart online, and this round-robin process continued iteratively until all experts shared their ideas. The *group discussion* stage involved experts verbally expressing and discussing ideas. The moderator ensured the equitable participation of each expert in this stage. Finally, in the *voting and decision-making* stage, experts collectively voted on the prioritized ideas and arrived at a collective agreement on the given topic. During the first meeting, the 11 enablers and their description identified across the content-centric literature review were presented to the experts. Besides recommending a few minor corrections to the labeling, experts confirmed the overall structure and inclusiveness of the enablers. Experts further identified the contextual relationships among each pair of enablers as well as their functionalities across meetings 2, 3, and 4. All expert panel meetings adhered to the five NGT stages. However, the duration and extent of each stage varied depending on the core objectives of each meeting.

3.3 | Identifying contextual relationships

Following the standard ISM methodology (Kumar et al., 2021), identifying the contextual relationships among enablers of Industry 5.0 transformation involves constructing the structural self-interaction matrix by subjecting the experts' opinions to the following coding system: V: Enabler i causes enabler j; A: Enabler i is caused by enabler j; X: Enablers i and j mutually cause each other; O: Enablers i and j are independent.

Table 2 represents the structural self-interaction matrix of the study. Symbols in this table should be interpreted according to the coding scheme explained above. For example, the STC-SUO entry in Table 2 is symbolized as X, meaning STC and SUO cause each other.

3.4 | Establishing initial reachability matrix

In this step, the symbols in the structural self-interaction matrix should be subjected to the following transition rules to establish the initial reachability matrix.

If the entry (i, j) in the structural self-interaction matrix is symbolized by V, the entries (i, j) and (j, i) in the initial reachability matrix should, respectively, be set to 1 and 0; if the entry (i, j) in the structural

TABLE 2 The structural self-interaction matrix for enablers of Industry 5.0 transformation

Enablers	TGV	SVR	SCG	SPM	SUO	STI	STC	RAC	PGS	EOI	DTC
Digital transformation competency (DTC)	O	V	O	O	O	V	O	A	A	V	–
Eco-innovation (EOI)	A	A	A	O	A	O	A	A	O	–	
Proactive governmental support (PGS)	V	O	V	V	V	V	O	V	–		
Resource availability and capabilities (RAC)	O	O	V	O	V	O	O	–			
Stakeholder collaboration (STC)	V	V	O	V	X	A	–				
Stakeholder integration (STI)	V	V	O	V	O	–					
Sustainability orientation and thinking (SUO)	V	V	V	O	–						
Sustainability performance management (SPM)	O	O	O	–							
Sustainable corporate governance (SCG)	V	O	–								
Sustainable value network reformation (SVR)	O	–									
Technology governance (TGV)	–										

TABLE 3 The initial reachability matrix for enablers of Industry 5.0 transformation

Enablers	DTC	EOI	PGS	RAC	STC	STI	SUO	SPM	SCG	SVR	TGV
Digital transformation competency (DTC)	1	1	0	0	0	1	0	0	0	1	0
Eco-innovation (EOI)	0	1	0	0	0	0	0	0	0	0	0
Proactive governmental support (PGS)	1	0	1	1	0	1	1	1	1	0	1
Resource availability and capabilities (RAC)	1	1	0	1	0	0	1	0	1	0	0
Stakeholder collaboration (STC)	0	1	0	0	1	0	1	1	0	1	1
Stakeholder integration (STI)	0	0	0	0	1	1	0	1	0	1	1
Sustainability orientation and thinking (SUO)	0	1	0	0	1	0	1	0	1	1	1
Sustainability performance management (SPM)	0	0	0	0	0	0	0	1	0	0	0
Sustainable corporate governance (SCG)	0	1	0	0	0	0	0	0	1	0	1
Sustainable value network reformation (SVR)	0	1	0	0	0	0	0	0	0	1	0
Technology governance (TGV)	0	1	0	0	0	0	0	0	0	0	1

self-interaction matrix is symbolized by A, the entries (*i*, *j*) and (*j*, *i*) in the initial reachability matrix should, respectively, be set to 0 and 1; If the entry (*i*, *j*) in the structural self-interaction matrix is symbolized by X, the entries (*i*, *j*) and (*j*, *i*) in the initial reachability matrix should both be set to 1; if the entry (*i*, *j*) in the structural self-interaction matrix is symbolized by O, the entries (*i*, *j*) and (*j*, *i*) in the initial reachability matrix should both be set to 0.

Table 3 represents the initial reachability matrix of the study. This table has been developed by applying the rules above to the self-interaction matrix of the study. For example, both STC-SUO and SUO-STC entries in Table 3 have been set to 1, given that the STC-SUO entry in Table 2 has been symbolized as X.

3.5 | Establishing final reachability matrix

Establishing the final reachability matrix (FRM) entails applying the transitivity law to the initial reachability matrix. Transitivity law explains that when factor a causes factor b, and factor b causes factor c, then factor a is assumed to cause factor c inadvertently (Krishnan et al., 2021). The FRM of the study is presented in Table 4, in which 1* values signify the transitivity law. For example, the value of the DTC-STC entry in Table 4 has been represented as 1*. Although DTC does not directly cause STC (DTC-STC entry in Table 3 is 0), DTC directly causes STI (DTC-STI entry in Table 3 is 1), and STI directly causes STC (STI-STC entry in Table 3 is 1). Therefore, the transitivity law is applied to the DTC-STC relationship, and its value is set to 1* within Table 4. This table also lists each enabler's driving and dependence powers while accounting for the transitivity law. Driving power and dependence power for a given enabler, respectively, refer to the number of enablers it causes and is caused by.

3.6 | Identifying hierarchy level

This step requires identifying the hierarchy levels of system components (enablers of Industry 5.0 in this study). The hierarchy levels identified will be further used to establish each enabler's placement level within the structural model. This process involves drawing on the FRM to establish each enabler's reachability, antecedent, and intersection sets. The reachability set for a given enabler consists of itself and the enablers it causes, whereas the antecedent set includes the enabler itself and other enablers that it is caused (determined) by. Enablers shared across an enabler's reachability set and antecedent set constitute its intersection set. The iterative identification of hierarchy levels can begin by establishing the reachability, antecedent, and intersection sets of all enablers. This process involves identifying enablers with identical reachability and intersection sets and extracting them from the proceeding iterations. The iterative extraction of enablers continues until the hierarchy levels of all enablers are identified. Table 5 represents the hierarchy levels of Industry 5.0 transformation enablers. This table shows that the hierarchy levels of the enablers have been identified across eight iterations. For example, EOI and SPM are the two enablers with identical reachability and intersection sets, which have been extracted in iteration 1.

3.7 | Constructing the structural model

The structural model is constructed by translating the hierarchy levels of enablers into the order in which they should visually appear within their designated placement levels. The number of placement levels in the structural model corresponds to the number of iterations. However, the placement order in the model would be the direct opposite of the iteration sequence, meaning the enablers identified in iteration 1 would appear in placement level 8 of the structural model and vice versa. Figure 4 represents the structural model of the study, in which the enablers have been positioned across the eight placement levels. Following the standard ISM procedure (Ghobakhloo, Iranmanesh, et al., 2021), transitivity law is ignored while visualizing the causal relationships within the structural model. Therefore, only the direct relationships between enablers positioned in the *successive* placement levels would be visually depicted by vector arrows. Since no enablers directly determine SUO in placement level 6, the SUO-TGV relationship is exceptionally presented by a vector arrow despite these enablers not belonging to successive placement levels. The model and underlying relationships will be scrutinized in the discussion section.

3.8 | Driving and dependence power analysis

This step involves constructing the MICMAC matrix according to the driving power and dependence power values identified within the FRM. Figure 5 represents the MICMAC analysis of Industry 5.0 transformation enablers. This matrix consists of four quadrants. The driver quadrant comprises enablers with strong driving power but weak dependence power. PGS, RAC, SUO, DTC, and STI are the driver enablers of the study. These enablers have greater relative importance, and their fulfillment should be prioritized under the Industry 5.0 transformation agenda. The linkage quadrant would involve enablers with strong driving and dependence powers. STC is the only linkage enabler of Industry 5.0 transformation, meaning it plays an essential role in transferring the value of driver enablers to more dependent enablers. The autonomous quadrant consists of enablers with weak driving and dependence powers. SCG is the only autonomous enabler of Industry 5.0 transformation because it has weak driving and dependence power. Since this enabler has lower relative importance than the driver and linkage enablers, it will take less strategic priority in Industry 5.0 transformation. Enablers with weak driving power but strong dependence power would be clustered under the dependent quadrant. SVR, TGV, SPM, and EOI are the four

TABLE 4 The final reachability matrix for enablers of industry 5.0 transformation

Enablers	DTC	EOI	PGS	RAC	STC	STI	SUO	SPM	SCG	SVR	TGV	Driving power	Rank
Digital transformation competency (DTC)	1	1	0	0	1*	1	0	1*	0	1	1*	7	4
Eco-innovation (EOI)	0	1	0	0	0	0	0	0	0	0	0	1	7
Proactive governmental support (PGS)	1	1*	1	1	1*	1	1	1	1	1*	1	11	1
Resource availability and capabilities (RAC)	1	1	0	1	1*	1*	1	0	1	1*	1*	9	2
Stakeholder collaboration (STC)	0	1	0	0	1	0	1	1	1*	1	1	7	4
Stakeholder integration (STI)	0	1*	0	0	1	1	1*	1	0	1	1	7	4
Sustainability orientation and thinking (SUO)	0	1	0	1*	1	0	1	1*	1	1	1	8	3
Sustainability performance management (SPM)	0	0	0	0	0	0	0	1	0	0	0	1	7
Sustainable corporate governance (SCG)	0	1	0	0	0	0	0	0	1	0	1	3	5
Sustainable value network reformation (SVR)	0	1	0	0	0	0	0	0	0	1	0	2	6
Technology governance (TGV)	0	1	0	0	0	0	0	0	0	0	1	2	6
Dependence power	3	10	1	3	6	4	5	6	5	7	8		
Rank	7	1	8	7	4	6	5	4	5	3	2		

TABLE 5 The hierarchy levels for enablers of Industry 5.0 transformation

Enablers	Reachability set	Antecedent set	Intersection set	Extraction level
Iteration 1				
DTC	DTC, EOI, STC, STI, SPM, SVR, TGV	DTC, PGS, RAC	DTC	
EOI	EOI	DTC, EOI, PGS, RAC, STC, STI, SUO, SCG, SVR, TGV	EOI	1
PGS	DTC, EOI, PGS, RAC, STC, STI, SUO, SPM, SCG, SVR, TGV	PGS	PGS	
RAC	DTC, EOI, RAC, STC, STI, SUO, SCG, SVR, TGV	PGS, RAC, SUO	RAC, SUO	
STC	EOI, STC, SUO, SPM, SCG, SVR, TGV	DTC, PGS, RAC, STC, STI, SUO	STC, SUO	
STI	EOI, STC, STI, SUO, SPM, SVR, TGV	DTC, PGS, RAC, STI	STI	
SUO	EOI, RAC, STC, SUO, SPM, SCG, SVR, TGV	PGS, RAC, STC, STI, SUO	RAC, STC, SUO	
SPM	SPM	DTC, PGS, STC, STI, SUO, SPM	SPM	1
SCG	EOI, SCG, TGV	PGS, RAC, STC, SUO, SCG	SCG	
SVR	EOI, SVR	DTC, PGS, RAC, STC, STI, SUO, SVR	SVR	
TGV	EOI, TGV	DTC, PGS, RAC, STC, STI, SUO, SCG, TGV	TGV	
Iteration 2				
DTC	DTC, STC, STI, SVR, TGV	DTC, PGS, RAC	DTC	
PGS	DTC, PGS, RAC, STC, STI, SUO, SCG, SVR, TGV	PGS	PGS	
RAC	DTC, RAC, STC, STI, SUO, SCG, SVR, TGV	PGS, RAC, SUO	RAC, SUO	
STC	STC, SUO, SCG, SVR, TGV	DTC, PGS, RAC, STC, STI, SUO	STC, SUO	
STI	STC, STI, SUO, SVR, TGV	DTC, PGS, RAC, STI	STI	
SUO	RAC, STC, SUO, SCG, SVR, TGV	PGS, RAC, STC, STI, SUO	RAC, STC, SUO	
SCG	SCG, TGV	PGS, RAC, STC, SUO, SCG	SCG	
SVR	SVR	DTC, PGS, RAC, STC, STI, SUO, SVR	SVR	2
TGV	TGV	DTC, PGS, RAC, STC, STI, SUO, SCG, TGV	TGV	2
Iteration 3				
DTC	DTC, STC, STI	DTC, PGS, RAC	DTC	
PGS	DTC, PGS, RAC, STC, STI, SUO, SCG	PGS	PGS	
RAC	DTC, RAC, STC, STI, SUO, SCG	PGS, RAC, SUO	RAC, SUO	
STC	STC, SUO, SCG	DTC, PGS, RAC, STC, STI, SUO	STC, SUO	
STI	STC, STI, SUO	DTC, PGS, RAC, STI	STI	
SUO	RAC, STC, SUO, SCG	PGS, RAC, STC, STI, SUO	RAC, STC, SUO	
SCG	SCG	PGS, RAC, STC, SUO, SCG	SCG	3
Iteration 4				
DTC	DTC, STC, STI	DTC, PGS, RAC	DTC	
PGS	DTC, PGS, RAC, STC, STI, SUO	PGS	PGS	
RAC	DTC, RAC, STC, STI, SUO	PGS, RAC, SUO	RAC, SUO	
STC	STC, SUO	DTC, PGS, RAC, STC, STI, SUO	STC, SUO	4
STI	STC, STI, SUO	DTC, PGS, RAC, STI	STI	
SUO	RAC, STC, SUO	PGS, RAC, STC, STI, SUO	RAC, STC, SUO	4
Iteration 5				
DTC	DTC, STI	DTC, PGS, RAC	DTC	
PGS	DTC, PGS, RAC, STI	PGS	PGS	

(Continues)

TABLE 5 (Continued)

Enablers	Reachability set	Antecedent set	Intersection set	Extraction level
RAC	DTC, RAC, STI	PGS, RAC	RAC	
STI	STI	DTC, PGS, RAC, STI	STI	5
Iteration 6				
DTC	DTC	DTC, PGS, RAC	DTC	6
PGS	DTC, PGS, RAC	PGS	PGS	
RAC	DTC, RAC	PGS, RAC	RAC	
Iteration 7				
PGS	PGS, RAC	PGS	PGS	
RAC	RAC	PGS, RAC	RAC	7
Iteration 8				
PGS	PGS, RAC	PGS	PGS	8

Abbreviations: DTC, digital transformation competency; EOI, eco-innovation; PGS, proactive governmental support; RAC, resource availability and capabilities; SCG, sustainable corporate governance; SPM, sustainability performance management; STC, stakeholder collaboration; STI, stakeholder integration; SUO, sustainability orientation and thinking; SVR, sustainable value network reformation; TGV, technology governance.

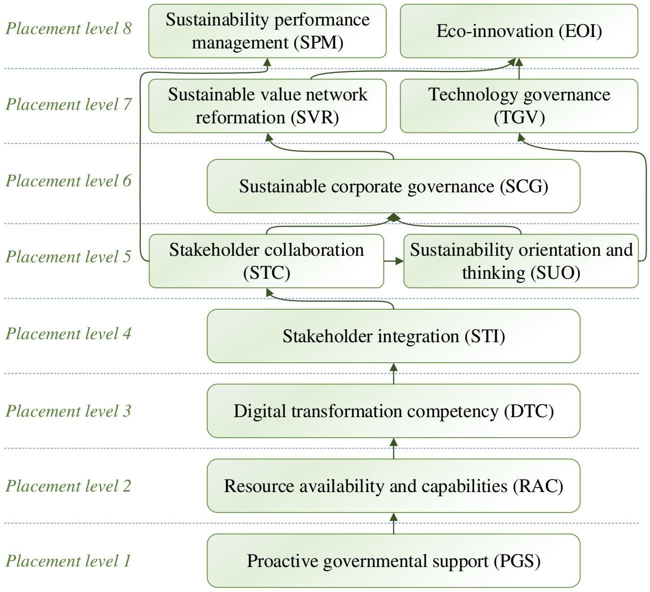


FIGURE 4 The structural model of enabling Industry 5.0-driven sustainable industrial transformation [Colour figure can be viewed at wileyonlinelibrary.com]

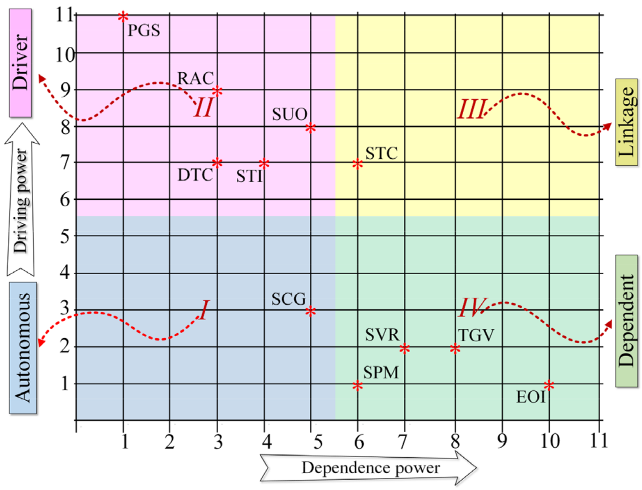


FIGURE 5 The Matrice d'Impacts Croisés Multiplication Appliqués à un Classement [Colour figure can be viewed at wileyonlinelibrary.com]

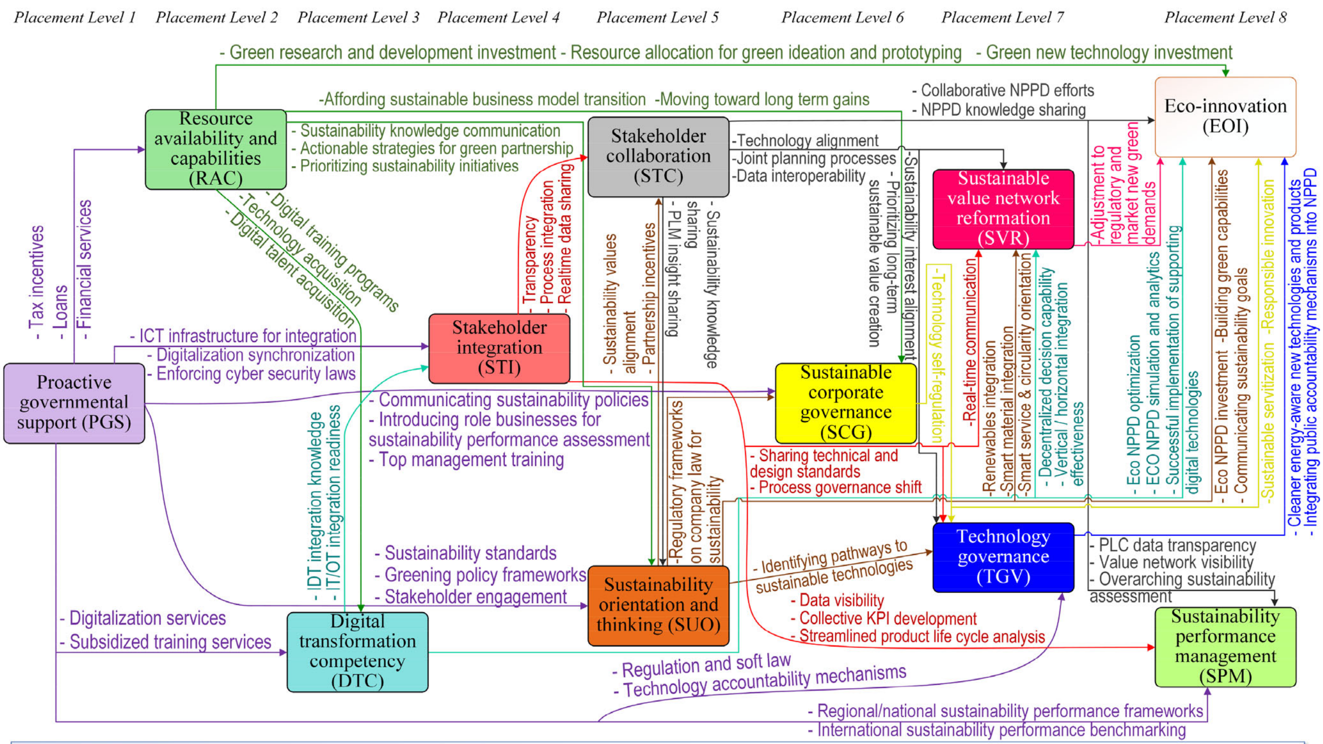
dependent enablers of Industry 5.0. The dependent enablers are complicated and challenging to develop since they functionally rely on other enablers to be precedingly established and achieved under the Industry 5.0 transformation environment.

4 | DISCUSSION

The study identified 11 enablers of Industry 5.0 transformation that are critical to delivering this phenomenon's sustainable industrial transformation objectives. The structural model in Figure 4 and the MICMAC analysis revealed that these enablers are highly interrelated, and complex precedence relationships exist between them. This finding implies that these enablers should be developed or presented in a specific sequence to deliver their intended enabling values. Although each of the enablers identified plays a unique role in enabling Industry 5.0, results reveal that facilitating Industry 5.0 transformation first involves developing the driving enablers, including proactive governmental support, resource availability and capabilities, digital transformation competency, sustainability orientation and thinking, and stakeholder integration. These driving enablers allow the development of more complex and dependent enablers, such as sustainable value network reformation, technology governance, sustainability performance management, and eco-innovation. As the only linkage enabler, stakeholder collaboration is fundamental to transferring the value of driver enablers to the dependent enablers. Sustainable corporate governance is the only autonomous enabler that can be developed somewhat independently of other enablers.

Overall, the results in Figures 4 and 5 explain the sequence in which these enablers should be present to optimally facilitate Industry 5.0-driven sustainable industrial transformation and its intended sustainable development values. Although the results offer important insights into the definition of enablers, their functionality for Industry 5.0, and their development sequence, the interpretation of the links among enablers is still missing. It is indeed a widely acknowledged limitation of ISM, as this method falls short in offering the interpretation of the direct link among each pair of system elements (Sushil, 2012). To address this shortcoming and consistent with the strategy roadmapping methodology implemented, the study drew on the experts' opinions gathered across the expert panel meetings and developed the ILB that interprets the direct relationships among enablers. Integrating the ISM results with the ILB led to the development of the 'strategy roadmap for enabling sustainable industrial transformation under Industry 5.0' as shown in Figure 6. The direct relationships among pairs of enablers in this roadmap correspond to the contextual relationships identified in the initial reachability matrix (Table 3). The functionality of each link in this roadmap represents the collective experts' opinions recorded in the ILB.

Results collectively show that proactive governmental support (PGS) is arguably the most critical enabler of Industry 5.0, as it has the highest driving power, directly facilitating several enablers. For example, PGS can enable stakeholder integration by enforcing cybersecurity or data protection laws, improving the digital synchronization of Industry 5.0 stakeholders, and developing the information and communication technology infrastructure to facilitate physical system integration technically. Overall, the enabling role of PGS involves various functions, including public policy-digitalization synchronization, incentivizing innovation, readjusting policy processes, or promoting new sustainable economic models. This finding supports academic research (Holroyd, 2022; Poma et al., 2020) or policy opinions (Renda et al., 2022) that highlight the crucial role of government in regulating and supporting the digital industrial transformation. The critical role of PGS identified in our roadmap supports Madhavan et al. (2022), who speculated that similar to the Industry 4.0 context, where government support is indispensable to the digital transformation of businesses, the government would play a significant role in promoting open innovation among smaller businesses under the Industry 5.0 paradigm. By exercising these enabling roles, PGS facilitates the development of resource availability and capabilities (RAC). PGS delivers this role by offering support in terms of goal-based financial incentives (e.g., tax exemptions) or loans that would allow corporations to improve the availability and capabilities of their resources to acquire



*Note: IT, information technology; OT, operations technology; IDT, information and digital technology; NPPD, new product and process development; PLC, product life cycle; PLM, product lifecycle management; KPI, key performance index.

FIGURE 6 The strategy roadmap for enabling Industry 5.0-driven sustainable industrial transformation [Colour figure can be viewed at wileyonlinelibrary.com] necessary technologies or afford upskilling and reskilling of their human resources needed for Industry 5.0 transformation.

The enabling role of RAC involves addressing the resource intensity of Industry 5.0 transformation. Corporations should have access to the necessary raw resources (e.g., skills or infrastructure) to digitalize operations and processes. They should also have the capability to combine resources and draw on their synergies to develop valuable capabilities and core competencies indispensable to Industry 5.0 transformation. This finding aligns with Čater et al.'s (2021) and Ghobakhloo et al.' (2022) studies, which recently showed that lack of resources had been a major reason for the corporate digital divide under Industry 4.0. According to Figure 6, RAC leads to the development of digital transformation competency (DTC) by allowing corporations to acquire the necessary technologies, hire fresh digital talents, or upskill their IT experts via training campaigns. This observation supports the mainstream IT literature proposing that resource availability is critical to the development of digitalization capabilities (Voudouris et al., 2012; Zhu et al., 2004). In turn, DTC streamlines Industry 5.0 transformation by granting corporations the necessary technical and knowledge competencies to implement the most innovative and disruptive technological constituents of Industry 5.0, such as adaptive robots, AI, blockchain, or IoE. More importantly, DTC allows businesses to manage the digital transformation journey strategically and fulfill the principal requirements of the Industry 5.0 digital ecosystem, such as interoperability or cybersecurity. In particular, DTC facilitates the stakeholder integration (STI) enabler as it allows corporations to build the necessary knowledge competencies for IDT integration and achieve the IT/OT readiness capabilities needed for Industry 5.0 integration. This finding supports previous studies, such as the work of Čater et al. (2021) and Murugaiyan and Ramasamy (2021), that introduced digitalization knowledge and competency as essential enablers of corporate digital transformation.

The enabling role of STI for Industry 5.0 transformation entails integrating all smart components of Industry 5.0, including factories, service companies, consumers, suppliers, and local communities, to promote socio-environmental accountability, traceability, and transparency. Figure 6 explains that STI plays a vital role in facilitating stakeholder collaboration (STC). Indeed, STI promotes STC by allowing stakeholders, particularly value network members, to communicate and exchange data in real-time and integrate value chain processes. Our finding on the enabling role of STI aligns with Ghobakhloo, Fathi, et al. (2021) and Ng et al. (2022), emphasizing such an enabling role for sustainable value network digitalization. The contribution of STC to Industry 5.0 transformation involves enabling stakeholders to collaborate on developing the culture of social dialog and communicate their needs and expectations to devise necessary industrial policies and legal frameworks. STC is the critical facilitator of sustainability orientation and thinking (SUO) and sustainable corporate governance (SCG), and sustainability performance management (SPM). The facilitating role of STC for SUO entails allowing Industry 5.0 stakeholders to build the necessary trust to share sustainability knowledge and product lifecycle management insights. STC facilitates SCG by aligning stakeholders' sustainability interests and prioritizing long-term sustainable value creation. STC supports the development of SPM by increasing the supply network visibility, introducing transparency to product lifecycle analytics, and implementing comprehensive sustainability assessment tools. This finding aligns with the recent sustainability literature explaining that stakeholder collaboration plays a critical role in boosting sustainability performance management across various business sectors, such as tourism (Wondirad et al., 2020) and the textile industries (Lyu et al., 2021).

SUO is essential to materializing Industry 5.0 framework as it provides Industry 5.0 actors with the necessary understanding of the interactions among socio-environmental, cultural, political, and economic ecosystems. By doing so, SUO allows the stakeholders, particularly corporations, to understand better how their decisions would impact the environment and society, promoting a sense of responsibility for sustainable development. Figure 6 reveals that SUO is essential to sustainable value network reformation (SVR) as it allows supply networks to gain the necessary modularity and decentralization to integrate renewables and smart materials and move toward circular business models. Focusing on the central role of corporations in the systemic transformation required by Industry 5.0, SCG enables this phenomenon by empowering businesses to integrate sustainability objectives into their core strategies and transition toward stakeholder primacy and long-term value gains. SCG and SUO promote technology governance (TGV) by allowing corporations to self-regulate their technology development processes and identify pathways to sustainably fusion technological innovations into their operations, products, and services. Our findings on the enabling roles of SCG and SUO provide support for the comparable studies by Aguilera et al. (2021) and Tibiletti et al. (2021).

TGV is indispensable to enabling Industry 5.0 transformation due to its underlying mechanism for regulating the pace of digital industrial transformation. Although TGV cannot prevent the Collingridge dilemma, it can lead to some remedies for the unpredictability of Industry 5.0 technological innovation impacts and offer some control mechanisms for revising disrupting technologies after their institutionalization or commercialization. This finding aligns with OECD (2022), highlighting the importance of technology governance for managing the impact and operation of emerging technologies in societies. The enabling role of SVR for the management of Industry 5.0 transformation entails building value networks that support regional development and environmental production through resilience and circularity. This finding supports Paul et al. (2021) and Morales et al. (2022), who recently showed that value network reconfigurability is an essential enabler of post-covid economic resilience and sustainability. SVR and TGV play a notable role in facilitating eco-innovation (EOI). SVR facilitates EOI by granting supply chains the necessary modularity, flexibility, and agility to adjust to emerging regulations and new sustainability demands in the market. The facilitating role of TGV for EOI consists of pushing the development of cleaner and energy-aware technological innovations and integrating public accountability mechanisms into new product and process development activities. These observations concerning the enabling role of TGV for EOI support and extend the study by Héroux and Fortin (2018) that showed IT governance promotes product and process innovation.

SPM and EOI, positioned at placement level eight of the structural model, have the lowest driving power, meaning they do not play any particular role in facilitating other enablers of Industry 5.0. Although these enablers have less priority concerning the order of development, their crucial role in enabling Industry 5.0 development cannot be overlooked. SPM is indispensable because it allows administrative, regulatory, socio-economic, and political authorities to monitor the achievement of Industry 5.0 sustainability objectives realistically. Indeed, SPM is vital for constantly screening the Industry 5.0 trajectory and devising policy tools for aligning digital industrial transformation with sustainability. The enabling role of EOI involves promoting sustainable development goals via environmental and social innovation. EOI concerns introducing innovation into products, processes, services, and business models, allowing Industry 5.0 stakeholders to commit equitably to the triple bottom line. As such, SPM and EOI offer important implications for supply chain resilience, sustainable business model, human-centricity, and carbon neutrality objectives of Industry 5.0. These findings align with the recent literature (e.g., Castro et al., 2021; Ghobakhloo, Iranmanesh, et al., 2021), highlighting the important role of eco-innovation and sustainability benchmarking for digitally-driven sustainable industrial transformation.

5 | CONCLUSION

The present study aimed to explore and describe the underlying mechanism for enabling Industry 5.0 transformation and achieving the intended sustainable industrial transformation values. Fulfilling this objective entailed three steps. First, the study identified 11 Industry 5.0 sustainability enablers by conducting a content-centric review of the literature. Second, ISM was performed to determine the sequence in which these enablers should be developed. Third, the study drew on ILB and interpreted each of the contextual relationships, elaborating on the unique role of each enabler. The findings are expected to offer important implications for industrialists, policy bodies, and scholars. The results are also expected to provide the following implications for applying digital industrial transformation policies at a national, European, international, and global level to pursue the Industry 5.0 transition.

5.1 | Theoretical implications

Industry 5.0 represents the vision of a sustainable future industry that moves past the classic productivity and consumption-driven economic models. Industry 5.0 has the propensity to address many prevailing economic and socio-environmental issues, such as inequitable regional development, income polarization, labor market disruption, and environmental degradation. This framework's unique and optimistic objectives require a very different collection of enabling approaches to ensure that the digital industrial transformation under Industry 5.0 aligns with sustainable development objectives. Indeed, our research identified 11 enablers indispensable to desirable Industry 5.0 transformation. Our results showed that these enablers are sequentially interrelated and should be developed in a specific order to deliver their enabling functionality optimally. For example, the structural model showed that Industry 5.0 stakeholders should first integrate their internal processes and gain the necessary information integration capabilities to build trust, transparency, and data sharing competencies for effective collaboration. Regardless of their driving and dependence powers, each of the enablers identified is uniquely indispensable to Industry 5.0. We believe that none of the enablers could be overlooked since the synergetic gains resulting from the complementarity among these enablers are genuinely critical to materializing the promised sustainability values of Industry 5.0 transformation.

It is imperative to note that the Industry 5.0 paradigm must not be understood as the fifth industrial revolution and a replacement for Industry 4.0. Industry 5.0 represents a forward-looking agenda that complements Industry 4.0's unique features by introducing sustainability as the core objective of the digital industrial transformation. In other words, Industry 5.0 involves reviving the lost 'inclusive sustainability' dimension of Industry 4.0. To strike a balance between economic growth and socio-environmental development, Industry 5.0 entails the integrative collaboration of industry and stakeholders. It is why stakeholder-centricity is the major point of differentiation that allows Industry 5.0 to address the socio-environmental shortcoming of Industry 4.0. Overall, promoting stakeholder-centricity via stakeholder integration is among the most critical enablers of sustainability goals within the Industry 5.0 environment, as it promotes the 'functional economy' vision, allowing society and industry to balance economic growth and socio-environmental needs. In delivering this enabling role, stakeholder integration boosts the functional economy by providing a structure that empowers a collective transition from resource over-exploitation to building the circular economy across the entire value network. Stakeholder integration further allows social actors to take a leading role in realizing various pillars of the functional economy, like eco-innovation, collaborative economy, and collaborative consumption, which in turn, offers valuable implications for achieving the environmental and social sustainability objectives of Industry 5.0.

5.2 | Policy implications

As a transformative model, the scope of Industry 5.0 expands well beyond governing corporate digitalization. The interpretive model explicitly emphasizes the role of stakeholders in regulating such transformation. In particular, governments should play a critical role in enabling Industry 5.0, as our results showed the dominating role of PGS. Learning from the Industry 4.0 experience in which the public sector significantly lagged behind the private sector in the pace of digitalization, governments should continuously synchronize with the digital transformation trajectory under Industry 5.0. Achieving such synchronization require governments to proactively update the related policy processes and execute the new policy and compliance processes in parallel. Accordingly, findings outline that governments should proactively facilitate critical enablers of Industry 5.0 transformation. First and foremost, governments should strive to improve the resource capabilities of businesses involved in digital transformation, notably smaller enterprises. In doing so, governments can provide support packages through tax incentives, loans, financial services, or consultation to improve target enterprises' resource availability and capability. To boost Industry 5.0 transformation, governments should further empower stakeholder-wide sustainability orientation and thinking via devising actionable strategies promoting green partnership, prioritizing sustainability initiatives, and disseminating sustainability knowledge. Alternatively, governments are advised to actively promote sustainable corporate governance, which may involve supporting and empowering corporations toward long-term gains and sustainable business model transition. Finally, yet importantly, the roadmap implies that the critical role of governments in enabling Industry 5.0 also involves boosting eco-innovation. Governments can achieve this particular goal in myriad ways, for example, through facilitating investment in green research and development, allocating resources for green ideation and prototyping, and boosting investment in cleaner new technologies.

On the same note, industrial and public actors should note that Industry 5.0 transformation relies on new approaches for empowering sustainable development via eco-innovation and devising measurement systems that continuously monitor the performance-based progress toward sustainability. Industry 5.0 actors should proactively develop and implement new approaches that offer the organizational, product, process, and business model changes needed for social welfare, especially regarding the employment, digital divide, and skill gap. In addition, they should equally focus on introducing environmentally friendly innovations that promote renewable integration, carbon neutrality, resource efficiency, and eco-consumption. Undoubtedly, robust sustainability measurement systems should be in place to allow regulatory and public actors to draw on the sector-specific metrics and indicators that streamline the continuous assessment of progress toward Industry 5.0 sustainability values. Despite the critical role of the sustainability performance management system in progressing Industry 5.0 sustainability values, achieving such an inclusive performance system would be complicated due to its requirements. The roadmap implies that to enable the sustainability performance monitoring and management system, the Industry 5.0 stakeholders must collaborate to develop and establish necessary sustainability performance frameworks, sustainability performance indices, product lifecycle data transparency, and value network visibility.

5.3 | Managerial implications

Businesses and their shareholders should be aware that Industry 5.0 would be significantly resource-intensive. One aspect of such resource intensity originates from the technology-centricity of Industry 5.0, requiring corporations to develop new technological innovations and implement them across their processes, products, services, and business models. Costs of technology acquisition or upskilling and reskilling are expenses caused by Industry 5.0 technology-centricity. Industry 5.0 is also a socio-cultural phenomenon, redefining value creation, production, and consumption norms. Corporations must depart from neoliberal capitalism and shift toward more circular, service-oriented, and non-profit business models that emphasize long-term shared value. Not only do these resource-intensive features challenge corporate profitability, but they also adversely impact product pricing and availability. Businesses can address these challenges by seeking external support initiatives that aim to improve companies' research and innovation capacity and their financial fluidity. More importantly, businesses should collaborate with social actors, particularly governments, to help them develop the capability to purposefully target funding and incentives at the specific business, sector, or industrial cases while defining case-wise deliverables. Alternatively, corporations should address the resource intensity of Industry 5.0 by improving their resource capabilities and strategically planning their digital transformation process.

The ambitious sustainability objectives of this phenomenon require Industry 5.0 actors to significantly orient toward sustainable thinking and synchronously collaborate to introduce sustainability norms into corporate and technology governance. Business leaders should note that transitioning toward Industry 5.0 would require substantial shifts in corporate incentive schemes, systematically transforming from profit-driven shareholder-centricity to sustainably delivering long-term values to stakeholders. It might be naive to expect corporations to intentionally alter their mindset and align their actions with the sustainable development values of Industry 5.0. We believe public and industrial actors should introduce the necessary legal frameworks and mandatory sustainability due diligence to push corporations toward integrating socio-environmental sustainability objectives into their corporate or business strategies. Similarly, as the key enabler of Industry 5.0 transformation, technology governance pertains to the collective role of stakeholders, including individuals, corporations, civil societies, and governments, in exercising regulatory authority in the ideation, development, diffusion, commercialization, and operationalization of technology in society. Therefore, stakeholders should closely collaborate to manage the risks and benefits of Industry 5.0 technological constituents such as AI, blockchain, or the internet of people. This can be achieved in numerous ways, including various institutional and normative mechanisms for managing technology development.

Achieving Industry 5.0 transformation goals also depends on the corporations' ability to sustainably reform their value network to gain circularity and resilience against disruptions. This enabler is primarily developed by decentralizing and modularizing supply nodes, giving supply partners the required flexibility and agility to shift toward a circular supply chain design and promptly readjust to market dynamics. Indeed, SVR is invaluable to Industry 5.0 as it provides the value network with the necessary means to resist disruptions in the supply and demand market, alleviate environmental degradation, prevent waste, and facilitate carbon neutrality. On the same note, corporations should note that stakeholder integration represents a techno-cultural capability, which depends on technological readiness and the culture of trust to gain the necessary process integration capabilities. Stakeholder process integration may come in different varieties, such as information flow integration, physical flow integration, or financial integration. Developing trust is critical to stakeholder integration and collaboration as it promotes data stewardship, transparency, and behavioral predictability of Industry 5.0 actors. Stakeholder integration is a complex capability, significantly relying on the digital transformation competency of value network partners. For example, corporations should build the necessary competency to measure their digitalization readiness, perform IDT/OT upgrading assessments, gain the required IDT expertise, implement new technologies, and develop the cybersecurity maturity to achieve interoperability, real-time communication, and integrability capabilities needed for stakeholder integration.

5.4 | Limitations and future research

Industry 5.0 is in its early development stage, and the current understanding of its functionality for sustainable development is widely limited. The study attempted to draw on the extant literature and experts' opinions to identify approaches that may enable Industry 5.0-driven sustainable industrial transformation. Nonetheless, we barely scratched the surface and merely identified the enablers and their functional roles. We believe our work should be extended in several ways by future research.

Although the study identified 11 core enablers of Industry 5.0 and scrutinized their interrelationships, it could not conceivably describe the depths (characteristics) and breadth (scope) of these enablers. For example, technology governance may pertain to various actors, from individuals and corporations to civil society organizations or governments. In terms of depth, technology governance may involve various mechanisms, from enforcing regulations to applying accountability or technical standards. The particularities of technology governance for Industry 5.0 are largely understudied, and addressing this knowledge gap would serve as a vital avenue for future research. The same could be said about other enablers identified in the study.

We identified the 11 enablers via a rigorous content-centric review of the literature. Nevertheless, Industry 5.0 is embryonic, and the advancement in this discipline would likely lead to identifying unexplored enablers. This is indeed a highly possible scenario, given this phenomenon's scope and dynamism. We invite future research to consult emerging academic and gray literature to expand the somewhat limited understanding of Industry 5.0 enablers. We do not believe that the scope of the Industry 5.0 phenomenon would be limited to the European Union, as Industry 4.0 unexpectedly became a global movement. Referring to the European background of experts consulted in the study, future studies can complement our findings by showcasing how the interactions among the enablers can be interpreted across other regions, especially in North America and Southeast Asia.

The present study merely serves as a stepping stone toward understanding how Industry 5.0 should be managed to deliver its sustainability values, and the strategic roadmap we developed serves as a general-purpose framework to deliver this goal. However, Industry 5.0 transformation would have an idiosyncratic meaning for unique actors. When discussing corporations in Industry 5.0, the unique role of manufacturers, service providers, technology developers, hospitals, or retailers could be implied. Little has been done to understand the unique role of each actor in developing the enablers of Industry 5.0 transformation. For example, the role of various actors and stakeholders in delivering the human-centricity or smart material-driven circularity goals of Industry 5.0 is largely unknown. Future research is invited to study how various Industry 5.0 actors, such as manufacturers or service providers, can effectively transition toward Industry 5.0 and remain resiliently competitive while delivering the intended environmental and social values.

Although it is widely acknowledged that Industry 5.0 shares a similar technological profile as Industry 4.0, the human-centricity objective of Industry 5.0 would rely on the emergence and widespread application of cognitive technologies that facilitate seamless man–machine symbiosis. Scholars believe that CAI, adaptive robots, and cognitive CPS are examples of symbiotic technologies needed for the human-centricity of Industry 5.0. Despite these speculations, the organizational adoption, integration, and usage of these technologies and their impact on the work environment and human well-being are largely understudied. Future research is invited to address this knowledge gap and outline how these technologies should be leveraged and governed to promote human-centricity.

Finally and yet importantly, future research is encouraged to shed more light on how the socio-economic resilience objective of Industry 5.0 can be achieved. The progressively reoccurring disorders, particularly the ever-worsening regional conflicts, put more emphasis on the critical role of corporate and supply chain resilience under the Industry 5.0 paradigm. Due to the severity of ongoing disorders, some scholars argue that the resilience outcome of digital transformation should also involve developing an antifragile future industry. The resilience-antifragility implications of corporate digital transformation under Industry 5.0 is significantly understudied, offering a critical avenue for extending knowledge by future research.

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ORCID

Morteza Ghobakhloo https://orcid.org/0000-0002-9341-2690

Azlan Amran https://orcid.org/0000-0002-9747-547X

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