Beyond Industry 4.0: a systematic review of Industry 5.0 technologies and implications for social, environmental and economic sustainability

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Abstract

Purpose – The study seeks to understand the possible opportunities that Industry 5.0 might offer for various aspects of inclusive sustainability. The study aims to discuss existing perspectives on the classification of Industry 5.0 technologies and their underlying role in materializing the sustainability values of this agenda.
Design/methodology/approach – The study systematically reviewed Industry 5.0 literature based on the PRISMA protocol. The study further employed a detailed content-centric review of eligible documents and conducted evidence mapping to fulfill the research objectives.
Findings – The advancement of Industry 5.0 is currently underway, with noteworthy initial contributions enriching its knowledge base. Although a unanimous definition remains lacking, diverse viewpoints emerge concerning the recognition of fundamental technologies and the potential for yielding sustainable outcomes. The expected contribution of Industry 5.0 to sustainability varies significantly depending on the context and the nature of underlying technologies.

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Practical implications – Industry 5.0 holds the potential for advancing sustainability at both the firm and supply chain levels. It is envisioned to contribute proportionately to the three sustainability dimensions. However, the current discourse primarily dwells in theoretical and conceptual domains, lacking empirical exploration of its practical implications.

Originality/value – This study comprehensively explores diverse perspectives on Industry 5.0 technologies and their potential contributions to economic, environmental and social sustainability. Despite its promise, the practical evidence supporting the effectiveness of Industry 5.0 remains limited. Certain conditions are necessary to realize the benefits of Industry 5.0 fully, yet the mechanisms behind these conditions require further investigation. In this regard, the study suggests several potential areas for future research.

Keywords Industry 5.0, Industry 4.0, Digital society, Artificial intelligence, Internet of things, Big data, Blockchain, Sustainability

Paper type Research paper

1. Introduction

Industry 5.0 represents a much-needed transformation in the landscape of industrial development, going beyond the boundaries set by its predecessor, Industry 4.0 (Borchardt *et al.*, 2022; Calzavara *et al.*, 2023). While Industry 4.0 primarily focuses on technology-driven advancements, automation, and data-driven efficiency gains, Industry 5.0 shifts the emphasis towards sustainability, human-centricity, and societal well-being (Youssef and Mejri, 2023). It recognizes the need for industries to operate within ecological limits, mitigate environmental impacts, and prioritize the welfare of workers and society as a whole (Battini *et al.*, 2022).

While Industry 5.0 builds on the technological foundation laid by Industry 4.0, it is essential to differentiate between the two concepts. Industry 4.0 was centered around digitalizing and automating industrial processes, leading to increased productivity and economic growth (Santhi and Muthuswamy, 2023). However, its implementation sometimes disregarded environmental and societal concerns, giving rise to discussions about the potential negative consequences of technological advancements on job displacement and social inequalities (Grybauskas *et al.*, 2022). In contrast, Industry 5.0 emerges as a societal-driven agenda, aiming to regulate the digital industrial transformation in a way that aligns with sustainability goals (Destouet *et al.*, 2023). It aspires to redefine the role of industries, no longer solely serving as wealth generators but also as active contributors to solving societal challenges (Sindhwani *et al.*, 2022). In this context, Industry 5.0 seeks to align economic growth with environmental preservation and social well-being (Kardush *et al.*, 2022; Waheed *et al.*, 2022). The timing of the emergence of Industry 5.0 alongside the ongoing progression of Industry 4.0 can be attributed to the growing urgency of sustainability concerns. The increasingly apparent consequences of climate change, biodiversity loss, and resource depletion have spurred discussions about the responsibility of industries to mitigate their environmental impact. Additionally, the rise of ethical consumerism and societal expectations for businesses to act responsibly have contributed to the relevance and importance of Industry 5.0.

The adoption of Industry 5.0 principles necessitates a paradigm shift in the way businesses operate (Turner and Oyekan, 2023). It requires the controlled and well-governed integration of cutting-edge technologies, such as Artificial Intelligence (AI), machine learning, and the Internet of Things (IoT), to create smart and interconnected systems that optimize resource utilization, reduce waste, and promote socio-environmentally responsible practices (Xian *et al.*, 2024). Furthermore, Industry 5.0 demands a reimagining of corporate social responsibility, encompassing ethical business practices and active engagement in addressing global challenges, such as climate change, resource depletion, and social inequalities (Zhang and Li, 2023). However, Industry 5.0 is not without its challenges and controversies. As it pivots towards a more sustainable and human-centric model, some critics argue that it may encounter resistance from businesses reluctant to deviate from profit-driven practices. The transition to Industry 5.0 may involve significant initial investments and restructuring, potentially deterring companies that prioritize short-term gains over long-term sustainability (Mukherjee *et al.*, 2023). Moreover, the lack of a self-propelled nature in Industry 5.0, in contrast to Industry 4.0's productivity-driven momentum, raises concerns about corporations' voluntary uptake of Industry 5.0 principles (Ghobakhloo *et al.*, 2023a).

Despite the theoretical underpinnings and ambitious goals of Industry 5.0, there remains a significant gap in the practical assessment of its effectiveness. Unlike Industry 4.0, which has been extensively studied and evaluated for its impact on firm profitability and productivity (Grybauskas *et al.*, 2022), Industry 5.0 lacks a comprehensive body of research examining its tangible contributions to sustainability and social well-being. The theoretical foundation of Industry 5.0 is undoubtedly strong, drawing on the advancements of Industry 4.0 and advocating for a paradigm shift that aligns industrial development with environmental and societal concerns (Ivanov, 2023). However, Industry 5.0 requires a fundamental rethinking of business models, supply chains, and organizational structures, which can be daunting for established industries that have long operated under profit-driven frameworks (Renda *et al.*, 2022). The voluntary uptake of Industry 5.0 principles by businesses remains uncertain, as it demands significant investments and restructuring without immediate guarantees of returns. The existing literature on the sustainability contributions of Industry 5.0 lacks a definitive conclusion. It is unclear what sustainability values Industry 5.0 can promise at the firm and industrial levels. More importantly, its status as either theoretical speculation and a desirable but impractical agenda or a foundation that has been successfully implemented and can truly work in favor of sustainability in the real world is profoundly unknown. The current state of knowledge remains inconclusive, requiring further research and empirical evidence to determine the potential and effectiveness of Industry 5.0 in promoting corporate profitability and sustainability.

Such evidence on the implications of Industry 5.0 might indeed exist within the literature. However, there has not been a comprehensive Systematic Literature Review (SLR) examining the Industry 5.0 agenda from the perspective of its practical implementation and impact on sustainability performance. Addressing this knowledge gap, the current study conducts an SLR using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol to explore the real-world outcomes of Industry 5.0 initiatives and their potential contributions to sustainability in organizations. By synthesizing 52 eligible documents, this review aims to provide valuable insights into the viability and effectiveness of Industry 5.0 in achieving its proposed objectives. Accordingly, the study seeks to answer the following research questions systematically:

RQ. How can the technological constituents of Industry 5.0 contribute to economic, environmental, and social sustainability at the firm and industrial levels?

The study has the potential to make significant contributions to the field of industrial development and corporate sustainability. By systematically reviewing existing literature, case studies, and empirical evidence, this research can offer a comprehensive and insightful analysis of the practical implementation and impact of Industry 5.0. The study's findings may shed light on successful Industry 5.0 initiatives and identify key drivers that facilitate its adoption and integration within corporate structures. Moreover, it may reveal challenges and barriers faced during implementation, providing valuable lessons for future endeavors. Importantly, the study's examination of Industry 5.0's effect on organizational profitability and sustainability will help inform policymakers, industry leaders, and researchers about the viability and potential benefits of this approach in addressing global challenges.

2. Review methodology

To answer the research question and fulfill the underlying objectives, the PRISMA protocol (PRISMA, 2023) was employed, comprising four distinct steps to ensure a rigorous and structured approach. Figure 1 visualizes and details these steps.

In the first step, a search query was developed to identify relevant documents. The query included key terms such as "Industry 5.0," "Fifth industrial revolution," and combinations with terms related to corporate sustainability performance. In the second step, the Scopus and Web of Science databases were utilized to conduct the initial search, which yielded a pool of 169 documents related to Industry 5.0. For the third step, exclusion criteria (as depicted in Figure 1) were carefully developed to filter the initial pool of documents.

The exclusion criteria applied in this were designed to maintain the integrity and validity of the research findings by filtering out irrelevant or low-quality sources. Firstly, the study limited the selection of journal articles, as they generally undergo rigorous peer review, ensuring their reliability and credibility. Journal articles are more likely to offer well-documented research and robust findings, making them essential sources for this SLR. Secondly, including documents in the English language was necessary to ensure uniformity and ease of analysis. While there may be valuable insights in other languages, restricting the

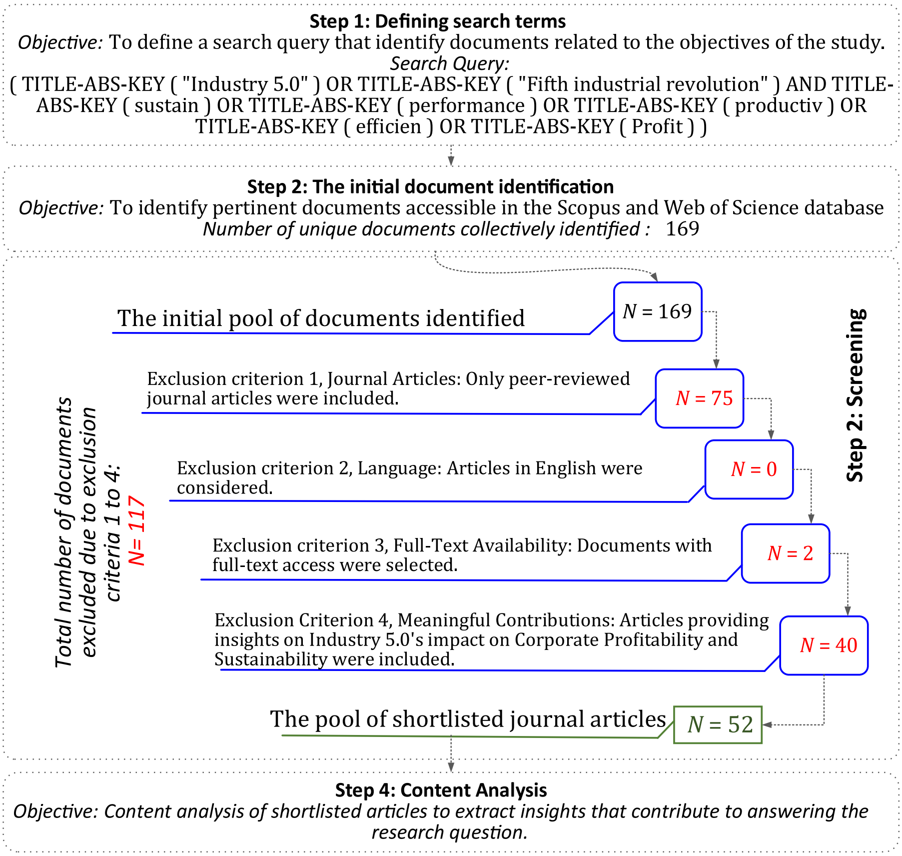

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Figure 1.
The process of performing SLR

study to English articles allowed for comprehensive analysis without the constraints of translation and language barriers. Furthermore, the requirement for full-text availability and accessibility ensured that the study could access and thoroughly examine the contents of the selected articles. Lastly, exclusion criterion four helped filter out irrelevant or tangential studies. For this exclusion criterion, each content analyst independently evaluated the selected papers, and any differences in judgment were resolved through consensus. The research team also introduced a comprehensive set of evaluation criteria to guide the paper selection process, ensuring a systematic and structured approach, thus fortifying the transparency and rigor of the selection methodology. By concentrating on documents directly relevant to the research question, the study aimed to yield insightful and substantial findings that would be valuable for the research community and practitioners in the field. As a result of subjecting the documents identified to the exclusion criteria, 52 documents were shortlisted for content assessment.

The fourth step involved a quantitative content analysis of the selected articles. A meticulous content analysis protocol was created and applied to ensure the method's rigor and the reliability and validity of the insights extracted. This involved a systematic and structured approach to categorizing and interpreting the data obtained from the shortlisted documents. During the content analysis step, several measures were undertaken to ensure the reliability and validity of the results. Parallel content analysis was conducted with multiple content assessors independently coding and categorizing the selected documents. A standardized coding scheme was developed and consistently applied to ensure uniformity and consistency in data extraction. In addition, clear inclusion criteria were established for data extraction, focusing only on relevant information related to Industry 5.0. Before the final content assessment, a pilot test was performed on a small sample of documents to refine the methodology. Throughout the content analysis, disagreement tracking and resolution procedures were implemented to address discrepancies among analysts and achieve consensus. The following sections discuss the outcomes of the content analysis.

Furthermore, the study employed an evidence-mapping approach (Ghobakhloo *et al.*, 2023b) to visualize the outcomes of content analysis, specifically focusing on the potential contributions of Industry 5.0 to corporations' sustainability performance. Evidence mapping is a systematic approach used in research to visually summarize and categorize a wide range of existing literature on a specific topic or research question. It provides a comprehensive overview, identifying research gaps and patterns in the available evidence, helping researchers, policymakers, and decision-makers prioritize areas for further investigation and make informed decisions.

3. Industry 5.0 evolution

Industry 5.0, as a transformative concept in the realm of industrial development, has undergone a notable historical evolution and maturation process since its inception. However, the lack of a standardized definition distinguishes Industry 5.0 from its predecessors, Industry 4.0 and the earlier industrial revolutions. Over the years, the perception of Industry 5.0 has been on a roller coaster ride, with scholars continually refining their understanding of this multifaceted phenomenon. Less than a decade ago, when Industry 5.0 was first introduced in academic discourse, its objectives and implications were embryonic and relatively unexplored. As scholars delved deeper into the concept, the evolution of Industry 5.0's definition paralleled its maturity. The understanding of this industrial agenda has evolved significantly, encompassing a more comprehensive and nuanced perspective. Despite the continuous progress in comprehending Industry 5.0, a universally accepted and standardized definition has remained elusive, and various interpretations persist. Recognizing the evolving nature of Industry 5.0's definition is crucial, as it directly influences the expected outcomes in terms of profitability and sustainability. The concept's conceptualization by scholars and experts plays a pivotal role in shaping the agenda's practical implementation and potential impact on corporations and society. Despite the absence of a universally agreed-upon definition, the contemporary academic landscape nowadays holds a much more mature understanding of Industry 5.0.

One of the earliest attempts to introduce Industry 5.0 can be traced back to Sachsenmeier's work in 2016. He conceptualized it as an industrial revolution, a transformative paradigm shift propelled by bionic technology with the potential for social disruption and profound impact. Sachsenmeier (2016) suggested that bionics, serving as a precursor to synthetic biology, would drive the fifth industrial transformation in a manner akin to how digital technologies spearheaded the advent of Industry 4.0. On the contrary, Özdemir and Hekim (2018) put forward a different perspective, suggesting that Industry 5.0 signifies an incrementally evolutionary shift building upon the foundations and technologies of Industry 4.0. Their proposal revolved around promoting symmetry in the innovation ecosystem design to address the limitations of Industry 4.0's innovation ecosystem. From their standpoint, Industry 5.0 could be seen as an enhanced version of Industry 4.0, acting as an improvement patch rather than an entirely new industrial revolution.

In the academic discourse of 2019 and 2020, a new school of thought emerged regarding Industry 5.0, proposing a vision that would embody a harmonious synergy between humans and autonomous machines, creating symbiotic factories (Nahavandi, 2019). While proponents of this idea did not explicitly argue that Industry 5.0 should be categorized as a new industrial revolution, they envisioned it as a profound restructuring of industrial development. In this vision, the primary objective of Industry 5.0 is to establish human-machine symbiosis, aiming to foster a more human-centric manufacturing environment (Longo *et al.*, 2020). From this perspective, two significant insights can be gleaned. Firstly, Industry 5.0 is primarily applicable in manufacturing, where the integration of human workers and advanced autonomous machines plays a central role in achieving the desired symbiosis. Secondly, the realization of Industry 5.0 relies heavily on cutting-edge technological innovations, such as machine vision, virtual reality, simulation, and AI (Aslam *et al.*, 2020). These technological advancements aim to augment human operators' capabilities, thereby driving technology-driven augmentation to enhance overall productivity and performance.

The envisioned Industry 5.0 paradigm represents a shift from the earlier focus on complete automation (Industry 4.0) to a more balanced and collaborative approach. The emphasis on creating symbiotic relationships between humans and machines highlights the growing recognition of the essential role human labor and creativity play in manufacturing processes. By integrating emerging technologies with human expertise, Industry 5.0 strives to optimize both efficiency and the human experience within the manufacturing domain. In addition to this emerging perspective, proponents like Javaid *et al.* (2020) have argued that the human-centric aspect of Industry 5.0 can manifest in leveraging advanced technologies to produce personalized products that cater to individual customer needs effectively.

The unveiling of the Industry 5.0 paradigm reached a pivotal moment with the introduction of the "Europe Industry 5.0″ perspective by the European Commission. In their agenda released in 2021, the European Commission presented Industry 5.0 as a complementary extension of the existing Industry 4.0 paradigm, designed to address emerging socio-environmental needs (Breque *et al.*, 2021). The European Commission took a more assertive stance against Industry 4.0 in early 2022, contending that this paradigm is ill-suited to tackle the pressing climate crisis and social tensions (Renda *et al.*, 2022). Instead, the policy document advocates for Industry 5.0 as a novel vision for industrial development, reshaping the role and functionality of value chains, business models, and digital transformation in today's hyperconnected business environment. This European Commission's view of Industry 5.0 brought together diverse perspectives to form a unified understanding. According to this view, Industry 5.0 integrates broad sustainable development goals into industrial development, especially environmental sustainability, resilience, and human-centricity. Combining these essential elements, the European Commission envisioned Industry 5.0 as a comprehensive framework prioritizing societal well-being, ecological preservation, and adaptability. The European Commission's agendas explicitly refrain from categorizing Industry 5.0 as a separate industrial revolution and a replacement for Industry 4.0. Instead, they regard Industry 5.0 as a policy agenda aimed at regulating the pace and outcomes of digital industrial transformation under the framework of Industry 4.0. The distinction lies in the acknowledgment that Industry 4.0 has been the driving force behind technological advancements and productivity gains and has made significant contributions to the industrial landscape. However, the emergence of Industry 5.0 is seen as a strategic approach to address potential challenges posed by Industry 4.0, especially concerning social and environmental concerns.

The European Commission's perspective on Industry 5.0 has served as a foundational framework that several scholars have embraced and expanded upon, contributing to its maturation, comprehensiveness, and scientific depth. These scholars have approached Industry 5.0 from various angles, examining its implications on different aspects of industrial development. However, it is essential to acknowledge that despite the efforts toward conceptual unification, some recent studies still label Industry 5.0 as to be a technology-driven phenomenon that may represent the fifth industrial revolution (e.g. Ghobakhloo *et al.*, 2023b). This ongoing variation in conceptualization presents a challenge, leaving us unable to reach a definitive conclusion about the nature of Industry 5.0. The coexistence of perspectives, some viewing it as an evolutionary extension of Industry 4.0 and others as a revolutionary shift, underscores the complexity and ongoing development of this concept within academic discourse. Irrespective of how Industry 5.0 is defined concerning previous industrial revolutions, a common thread runs through all scholarly works: digital technological innovations serve as the fundamental constituents of Industry 5.0.

3.1 Industry 5.0 technological paradox

While scholarly works concur that technological advancement is a central element of Industry 5.0, there exist three distinct perspectives among scholars regarding the recognition and categorization of its technological constituents. Firstly, some scholars view Industry 5.0 as a natural yet incremental extension of Industry 4.0, emphasizing the continuation and refinement of existing digital technologies (Sharma *et al.*, 2022; Verma *et al.*, 2022). From this perspective, Industry 5.0 builds upon the technological foundation of Industry 4.0, incorporating and enhancing its technological components to address emerging challenges and opportunities (Huang *et al.*, 2022; Xian *et al.*, 2024). For instance, Ghobakhloo *et al.* (2023a) proposed that Industry 5.0 draws upon a combination of standardized (mature) technologies and emerging technologies to drive digital industrial transformation. Standardized technologies encompass digital, information, and operations technologies like computer-aided design tools, execution systems, and enterprise systems that have been widely accessible and commercialized over the past few decades. Ghobakhloo *et al.* (2023a) argued that these technologies had been around since half a century ago but continue evolving to meet current business demands, which is pivotal in propelling the Industry 5.0 transformation. In addition to these established technologies, Industry 5.0 embraces emerging technologies, like generative AI, that have the potential to disrupt and reshape the industrial landscape, driving innovation and fostering a more dynamic and adaptive industrial ecosystem.

Similarly, Santhi and Muthuswamy (2023) propose that Industry 5.0 technologies comprise three categories: core, supporting, and beneficial. Technologies such as AI and IoT are core technologies that will share the main features of Industry 5.0, whereas big data, blockchain, and cloud computing are among the supporting technologies that provide the needed infrastructure for core technologies to function correctly. Lastly, technologies such as digital twins and collaborative robots are regarded as ‘beneficial’ due to their complexity and integrative nature. Their successful implementation and operation necessitate correctly integrating all essential core and supporting technologies. Santhi and Muthuswamy (2023) concluded that Industry 5.0 technologies represent minor upgrades to Industry 4.0 technologies with a distinct emphasis on human inclusion and environmental and social conscientiousness. Numerous other scholars, among them Nahavandi (2019) and Ordieres-Meré *et al.* (2023), advocate a similar viewpoint, contending that Industry 5.0 builds upon incremental enhancements of Industry 4.0 technologies. However, Industry 5.0 emphasizes design principles, such as integration, interoperability, and real-time capability, which underpin a more human-centric orientation and implications of the technologies within the Industry 5.0 agenda (Huang *et al.*, 2022; Sharma *et al.*, 2022).

Secondly, another group of scholars perceives Industry 5.0 as a more radical departure from Industry 4.0, characterizing it as a paradigm shift that introduces entirely novel and disruptive technologies. In this viewpoint, Industry 5.0 represents a departure from conventional digital technologies and embraces revolutionary advancements to create a new industrial landscape. This perspective was initially introduced by Sachsenmeier (2016), who posited that synthetic biology would trigger a tectonic shift within the industrial development landscape under Industry 5.0. Subsequently, in its 2020 agenda, the European Commission reinforced this viewpoint and put forth a comprehensive roster of futuristic and disruptive technologies, which, together with established technologies, can shape the landscape of Industry 5.0 (Müller, 2020). Notable examples of these futuristic technologies outlined by this agenda include human interaction technologies, bio-inspired technologies, smart living materials, and brain-machine interfaces. These innovations exemplify the forward-looking and transformative vision of Industry 5.0 proposed by the European Commission, underscoring the profound potential for technological advancements to drive the evolution of industrial development. Building upon this concept, scholars have contextualized the emergence of novel technologies that may characterize Industry 5.0 within different business contexts. For instance, Sherburne (2020) suggests that functional fiber computing technologies will serve as the foundation for the advancement of Textile Industry 5.0. On the other hand, Javaid *et al.* (2020) propose that emerging medical technologies, such as humanoid robots and the Internet of Medical Things, will pave the way for the development of Medical Industry 5.0. Intriguingly, the European Commission diverged from perceiving Industry 5.0 solely as an avenue for futuristic and radical technological innovations in their 2021/2022 agenda, and the academic community subsequently embraced this perspective.

Lastly, some scholars adopt an inclusive stance, recognizing Industry 5.0 as a hybrid approach incorporating elements from Industry 4.0 and new transformative technologies (Leng *et al.*, 2022). They view Industry 5.0 as blending established digital technologies with cutting-edge innovations, combining the best of both worlds to foster a more holistic and synergistic industrial environment (Mukherjee *et al.*, 2023; Xu *et al.*, 2021). Scholars have envisioned several ways in which Industry 4.0 technologies could be upgraded and evolved to meet the functional requirements of Industry 5.0. Under this perspective, several scholars have proposed that technological advancement in Industry 5.0 would entail the evolution of well-established Industry 4.0 technologies by gaining cognitive capabilities (Rožanec *et al.*, 2022). Specifically, scholars posit that cyber-physical systems and AI should acquire cognitive abilities, enabling seamless integration with human operators to enhance productivity and efficiency in industrial operations (Maddikunta *et al.*, 2022).

This integration between humans and intelligent machines is believed to foster a symbiotic relationship, with technology serving and supporting humans while driving industrial performance (Thakur and Sehgal, 2021). By adopting cognitive capabilities, Industry 5.0 seeks to create a harmonious coexistence of humans and advanced technologies, yielding integrative scientific insights into the transformation of industrial processes (Khan *et al.*, 2023). In a forward-thinking approach, Ghobakhloo *et al.* (2022) advocate for cognitive (adaptive) robotics as a transformative step towards achieving both human-centricity and productivity within Industry 5.0. Building upon their analysis of collaborative robots in Industry 4.0, Ghobakhloo *et al.* (2022) highlighted the inherent human-centric nature of collaborative robots, albeit at the cost of reduced productivity compared to conventional robots and proposed the critical role of adaptive robots in Industry 5.0. Adaptive robots surpass the capabilities of collaborative robotics by acquiring cognitive abilities that enable them to adapt to and learn from their environment dynamically. Moreover, they seamlessly interact with humans in a safe manner while sustaining high levels of productivity.

It should be noted that scholars have differing views on cognitive ability within the context of Industry 5.0. For example, Lu *et al.* (2022) defined it as the capability to deduce human intent based on observed actions, guiding subsequent actions accordingly. On the other hand, Ghobakhloo *et al.* (2023b) described cognitive technologies in Industry 5.0 as possessing pattern detection capabilities during ongoing operations, self-recognition, the ability to correct failures, and informed decision-making. Within this perspective, scholars argue that certain technologies that originated in Industry 4.0 experience significant expansion under the Industry 5.0 agenda (Maddikunta *et al.*, 2022). Notably, the term "Internet of Everything" (IoE) has gained prominence to emphasize the broader application of the IoT within Industry 5.0 (Leng *et al.*, 2022). Scholars contend that IoE involves integrating industrial systems, data management systems, smart products, and smart consumers to fulfill the inclusive integration requirements of Industry 5.0 (Fraga-Lamas *et al.*, 2021; Iyengar *et al.*, 2022). Similarly, niche technologies like intelligent energy management systems and intelligent product life-cycle management systems are now recognized as vital technological constituents in Industry 5.0, contributing to achieving circularity goals within this agenda (Ghobakhloo *et al.*, 2023c; Maddikunta *et al.*, 2022). Furthermore, under this perspective, human integration recognition technologies, smart wearables, and extended reality are commonly regarded as core technologies of Industry 5.0 (Grech *et al.*, 2023; Leng *et al.*, 2022), as they play a vital role in fulfilling the human-centricity requirements of this transformative era (Ordieres-Meré *et al.*, 2023; Rožanec *et al.*, 2022).

Overall, the three perspectives discussed above highlight the dynamic expansion and integration of diverse technologies in Industry 5.0, fostering an integrative scientific exploration of its evolving technological landscape. Figure 2 comprehensively summarizes the three perspectives and their respective associations with technologies within Industry 5.0. Figure 2 sheds light on the prevailing lack of consensus among scholars regarding the specific technologies that constitute Industry 5.0. As a result, the expected profitability and sustainability outcomes of Industry 5.0 will likely vary significantly due to these differences in perspectives. The subsequent section will delve into a comprehensive analysis of these diverse perspectives concerning the values and implications of Industry 5.0.

4. Profitability and sustainability of industry 5.0

The results of evidence mapping indicate that the eligible articles under investigation explored these contributions within three distinct scopes: economic performance, environmental performance, and social performance of corporations. Furthermore, their analysis generally considered two levels of examination: micro analysis, which focused on the individual corporation, and macro analysis, which extended to the broader context of the value network or industrial level.

Perspective one: Natural yet incremental extension of Industry 4.0:	*Perspective two: Radical Departure from Industry 4.0:*	*Perspective three: Considerable transformation of Industry 4.0 technologies:*
Industry 5.0 technologies build on the continuation and refinement of existing digital technologies.	Industry 5.0 represents a departure from conventional digital technologies and embraces revolutionary technological advancements.	Industry 5.0 is a hybrid approach incorporating elements from Industry 4.0 and new transformative technologies.
. Additive manufacturing . Big data . Blockchain . Cloud computing . Cybersecurity and cryptography . Edge computing . Embedded System . Enterprise systems . Execution systems . Industrial control systems . Industrial robots . Internet of things . Machine learning . Networking infrastructure	. Artificial general intelligence . Bio-inspired technologies . Biosensors . Brain-machine interfaces . Causal artificial intelligence . Fiber computing technologies . Genomics . Humanoid robots . Internet of medical things . Self-healing/repairing material . Smart learning material . Swarm intelligence	. Adaptive (cognitive) robotics . Cognitive cyber-physical systems . Cognitive/generative artificial intelligence . Extended reality . Human recognition technologies . Industrial wearables . Internet of Everything . Mobile autonomous robots . Multiscale dynamic simulation . Smart energy management system . Smart product lifecycle management

Source(s): The authors

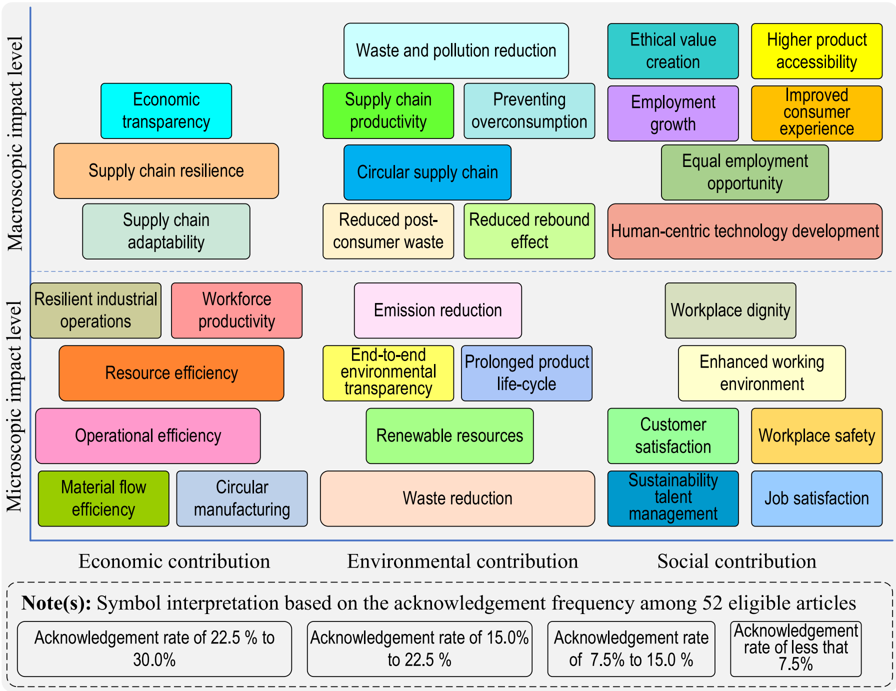
Figure 2.
Perspectives on Industry 5.0 technologies and underlying classifications

The evidence mapping process involved categorizing and organizing the insights and observations from the selected articles according to the three performance levels and two analysis levels. This comprehensive approach is depicted in Figure 3, offering a visual representation of the diverse implications and potential benefits that Industry 5.0 could hold for corporations in terms of sustainability performance. By presenting the findings in this manner, the study aimed to provide a clear and structured understanding of the multifaceted impacts of Industry 5.0 on corporations' sustainable practices at various levels of analysis.

The evidence map in Figure 3 is particularly intriguing as it reveals that the literature presents a well-balanced perspective on the contributions of Industry 5.0 to the three core elements of sustainability, holding true for both micro and macro levels of analysis. This starkly contrasts the viewpoint associated with Industry 4.0, which predominantly emphasizes economic value creation, mainly at the level of individual businesses.

4.1 Economic values

Figure 3 highlights the noteworthy similarity in the microeconomic goals of Industry 5.0 when compared to Industry 4.0. Scholars suggest that, within the context of Industry 5.0, the advancement of prosperity and growth hinges upon corporations' financial success and economic efficiency (Guo *et al.*, 2023; Waheed *et al.*, 2022). Achieving this necessitates leveraging advanced technologies to enhance the management of logistics and material flow, streamline operations, and boost workforce productivity (Turner and Oyekan, 2023). This approach lays the foundation for corporations to amass the necessary resources and financial stability that enable them to prioritize enhancing socio-environmental values (Ghobakhloo *et al.*, 2023c). Additionally, Industry 5.0 technologies are believed to allow corporations to bolster their internal operational resilience, ensuring adaptability in the face of existing and forthcoming disruptions, thereby securing their long-term survival and competitive edge (Sindhwani *et al.*, 2022). The literature details various mechanisms through which Industry 5.0 would improve micro-economic sustainability. For example, Industry 5.0, characterized



Source(s): The authors

Figure 3. The evidence mapping of Industry 5.0 sustainability values

by the integration of cutting-edge technologies like AI, IoE, and robotics, has the potential to elevate workforce productivity through a range of mechanisms substantially (Ahmed *et al.*, 2023). By enabling harmonious collaboration between humans and machines, it allows for delegating repetitive and mundane tasks to automated systems (Destouet *et al.*, 2023). Moreover, the real-time data insights offered by Industry 5.0 facilitate the optimization of production processes, leading to streamlined operations and heightened efficiency (Javeed *et al.*, 2023). Industry 5.0 can also introduce personalized training and skill development opportunities, utilizing virtual platforms to empower employees with the knowledge and proficiencies needed for intricate tasks (Li *et al.*, 2023). Consequently, Industry 5.0 empowers the workforce to allocate their efforts towards tasks of greater strategic importance, fostering an agile, adaptable, and ultimately more productive work environment (Maddikunta *et al.*, 2022).

Figure 3 underscores the potential of Industry 5.0 to provide notable advantages in terms of macroeconomic sustainability, specifically concerning economic transparency, adaptability, and supply chain resilience. The scholarly discourse emphasizes the salience of Industry 5.0's transformative attributes, particularly during disruptions, as exemplified by the COVID-19 pandemic. It is posited that conventional smaller-scale supply chains, which play a pivotal role in equitable wealth distribution within vulnerable societal segments, face heightened susceptibility to disturbances and operational fragility. Within this paradigm, Industry 5.0 emerges as a crucial enabler, offering pivotal avenues for augmenting supply chains' adaptability and operational resilience (Ivanov, 2023). By embracing the foundational design principles and technologies intrinsic to Industry 5.0, supply chains can proactively strengthen their capacity to navigate challenges, securing their viability and perpetuating the critical provision of indispensable goods and value to the broader social fabric (Karmaker *et al.*, 2023). This, in turn, advances the overarching aim of sustaining equitable socio-economic equilibrium and resilience (Ahmed *et al.*, 2023). The literature outlines that Industry 5.0 offers these values by enabling real-time monitoring and analysis of supply chain processes, thereby facilitating proactive identification of potential disruptions and vulnerabilities. This heightened situational awareness empowers supply chain managers to swiftly respond to emerging challenges, optimize routes, adjust production schedules, and allocate resources effectively (Nayeri *et al.*, 2023). Furthermore, Industry 5.0's emphasis on human-machine collaboration enables dynamic decision-making, where AI-powered algorithms and predictive models assist human experts in making informed choices under rapidly changing circumstances (Rožanec *et al.*, 2022). The concept of cognitive cyber-physical systems within Industry 5.0 fosters interconnectedness across various supply chain components, allowing for rapid reconfiguration and rerouting in response to unforeseen events (Huang *et al.*, 2022).

In addition, Industry 5.0, characterized by its distinctive principles of stakeholder centricity and collaborative integration, synergistically augments economic transparency. Through the orchestrated interplay of advanced technologies like blockchain and data analytics, Industry 5.0 facilitates seamless information exchange and aligns this exchange with stakeholders' diverse needs and perspectives (Leng *et al.*, 2022; Maddikunta *et al.*, 2022). This approach ensures that relevant parties can access accurate, real-time data encompassing transactions, operations, and resource utilization, transcending traditional barriers and mitigating information disparities. Consequently, economic interactions become more coherent, inclusive, and ethically grounded, promoting trust, accountability, and equitable participation (Wang *et al.*, 2023). Harmonizing these principles and technologies within Industry 5.0 boosts economic transparency by fostering an environment where stakeholders collectively contribute to and benefit from an open, accountable, and dynamic economic ecosystem (Ahmed *et al.*, 2023; Verma *et al.*, 2022).

4.2 Environmental values

The evidence mapping delineates waste reduction as the preeminent microenvironmental advantage of Industry 5.0 for corporations (Guo *et al.*, 2023). Industry 5.0 offers a multifaceted pathway to waste reduction within corporations through its transformative technologies and principles. By embracing interconnected cyber-physical systems, advanced sensors, and real-time data analytics, Industry 5.0 enables precise monitoring and analysis of production processes (Massaro, 2022). This heightened visibility empowers corporations to identify inefficiencies, bottlenecks, and areas of excess in their operations (Cimino *et al.*, 2023). Subsequently, by integrating AI and machine learning algorithms, Industry 5.0 facilitates predictive maintenance, enabling proactive identification of equipment malfunctions or breakdowns. This reduces unplanned downtime, prevents wastage of resources due to sudden stoppages, and optimizes maintenance schedules (Nahavandi, 2019; van Oudenhoven *et al.*, 2022). Industry 5.0's emphasis on stakeholder centricity also encourages collaboration among various participants, fostering shared responsibility for waste reduction across the supply chain. This collaborative approach facilitates the exchange of best practices, innovative ideas, and circular initiatives, leading to implementing more efficient processes and minimizing waste generation. Ultimately, Industry 5.0's amalgamation of technology-driven insights and collaborative engagement coalesces to drive substantial waste reduction, aligning corporations with environmentally responsible practices (Ghobakhloo *et al.*, 2023a, c).

Industry 5.0 also enhances corporate environmental sustainability by optimizing resource utilization efficiency within business operations and concurrently reducing emissions.

Industry 5.0 delivers these functions through an array of transformative technologies. Integrating IoT devices, AI algorithms, and advanced data analytics, Industry 5.0 offers corporations a sophisticated toolkit for meticulously monitoring and optimizing resource consumption across diverse operational dimensions (Ivanov, 2023). This newfound transparency empowers companies to fine-tune production processes, limit extraneous resource allocation, and optimize energy usage (Aheleroff *et al.*, 2022). Furthermore, Industry 5.0's embrace of innovative technologies like additive manufacturing fosters the creation of intricate designs and structures, minimizing material waste through precise layer-by-layer fabrication (Alojaiman, 2023). The concept of digital twins, which entails virtual replicas of physical assets, enables simulation and analysis of multiple scenarios, thereby identifying resource-efficient strategies that mitigate emissions before implementation (Huang *et al.*, 2022). This approach also extends to energy management, wherein Industry 5.0 facilitates the establishment of intelligent grids and systems for real-time energy monitoring and control, further diminishing unwarranted emissions (Wang *et al.*, 2022).

While it received comparatively less recognition, Industry 5.0 is also perceived as a catalyst enabling corporations to enhance end-to-end environmental transparency and extend the lifespan of their products. This aspect of Industry 5.0 entails a comprehensive view of the entire product life-cycle, from raw material extraction to disposal or recycling (Ghobakhloo *et al.*, 2022). By harnessing technologies such as the IoE, data analytics, and digital twins, corporations can gain unprecedented insights into each stage of their product's journey. This transparency facilitates better tracking of resource usage, waste generation, and environmental impacts, enabling more informed decision-making aimed at reducing ecological footprints (Dwivedi *et al.*, 2023). Additionally, Industry 5.0's emphasis on customization and modular production facilitates design and manufacturing processes that can be adapted, upgraded, or repurposed, thus extending the useful life of products (Coelho *et al.*, 2023). In addition, Industry 5.0 requires companies to move toward offering intelligent products that can establish a direct conduit of real-time data exchange between consumers and manufacturers, heralding transformative possibilities. By collecting and transmitting consumption data, these products enable corporations to gain unprecedented insights into user behavior and product performance, empowering manufacturers to recalibrate production processes with precision, optimizing resource allocation, reducing waste, and ultimately minimizing the environmental footprint (Leng *et al.*, 2023). Simultaneously, this continuous data feedback loop fosters a novel level of consumer engagement, where personalized recommendations and timely maintenance alerts are seamlessly delivered. Such proactive interventions prolong the product life cycle by averting potential malfunctions and facilitating timely repairs (Di Nardo and Yu, 2021).

Seen from a broad perspective that considers the entire supply chain process, Industry 5.0 brings about significant changes to address critical environmental issues on a larger scale. Among these changes, two major ones are reducing waste and pollution in industries and pushing for circularity in supply chains (Maddikunta *et al.*, 2022). Industry 5.0 engenders a holistic restructuring of supply chain dynamics, fostering elevated interconnectivity and data-driven insights across the entire value chain continuum (Varriale *et al.*, 2023). This orchestration empowers industrial entities to optimize their internal operational modalities and collaboratively recalibrate the composite production ecosystem. By assimilating sophisticated technologies such as real-time monitoring systems, predictive analytics, and digital twin simulations, Industry 5.0 significantly mitigates waste generation and pollution within industrial processes (Karmaker *et al.*, 2023). Concurrently, through real-time data exchange, digital twins, and interconnected systems, Industry 5.0 enables stakeholders to meticulously map material flows, identify recycling, remanufacturing, and reutilization opportunities, and optimize resource allocation throughout the supply chain life cycle (Nayeri *et al.*, 2023). This dynamic integration empowers industries to transition from linear models, where resources are disposed of after single use, to circular models, where materials and products are continuously regenerated, reducing waste, conserving resources, and fostering sustainable practices across the entire supply chain ecosystem (Enang *et al.*, 2023; Sindhwani *et al.*, 2022).

Alternatively, Industry 5.0 enhances supply chain productivity by seamlessly integrating transformative technologies and innovative principles. For instance, Industry 5.0 is believed to enable agile decision-making across all facets of the supply chain, empowering businesses to optimize production processes, streamline logistics, and dynamically respond to fluctuations in demand and market conditions (Xu *et al.*, 2021). Industry 5.0's emphasis on human-machine collaboration and stakeholder centricity cultivates a collaborative ecosystem where expertise is harnessed synergistically, leading to streamlined communication, reduced operational bottlenecks, and efficient resource allocation throughout the supply chain (Alves *et al.*, 2023).

Figure 3 further implies that Industry 5.0 may offer a multifaceted framework that empowers corporations to address the challenges of overconsumption, post-consumer waste, and the rebound effect. Through real-time data-driven insights and IoT integration, Industry 5.0 enhances demand forecasting accuracy, enabling companies to align production levels more closely with actual consumer needs (Leng *et al.*, 2022). This minimizes overproduction, curbing excess consumption and reducing the generation of waste. Additionally, Industry 5.0 fosters product design and manufacturing processes that prioritize durability, modular components, and ease of repair, thus extending the product life cycle and reducing waste. Furthermore, the circular economy principles embedded within Industry 5.0 encourage corporations to adopt recycling, remanufacturing, and waste reduction practices, mitigating the rebound effect (Ghobakhloo *et al.*, 2023a, c). By orchestrating a holistic approach that combines data-driven decision-making, sustainable design, and circular strategies, Industry 5.0 empowers corporations to mitigate overconsumption, curtail post-consumer waste, and effectively manage the rebound effect, contributing to a more sustainable and responsible industrial landscape (Atif, 2023; Dwivedi *et al.*, 2023).

4.3 Social values

Scholars have held optimistic expectations in elucidating the potential societal benefits that Industry 5.0 can confer. Especially at the corporate level, these benefits primarily revolve around improving the working conditions for employees, entailing a more intelligent, secure, dignified, and fulfilling work environment (Ivanov, 2023; Leng *et al.*, 2022). Through the orchestrated integration of cutting-edge technologies such as AI, IoE, intelligent automation, and smart wearables, Industry 5.0 instigates the creation of intelligent workspaces that underscores employee comfort and well-being, signifying a notable departure from the conventional approach, where technology dictates work processes (Orlova, 2021). In Industry 5.0, technology is tailored to accommodate the workforce's needs. This shift enhances the workforce's sense of dignity as they recognize their integral role in an environment that values their expertise and preferences. This transformation fosters a sense of empowerment and self-respect among employees, elevating their overall job satisfaction and self-esteem (Frutos-Bencze *et al.*, 2022; Laskowska and Laskowski, 2022).

Industry 5.0 technologies, including adaptive robots, smart wearables, and cognitive systems, substantially enhance the operational landscape for human operators (Ghobakhloo *et al.*, 2023b). This improvement stems from effectively delegating repetitive or physically demanding tasks to automated systems, allowing workers to engage in more intellectually intricate endeavors. These technologies also facilitate seamless access to essential data, empowering workers to exercise decision-making processes and assume an empowered role without necessitating ongoing supervision (Alves *et al.*, 2023; Cimino *et al.*, 2023). Indeed, Industry 5.0 provides the workforce with heightened efficiency and autonomy, fostering a productive and self-directed environment. Furthermore, Industry 5.0 can boost workplace safety by integrating a multifaceted approach encompassing cognitive computing, predictive analytics, real-time monitoring, and smart sensors (Nahavandi, 2019; Xu *et al.*, 2021). These technologies proactively identify potential hazards, such as equipment malfunctions or environmental anomalies, enabling swift interventions and safeguarding employee well-being (Panagou *et al.*, 2023). This safety augmentation extends to the realm of manufacturing, where automated quality control systems ensure the production of safe and reliable products, minimizing occupational risks (Wang *et al.*, 2024).

The literature also identifies a few niche mechanisms through which Industry 5.0 may boost work satisfaction. For example, Industry 5.0 can facilitate remote work and flexible schedules, empowering employees to achieve a healthier work-life balance (Kasinathan *et al.*, 2022). Furthermore, the personalized training and skill development opportunities provided by Industry 5.0 equip employees with the tools to advance their careers, fostering a sense of professional growth and fulfillment. The collaborative ethos inherent to Industry 5.0 also engenders an inclusive and participatory organizational culture, amplifying a sense of belonging and job engagement (Akundi *et al.*, 2022; Leng *et al.*, 2022).

Scholars also believe Industry 5.0 can significantly empower corporations to boost their customer satisfaction. Integrating advanced technologies such as AI-driven analytics and IoT-enabled devices, Industry 5.0 allows businesses to gather and analyze real-time customer feedback and preferences (Orea-Giner *et al.*, 2022). This data and service-driven approach facilitates the customization of products and services, ensuring a more tailored and responsive customer experience, thus bolstering their satisfaction levels (Aslam *et al.*, 2020; Leng *et al.*, 2022). Under Industry 5.0, generative AIs have the potential to revolutionize continuous customer service by autonomously producing human-like responses, enabling prompt and personalized interactions with customers. In real-time, generative AIs can understand and address customer inquiries, concerns, and requests through machine learning and natural language processing. This innovation enhances customer service operations' efficiency, scalability, and consistency, ultimately elevating customer satisfaction and engagement while reducing response times and operational costs (Al Mubarak, 2023).

Concerning sustainability talent management, Industry 5.0's data-driven capabilities can effectively identify and attract skilled individuals aligned with sustainability and social value objectives, leveraging diverse data sources to pinpoint candidates whose ethos aligns with corporate social responsibility goals. Secondly, Industry 5.0 facilitates the deployment of innovative development programs that instill a culture of sustainability among employees (Ghobakhloo *et al.*, 2022). Utilizing AI-driven learning platforms and virtual collaboration tools, these programs provide tailored training and engagement experiences, nurturing a workforce adept at integrating sustainable practices into their roles while fostering a collective awareness of the broader social implications of their actions (Cillo *et al.*, 2022; Saniuk *et al.*, 2022).

Industry 5.0 offers a promising landscape for cultivating several crucial macro-social values, each fortified by distinct delivery mechanisms that harness the transformative potential of advanced technologies. Industry 5.0 is a stakeholder-driven agenda driven by a collective imperative to prioritize the well-being and needs of individuals, impelling the industrial landscape to cultivate technologies that are explicitly attuned to human requirements (Guo *et al.*, 2023). This imperative transcends the boundaries of industrial operations, extending its reach into consumer products (Maddikunta *et al.*, 2022). As a result, the evolution of Industry 5.0 necessitates the creation of technologies that seamlessly align with and enhance human experiences, whether in the context of workplace interactions or consumer engagements (Akundi *et al.*, 2022). Thus, human-centric technology development emerges not merely as a desirable endeavor but as an essential response to the mandate of

Industry 5.0's stakeholders, propelling the industrial domain toward a more empathetic, efficient, and user-centered technological ecosystem (Longo *et al.*, 2020; Nahavandi, 2019; Rožanec *et al.*, 2022).

Some scholars also believe that equal employment opportunity is a foundational principle underpinning Industry 5.0, fortified by an ecosystem of continuous learning, upskilling, and reskilling (Ghobakhloo *et al.*, 2022). At the heart of Industry 5.0's ethos is the recognition that technological evolution necessitates a corresponding evolution in workforce skills. This realization propels Industry 5.0 stakeholders to champion comprehensive training initiatives that transcend traditional occupational silos. By fostering a culture of lifelong learning, Industry 5.0 ensures that employees have the tools to adapt to technological shifts, eliminating potential barriers to equal employment participation (Li *et al.*, 2023; Mukherjee *et al.*, 2023). This commitment to upskilling and reskilling empowers individuals to navigate evolving job landscapes and dismantles systemic biases, opening pathways for diverse talents to flourish (Broo *et al.*, 2022). On the other hand, employment growth is a natural outcome of Industry 5.0's transformative impact on industries. As companies adopt automation, robotics, and data analytics, new job roles will emerge within technology implementation, data interpretation, and digital infrastructure management contexts. Moreover, the need for skilled personnel to operate, maintain, and innovate these technologies generates continuous workforce development and expansion opportunities (Coronado *et al.*, 2022; Maddikunta *et al.*, 2022).

In Industry 5.0, the core ideas of servitization (offering services alongside products) and unwavering focus on customers greatly enhance how consumers experience products and services (Nicoletti and Appolloni, 2023). This shift means companies do not just sell things – they provide complete solutions that meet individual needs. Industry 5.0 refines how companies interact with consumers using real-time data analysis and AI-driven insights, leading to personal customer experiences (Yao *et al.*, 2022). Furthermore, the Industry 5.0 paradigm promotes higher product accessibility through optimized production processes. Smart automation and digital twin simulations enable efficient resource allocation, waste reduction, and quality control, which in turn streamline production cycles and minimize costs (Fatima *et al.*, 2022; Xu *et al.*, 2021). This efficiency-driven approach contributes to affordability, making products more accessible to a broader demographic (Ghobakhloo *et al.*, 2022).

5. Discussion

The present study strived to answer the question of "How can the technological constituents of Industry 5.0 contribute to economic, environmental, and social sustainability at the firm and industrial levels?" SLR findings underscore that Industry 5.0 is an emerging field in academia, explaining the limited coverage of its impact on corporate sustainability performance. The identified studies presented an optimistic perspective, accentuating Industry 5.0's potential to enhance corporate sustainability practices. Both the SLR and evidence mapping outcomes illuminate Industry 5.0's endeavor to harmonize economic, social, and environmental facets of corporate sustainability. It is crucial to recognize that these advantages extend beyond individual corporations; widespread Industry 5.0 adoption could catalyze a more sustainable industrial ecosystem, benefiting businesses, the environment, and society as a whole. However, certain critical controversies warrant deeper examination amid the valuable insights these early studies offer.

The central issue identified within the present study pertains to the nature of insights presented in the literature regarding Industry 5.0's contributions. Notably, a predominant characteristic of these insights is their theoretical or perceptual nature. The existing insights on the industry's potential impact on corporate sustainability can be broadly categorized into two groups. The first category encompasses conceptual explorations, such as the research undertaken by Bednar and Welch (2020), Ivanov (2023), Leng *et al.* (2022), and Lu *et al.* (2022), which draws from the historical context of Industry 4.0 and references white literature related to Industry 5.0, including agendas set forth by the European Commission. These conceptual studies endeavored to determine the prospective sustainability contributions that Industry 5.0 might or should offer. The second category encompasses investigations that involve expert consultations to elucidate conceivable sustainability values inherent to Industry 5.0 (e.g. Dwivedi *et al.*, 2023; Sindhwani *et al.*, 2022). For example, a recent survey conducted by Guo *et al.* (2023) among Chinese agricultural firms revealed that respondents perceive the Industry 5.0 model to possess substantial potential in significantly enhancing all three pillars of sustainability. Ghobakhloo *et al.* (2022) drew upon the perspectives of European experts to pinpoint the specific sustainability values that should ideally emanate from the implementation of Industry 5.0.

While these early insights are undoubtedly invaluable, the absence of empirical data detailing the proven pathways through which Industry 5.0 can effectively foster inclusive sustainability presents a notable concern. To underscore this issue, we can draw parallels with the case of Industry 4.0. Initially centered around a productivity-driven agenda, Industry 4.0 entailed the adoption of novel technologies, particularly among manufacturers, to enhance overall corporate performance. Despite early enthusiasm surrounding Industry 4.0, the dearth of empirical evidence led to widespread skepticism. Over time, however, a series of real-world case studies and industrial reports emerged, illustrating instances where the successful implementation of Industry 4.0 technologies yielded substantial performance improvements. For example, longitudinal studies (e.g. Ghobakhloo and Fathi, 2019; Pozzi *et al.*, 2023) revealed that Industry 4.0 transformation, though disruptive initially, ultimately augments the financial and operational performance of manufacturing firms. Regrettably, equivalent practical insights into the implications of Industry 5.0 are notably lacking. This is a critical concern as Industry 5.0 transcends mere technology adoption; it signifies the responsible digital transformation of businesses to harmonize profitability with socio-environmental values. It is evident that perfect optimization of all three sustainability aspects is implausible, often necessitating trade-offs between them. Prioritizing societal values may entail profitability or resource costs, yet scholars posit that achieving socio-environmental goals could yield value return mechanisms that offset productivity or financial setbacks, such as through enhanced corporate image. However, a lack of practical evidence exists on this front, leaving corporations uncertain about the potential impacts of Industry 5.0 transformation on their future corporate performance.

The content-centric synthesis of eligible articles also unveils a substantial concern about how Industry 5.0 can effectively deliver sustainability values. Scholars frequently contend that specific prerequisites and underlying mechanisms must be established to enable Industry 5.0 to realize its intended values. Two critical issues arise in this context. Firstly, Industry 5.0 is still evolving, with only a limited subset of these prerequisites identified. Secondly, the identified requisites and their underlying mechanisms appear intricate and complex, rendering it overly optimistic to expect typical corporations or Industry 5.0 stakeholders at large to manage them adeptly. For instance, scholars assert that sustainable corporate governance, eco-innovation, technology governance, and sustainability performance management systems are integral requirements for Industry 5.0 to actualize its envisioned values. Ghobakhloo *et al.* (2023a) exemplified that a real-time sustainability performance management system is deemed crucial, enabling all Industry 5.0 stakeholders to monitor sustainability indices seamlessly. This permits timely intervention when deviations occur during digital transformations under this framework. Unfortunately, a significant dearth of knowledge exists regarding developing and implementing such prerequisites, rendering the promised values of Industry 5.0 even more challenging to attain.

The scarcity of empirical research on Industry 5.0 can be attributed to a combination of two primary reasons. Firstly, Industry 5.0 is a relatively nascent concept in the industrial landscape that requires time to mature and evolve into a fully-fledged empirical domain. This is partly because many companies are still in the process of fully implementing and harnessing the potential of Industry 4.0, which acts as a precursor and foundation for Industry 5.0. Thus, the industry is still transitioning, and practical research on the latest stage, Industry 5.0, is limited as a result of this embryonic state. Secondly, the nature of Industry 5.0 is distinct from its predecessors, particularly Industry 4.0. While both build upon technological innovations to drive industrial evolution, Industry 5.0 is primarily characterized as a socially driven governance agenda for technological transformation. It is not perceived as a new industrial transformation *per se* but rather as a regulatory framework that complements Industry 4.0. Its fundamental objective is to ensure that technological transformation advances while effectively balancing economic, environmental, and social values, not only at the micro-level within individual firms but also across the entire supply chain and macro-regional level. This unique positioning of Industry 5.0 makes it a comprehensive and integrative concept. It means Industry 5.0's broad and integrative nature could also be a contributing factor to the limited practical research, as it necessitates a more holistic and intricate approach that incorporates social and regulatory dimensions alongside technological aspects, potentially making empirical research more challenging. In essence, the dearth of practical research on Industry 5.0 can be understood as a consequence of its emerging nature, coupled with its distinctive role as a socio-technological governance agenda.

6. Conclusions

Industry 5.0 is undergoing rapid transformation, accompanied by much anticipation and discourse surrounding its imperative. The prevailing notion is that Industry 5.0 holds the potential to address persistent and increasingly aggravated socio-economic and environmental challenges that pose threats to the well-being of future generations. In light of this view, the present study addresses a pivotal inquiry: to what extent has the Industry 5.0 agenda been effectively assimilated within corporate frameworks, and has it engendered favorable outcomes regarding corporate profitability and sustainability?

The study employed an SLR, supplemented by a concentric assessment of eligible articles, followed by an evidence-mapping exercise to address this critical question. The results revealed some interesting and debated facts about Industry 5.0, which could have important implications for both theory and real-world applications.

6.1 Implications

The findings of this study shed light on the evolving nature of the Industry 5.0 agenda, indicating that it has yet to reach a stage of maturity. It is plausible to infer that the current state of Industry 5.0 remains rooted in speculation and conceptualization. While this assertion may appear assertive, it is substantiated by certain factors. Notably, the very definition of Industry 5.0 remains elusive, with diverse interpretations prevailing. It has been depicted as a framework for digital transformation, a regulatory initiative, or even an extensive industrial revolution.

The fact of the matter is that Industry 5.0 has been subject to a multitude of divergent and sometimes contradictory perspectives. A significant juncture arose when the European Commission intervened, releasing policy agendas that coalesced and streamlined the trajectory of this phenomenon. However, it is noteworthy that the European Commission's engagement was similar to navigating uncharted waters, driven by an awareness that digital industrial transformation required regulation and that the former Industry 4.0 framework was inadequate for the future of European industry. While the overarching objective of this regulatory initiative was clear, the specifics about its execution, stakeholders involved, and extent of engagement remained uncertain.

The ramifications of this perceptual and directional ambiguity are manifest in the academic discourse influenced by the European Commission's agendas. Scholars widely anticipate that Industry 5.0 holds promise for enhancing various dimensions of sustainability. Intriguingly, they envision a harmonious equilibrium in Industry 5.0's contributions to the economic, environmental, and social facets of corporate performance. Nonetheless, empirical evidence confirming the adoption and implementation of this agenda within corporate domains is evidently absent. Consequently, the real-world impact of Industry 5.0 on enhancing corporate profitability and sustainability performance remains unverified.

It is essential to clarify that the aforementioned conclusion should not be misconstrued as an indication of the ineffectiveness or failure of Industry 5.0. Instead, it signifies the present developmental phase of Industry 5.0, which is characterized by its conceptual development. This progression is occurring much slower than initially anticipated, mainly owing to the intricate nature inherent to the conceptualization of Industry 5.0. The scope of Industry 5.0 extends beyond mere technological implementation. It encompasses a holistic paradigm, necessitating synchronized endeavors to govern and oversee the entire life-cycle of technological evolution, encompassing development, integration, and application within both corporate and industrial domains. Industry 5.0 also requires maintaining a longitudinal viewpoint that considers the potential enduring implications of technologies on both the environment and, more notably, society. In addition, to make Industry 5.0 successful, different groups like companies, tech providers, governments, social groups, worker unions, and regulators need to work together in a well-coordinated way. This collaboration is crucial for achieving the overall goals of Industry 5.0.

Therefore, the gradual pace at which Industry 5.0 is evolving aligns with reasonable expectations, considering the inherent complexity of coordinating cooperative efforts that involve societal goals. Adding to the challenge is the rapid rate at which new digital technologies emerge. This is exemplified by the unprecedented rise of generative AI, which is causing significant disruptions to socio-economic systems. In contrast, the Industry 5.0 agenda and its associated ideas within academic literature seem to be falling behind and not keeping up with these transformative technological advancements. In conclusion, this indicates that the development and maturation of Industry 5.0 are progressing much more slowly than the rapid emergence of disruptive technologies or the broader changes in the market and business landscape. This might clarify why Industry 5.0 appears to be at a theoretical and aspirational stage, where there is enthusiastic talk about achieving sustainable outcomes, but practical progress remains limited.

While there is currently no concrete evidence showcasing the practical advantages of Industry 5.0 for the economy, society, and the environment, we firmly believe in establishing Industry 5.0 as a vital regulatory framework. Significant strides are being made in major economies like the United States, Japan, and various European nations to regulate the development, marketing, and widespread utilization of technologies, particularly AI. Industry 5.0 presents a promising avenue for facilitating such a regulatory movement. The critical aspect lies in stakeholders' commitment to advancing the Industry 5.0 agenda. Their concerted efforts should be expedited to mature the framework and transition it from a conceptual realm to practical implementation in the real world.

6.2 Future directions

The SLR findings have highlighted several promising avenues for future research, aiming to address the existing gaps in understanding the role of Industry 5.0 in promoting sustainability objectives. Among these, a particularly pertinent and constructive avenue for further exploration would involve conducting a longitudinal analysis of Industry 5.0 adoption and its resultant outcomes. In forthcoming studies, a comprehensive longitudinal investigation could be undertaken to meticulously trace the progression of Industry 5.0 implementation across diverse sectors. Such research endeavors would entail an evaluation of its impact on both corporate profitability and sustainability over an extended timeframe. This could be achieved by scrutinizing data from enterprises that have wholeheartedly embraced Industry 5.0 methodologies, allowing for a comparative assessment of their financial and sustainability performance before and after the assimilation of these innovative practices. It is imperative to underscore that these case studies should extend beyond mere technological integration. Instead, they should meticulously focus on encompassing the strategic orchestration of technological deployment, which is intentionally aligned with socio-environmental values. This approach facilitates a deeper understanding of the harmonization between technological advancement, economic viability, and responsible ecological and societal stewardship, ultimately contributing to the broader discourse surrounding Industry 5.0's impact and potential.

Another avenue for future research would be to investigate the collaborative mechanisms and partnerships that should be established among diverse stakeholders (e.g. corporations, technology providers, governments, and regulatory bodies) to facilitate Industry 5.0 implementation. Examining the challenges, successes, and lessons learned in building and maintaining such partnerships and their implications for corporate outcomes would also be an exciting avenue for future studies. Furthermore, comparing the regulatory approaches adopted by different countries or regions to govern the development and utilization of technologies like AI within the context of Industry 5.0 is truly needed. Understanding how these regulations impact corporate profitability and sustainability is vital.

The common assumption that implementing Industry 5.0 in corporations brings only benefits and no risks needs reconsideration. Logically, any move involving technology investment and strategic changes carries a risk, potentially harming a company's future. Therefore, it is crucial to thoroughly examine the possible risks associated with adopting the Industry 5.0 framework. These include cybersecurity vulnerabilities, ethical issues, impacts on employees, and disruptions to established business processes, among other things. Recognizing these diverse risks is essential for a wise approach to adopting Industry 5.0. Thus, developing rigorous strategies and frameworks to deal with these risks becomes crucial in this context. By addressing these risks proactively, companies can protect themselves from potential problems and improve their ability to handle unexpected challenges. Importantly, aligning these risk management strategies with the main goals of Industry 5.0 – like increasing corporate profits and sustainability – becomes a key consideration. This means taking a well-rounded approach that combines technological progress with smart risk management practices, ultimately improving the potential for Industry 5.0 to bring valuable and lasting benefits to companies.

It is also notable that the present systematic review mainly focused on the academic literature, which provides a robust foundation for understanding the theoretical aspects of Industry 5.0 and its sustainability implications. However, there is a wealth of knowledge and valuable insights that exist within the gray literature and practical industry reports. This untapped resource can offer a real-world perspective on the status of Industry 5.0 advancements within the industrial and policy contexts. To address this limitation and further enrich our understanding, we propose future research directions that involve the utilization of AI-based tools and web crawling techniques. By leveraging these advanced technologies, scholars can delve into the gray literature, including industry reports, government publications, and policy documents. This approach will enable the capture of the practical implementations and advancements of Industry 5.0, shedding light on how it is being adopted in real-world scenarios. Additionally, it will help gain insights into the challenges and barriers faced by industries and policymakers as they strive to integrate Industry 5.0 practices.

Incorporating findings from both the academic and gray literature can provide a more comprehensive and holistic understanding of Industry 5.0's current status, its impact on sustainability, and the challenges that need to be addressed. This integrated approach will contribute to bridging the gap between theory and practice, making our research more applicable and valuable for industry stakeholders, policymakers, and researchers alike.

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