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Global Context of Industry 5.0 : Current Trends and Challenges in Indonesia

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ABSTRACT

This article reviews the strategies and potential implications of implementing Industry 5.0 in Indonesia, emphasizing environmental impact, process technology, and energy conservation. To provide a comprehensive understanding of Indonesia's challenges and opportunities in transitioning to Industry 5.0 and to elucidate the impact of this shift on environmental sustainability, technological processes, and energy efficiency. An in-depth analysis was conducted on current technological trends, such as 3D printing, augmented reality, virtual reality, IoT, and AI, and their potential roles in the Indonesian industrial sector. We also explored the infrastructural needs, the significance of a skilled workforce, and the regulatory framework essential for a seamless transition. Findings highlight the critical importance of human-centric manufacturing, the potential benefits of Industry 5.0 technologies for environmental and energy efficiency, and the need for robust collaborations among government, industry, and research institutions for a successful transition. Recommendations emphasize infrastructure development, human resource enhancement, supportive policies, and multi-sectoral collaboration.

1. INTRODUCTION

The progression of the Industrial Revolution is evident through its various phases, transitioning from Industry 1.0's essential mechanization to the sophisticated digitization seen in Industry 4.0 (Destouet et al., 2023). Now, the global arena is advancing towards Industry 5.0. This phase underscores a blend of human and technological collaboration, aiming for a balanced coexistence between man and machine (Demir et al., 2019). To embody this vision, Industry 5.0 integrates advanced technologies including, but not limited to, 3D printing, Augmented Reality (AR), Virtual Reality (VR), the Internet of Things (IoT), and Artificial Intelligence (AI) (Mourtzis et al., 2022; Elshenawy et al., 2023).

With a commitment to enhancing production processes, Industry 5.0 champions a synergistic approach to manufacturing, placing humans at its core. Harnessing these groundbreaking technologies could profoundly augment environmental stewardship, refining process technology, and bolster energy conservation. Nonetheless, the journey to inculcate Industry 5.0 Indonesia's framework is complex – from infrastructural enhancements to upgrading workforce skills and sculpting favorable legislative environments (Hein-Pensel et al., 2023; Yin & Yu, 2022). Thus, a unified front between government bodies, industrial sectors, and academic circles becomes paramount to spur innovation and research.

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Globally, the buzz around Industry 5.0 has intensified. This paper endeavors to curate an overview of the prevailing trends and trajectories in Industry 5.0. By gauging its global momentum to spotlight potential challenges that might surface when introducing it to the Indonesian milieu. Recognizing that Indonesia's tryst with Industry 5.0 is still in its infancy, conjectures draw from an intricate understanding of its present global status. Through narrative to carve a roadmap for Indonesia, spotlighting strategic imperatives in areas like environmental preservation, advanced process technology, and energy efficiency during this pivotal industrial metamorphosis.

The essence of this article transcends a mere chronicle of the dynamic realms of Industry 5.0. In light of the seismic shifts the global industrial sectors are witnessing with the dawn of Industry 5.0, this manuscript not only stands as a contemporary dossier but also illuminates the distinctive barriers Indonesia, an emergent powerhouse, might face in its voyage to assimilate Industry 5.0. For Indonesian stakeholders, deciphering these intricacies is critical to charting a visionary yet pragmatic implementation path.

Delving deep, this review shines a light on the recent breakthroughs in Industry 5.0, its foundational technologies, and the intertwined challenges and prospects it ushers in for manufacturing. Highlighting environmental sustainability, avant-garde process technology, and energy thriftiness as pivotal axes (Demir et al., 2019; Destouet et al., 2023), the potential for Indonesia to refine these facets through Industry 5.0's lens is significant. This discourse aims to bequeath discerning insights, enabling Indonesia to navigate this transformative era and reap its advantages.

Navigating the transition from Industry 4.0 to 5.0, Indonesia is on the brink of a revolution. With aspirations to institute strategies accentuating environmental impact, advanced process technology, and energy prudence, lucidity and precision in elucidating these imperatives are non-negotiable. Marrying the nuances of Industry 5.0 with Indonesia's distinct challenges and potentials necessitates that our communication mirrors the rigor and meticulousness with which we approach this pivotal shift.

2. METHODS

This study employs a qualitative review approach. Undertook a systematic review of existing literature related to Industry 5.0, focusing on its implementation strategies and the challenges countries face, especially Indonesia. This method allows for a comprehensive understanding of the topic by synthesizing various perspectives and findings from multiple sources.

Instrument The research was conducted remotely, with sources primarily being academic journal publications focusing on Indonesia's industrial sector and transition to Industry 5.0. Academic databases were used to gather peer-reviewed articles, and platforms such as Google Scholar, Scopus, and ScienceDirect were utilized. Software VOSviewer was employed for qualitative data analysis, enabling us to categorize and code themes emerging from the literature.

Procedure The study began with a keyword search on the chosen databases, focusing on terms like "Industry 5.0", "Indonesia industrial challenges," and "sustainable industrial practices." After gathering a significant number of articles, a review was undertaken. Articles were classified as critical themes and selected using VOSviewer toward reading in depth. The data was then synthesized, and key findings related to Indonesia's transition to Industry 5.0 were identified.

3. RESULTS AND DISCUSSION

3.1. Diverse Perspectives on Industry 5.0: A Foundation For Indonesian Strategy

The rapid evolution of Industry 5.0 has led to many opinions and projections about its potential implications and best practices for implementation. Recognizing the importance of this diversity in thought, the manuscript gathers opinions from various experts in the field. Each perspective provides a unique insight into the challenges and opportunities of Industry 5.0, especially within Indonesia's unique industrial and socio-economic landscape. By synthesizing these varied viewpoints, we aim to offer a comprehensive strategy for Indonesia, ensuring the nation's approach is informed and innovative. Table 1 shows a

comparative approach of the five industrial revolutions, highlighting the evolution in process technology, environmental impact, and energy conservation strategies.

3.2. The current stage of Indonesia in the transition to Industry 5.0

As a rapidly developing nation, Indonesia has shown significant strides in embracing industrial revolutions over the past decades. As of the recent assessment, Indonesia is predominantly in the Industry 4.0 phase, focusing on digitization, automation, and adopting the Internet of Things (IoT) in its manufacturing and industrial sectors. Several industries have started integrating intelligent technologies, data analytics, and AI-driven processes into their operations.

However, while Industry 4.0 principles are being adopted, the shift towards Industry 5.0 — emphasizing human-machine collaboration, customized production, and enhanced sustainability — is in its nascent stages. The government has launched initiatives and roadmaps to drive the country towards Industry 4.0 and 5.0. These include the "Making Indonesia 4.0" strategy, which lays the foundation for a more advanced stage of industrialization. However, the complete realization of Industry 5.0 is still a vision for the future, with several challenges to overcome and opportunities to seize.

Understanding Indonesia's current position in the industrial evolution spectrum is crucial as it provides context to the subsequent discussion on strategies for the transition to Industry 5.0.

As one of Southeast Asia's largest economies, Indonesia has been working diligently on embracing the next industrial revolution, colloquially referred to as Industry 5.0. This phase of the industrial revolution emphasizes collaboration between humans and machines, bridging the gap between technological advancements and human-centric approaches to ensure efficient and humane production processes.

3.3. Human collaboration in the packaged drinking water industry

One notable development in the Indonesian industrial landscape is the pilot projects in the Packaged Drinking Water (AMDK) sector. Historically, the production processes in this industry, particularly packaging, have been predominantly automated. However, the transition towards Industry 5.0 has seen a more significant involvement of human roles in production. The rationale is to leverage human workers' unique insights, dexterity, and adaptability while machines provide precision, speed, and consistency.

Table 1. Evolution of industrial revolutions: Differences in process technology, environmental impact, and energy conservation

Industrial Revolution	Process Technology	Environmental Impact	Energy Conservation
Industry 1.0	Mechanization using steam and water power	Significant increase in emissions	Reliance on non-renewable sources (coal, wood)
Industry 2.0	Mass production using electrical energy	Continued rise in pollution	Increase in electrical energy consumption
Industry 3.0	Automation using electronics and IT	Mixed; adoption of cleaner tech	Improved efficiency but increased consumption
Industry 4.0	Digitalization and the advent of intelligent systems	Focus on green technologies	Emphasis on renewable energy and energy-saving
Industry 5.0	Collaboration between humans and machines	Human-centric & sustainable	Enhanced conservation through AI and optimization

The goal of these pilot projects is to create a harmonious working environment where machines can support and augment the abilities of their human counterparts. This approach increases productivity, reduces errors, and leads to a more fulfilling and meaningful work experience for employees.

3.4. AI-Based production control in the ozonation process

Another noteworthy implementation is in the process of ozonation, a crucial step in purifying water for consumption. With the challenges posed by variations in source water quality and the imperative to ensure consistent, safe drinking water, companies have turned to AI-powered databases. These databases collate extensive data on water sources, ozonation parameters, and final product quality.

With the help of AI, predictions can be made about the future quality of the product. It allows industries to make proactive decisions, optimize the real-time ozonation process, and consistently produce high-quality drinking water. Integrating AI ensures the product meets stringent safety standards while optimizing resource use and minimizing waste.

Apart from the sectors above, various industries in Indonesia have been adopting similar approaches. From intelligent manufacturing that employs sensors and IoT devices to monitor and optimize factory operations to the agriculture sector leveraging drone technology and AI for precision farming — the wave of Industry 5.0 is being felt throughout.

It is worth noting that the government, aware of the potential of Industry 5.0, has been implementing policies and initiatives to foster an environment conducive to this transition. It includes investments in infrastructure, upskilling programs for the workforce, and collaborations with international tech giants.

The journey of Indonesia toward Industry 5.0 is a testament to its commitment to embracing the future while being cognizant of the human element in the industrial process. By harmonizing technology with human collaboration and utilizing the potential of AI, Indonesia is poised to become a leader in the next phase of the industrial revolution.

3.5. Industry 5.0 Environmental Technology

Industry 5.0 emphasizes human centricity, sustainability, and resilience throughout the manufacturing process, which includes air pollution control technologies, wastewater treatment, and solid waste and hazardous waste management (Destouet et al., 2023). Effective and sustainable environmental technologies are critical in Industry 5.0 to address diverse industrial sectors' environmental challenges.

Blockchain technology has been considered an air pollution control method in Industry 5.0 to resolve centralization, privacy, latency, and security concerns in industrial IoT infrastructure (Elshenawy et al., 2023). The proposed solution, FusionFedBlock, combines Blockchain with Federated Learning to maintain anonymity between industrial divisions. Efficient and sustainable environmental technologies will play a vital role in reducing the negative environmental impact of industrial operations in the context of Industry 5.0. The Indonesian industry can meet its sustainability targets and minimize environmental impact by implementing air pollution control technologies, wastewater treatment, solid waste, and hazardous waste management (Destouet et al., 2023). Table 2 shows the impact of Industry 5.0 in Terms of environmental impact, efficiency, and energy conservation.

One of the primary objectives of implementing Industry 5.0 is to optimize manufacturing processes while minimizing environmental impact. For example, AI and data analytics technologies can contribute to this goal. Li et al. (2022) demonstrated implementing a NOMA-based cognitive radio network with a hybrid FD/HD relay, which allows opportunistic switching of RATs and offloading methods to reduce delays, thereby enhancing the efficiency and reliability of communication systems in Industry 5.0.

Furthermore, AI technology can improve resource allocation systems, increasing production efficiency (Ahmed et al., 2022). Ahmed et al. (2022) proposed a Secondary Resource Allocation (SRA) method based on multiple time

scales in conjunction with the QMix Multi-Agent Reinforcement Learning (MARL) algorithm, which can increase the overall utility value by 70% and job completion rate by 6%, enhancing the efficiency of industrial operations.

Industry 5.0 has led to significant changes in design engineering, mainly through AR, VR, IoT, and AI technologies (Mourtzis et al., 2022). An example of this technology application is the development of automated tool exchange systems for robots, which can improve efficiency and accuracy in equipment replacement. Moreover, Industry 5.0 emphasizes creating more efficient technology for detecting and controlling pollution.

Table 2. Impact of Industry 5.0 in Terms of environmental impact, efficiency, and energy conservation

Aspect	Positive Impact	Negative Impact
Environment	• Reduction of greenhouse gas emissions. • Use of renewable energy sources. Waste reduction through process efficiency	• Disposal of e-waste. • Unsustainable use of natural resources.
Process Technology	• Process automation that improves efficiency. • Improved product quality control. • Increased flexibility in the production process	• Job loss due to automation. • High technological dependability.
Energy Conservation	• Use of energy-friendly technologies. • Better energy management thanks to IoT. • Reduction of energy consumption through process optimization.	• Increased energy consumption in certain sectors.

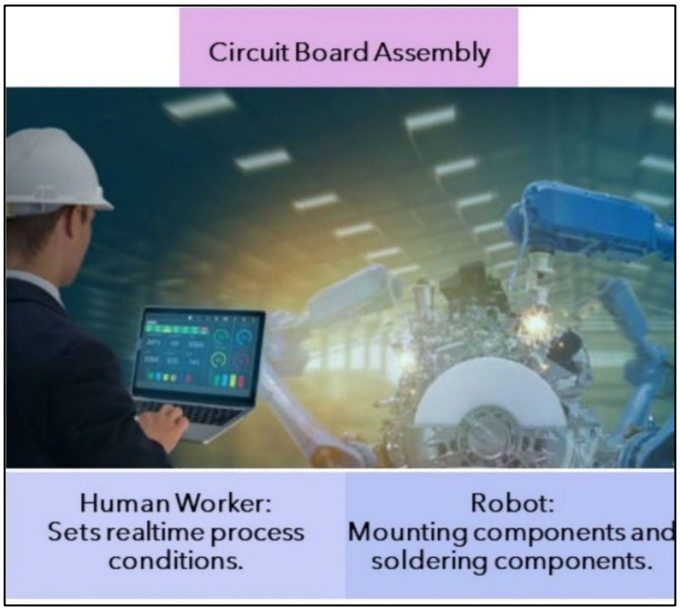

Figure 1. Illustration of the concept of cooperation between humans and robots in the context of Industry 5.0

AI technology in Industry 5.0 also enhances supply chain resilience and sustainability (Ahmed et al., 2022). Challenges in Industry 5.0 involve human collaboration in a human-centered manufacturing environment. Wang et al. (2023) suggested a Digital Twin-based strategy to address safety management challenges in such a manufacturing context. This approach includes machine-readable semantic reasoning frameworks, insecure state ontologies, high-speed virtual Digital Twin workshops, virtual dataset generation, network target identification, and tests to demonstrate the proposed method's effectiveness.

Figure 1 illustrates the cooperation between humans and robots in Industry 5.0, showing how technologies such as cobots (collaborative robots) and augmented reality enable more efficient and safe interactions between human workers and machines. Robots assist human workers in assembling small components on circuit boards with exact spot welding. Robots can provide speed, precision, and consistency that are difficult for human workers to achieve.

Orea-Giner et al. (2022) investigated the impact of deploying robots in hotels on overall TripAdvisor rankings in the tourism setting. The study found a connection between emotions and attitudes elicited by hotel robot interactions, the robot's functional typology, traveler classifications, and hotel evaluations. This finding illustrates how AR, VR, IoT, and AI technologies can be leveraged to enhance customer experience and service quality in various industries.

Industry 5.0 offers opportunities for developing and utilizing environmentally friendly materials as alternatives in the industrial sector. Mourtzis et al. (2022) explored the potential of 3D printing in creating automated tool interchange systems for robotic arms in Industry 5.0. This study developed an efficient system that allowed for adequate tool replacement and demonstrated the possibility of creating collaborative systems for educational instruction using robots.

Furthermore, Mirza et al. (2023) showed how reinforced deep learning (DRL) could be used to increase accuracy, reliability, and real-time decision-making

capabilities in optimizing task procrastination offloading in Industry 5.0-based vehicle edge computing networks (VECNs). These findings illustrate how technological advancements in Industry 5.0 can support developing and using environmentally friendly materials by enabling more efficient and sustainable operations (Mirza et al., 2023).

Overall, Industry 5.0 presents opportunities for developing and using eco-friendly materials as industrial alternatives through various innovative technologies, such as 3D printing and AI-based techniques like DRL. Adopting these environmentally friendly products will help reduce the industry's negative environmental impacts and promote sustainability in the manufacturing process.

Energy conservation is a critical aspect of Industry 5.0, and technologies like IoT and AI can help optimize energy consumption. Mirza et al. (2023) demonstrated how AI technologies, such as deep reinforcement learning (DRL), can be used to increase accuracy, reliability, and real-time decision-making capabilities in minimizing offloading job delay in Industry 5.0-based vehicle edge computing networks (VECNs). This study highlights the potential of IoT and AI technologies for reducing energy costs and consumption through process optimization.

Renewable energy and efficient energy conversion technologies are also essential in Industry 5.0. Harihastuti et al. (2021) described a full-scale implementation of a high-performance anaerobic reactor with substrate modification and effluent recirculation for vintage sugarcane degradation and biogas generation. In the context of Industry 5.0, this technology has the potential to produce renewable energy and enhance energy conversion efficiency.

IoT and AI technologies, renewable energy, and efficient energy conversion technologies can be harnessed to optimize energy use and support environmental sustainability in Industry 5.0. By integrating technologies such as DRLs, membrane-less MFCs, and high-performance anaerobic reactors, Industry 5.0 can reduce energy consumption and generate renewable energy, thus promoting energy conservation in the industrial sector.

3.6. Global Industry 5.0 Innovation

Industry 5.0 emphasizes numerous innovations and discoveries in areas such as air pollution control, wastewater treatment, solid waste B3 management, and energy conservation to support its process technology. AI technologies, such as real-time tracking via IoT, can be employed in Industry 5.0 to build robust and sustainable supply chains (Ahmed et al., 2022). Furthermore, Yin and Yu (2022) recommend adopting and implementing a digital green knowledge framework for Industry 5.0, which can enhance the effectiveness of digital green innovation practices by emphasizing the need for collaboration with external knowledge seekers.

Human-robot Collaboration is a significant aspect of Industry 5.0. Pozo et al. (2022) discuss the open-lab approach to building collaborative robotic environments in educational teaching. Rannertshauser et al. (2022) propose the concept of human-centricity in the design of production planning and control systems to eliminate errors caused by cognitive biases. Moreover, Wang et al. (2023) suggest a Digital Twin-based safety management strategy for addressing safety management challenges in human-centered production aligned with Industry 5.0 requirements.

In the context of Industry 5.0, technologies such as Blockchain and Federated Learning have emerged. Elshenawy et al. (2023) propose a solution that combines Blockchain with Federated Learning to ensure anonymity among industry divisions while storing and validating global models.

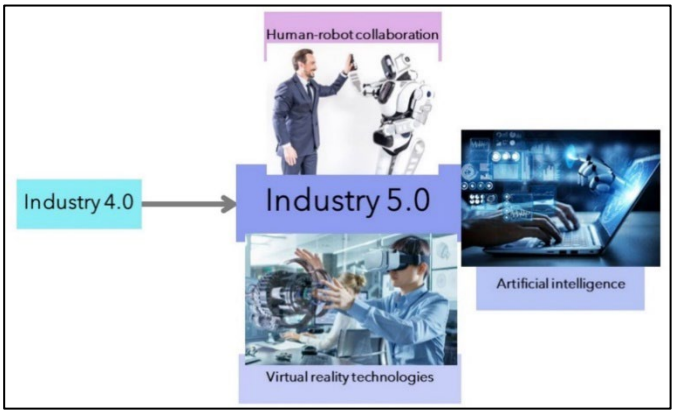

Figure 2. Industry 5.0 flowchart

Industry 5.0 has brought about significant innovations and improvements in various industrial sectors. Multi-Agent Reinforcement Learning (MARL) technology in resource allocation is a critical component of Industry 5.0 (Ahmed et al., 2022). According to Ahmed et al. (2022), this technology increases total utility value by up to 70% and results in a 6% rise in job completion rates, contributing to developing more effective resource allocation systems for connected and autonomous vehicles (CAV).

Robots in the hospitality industry have significantly impacted TripAdvisor's overall rankings, highlighting the connection between emotions and sentiments generated by robot interactions and hotel evaluations (Orea-Giner et al., 2022). Industry 5.0 also encompasses a green digital knowledge adoption-implementation framework, which can help manufacturing organizations enhance the performance of their green digital innovations (Yin & Yu, 2022). Pozo et al. (2022) provide an example of Industry 5.0 technology through an open laboratory approach to collaborative robotic environments in educational instruction. Figure 2 shows the Industry 5.0 flowchart illustrating the transition from Industry 4.0 to Industry 5.0, including vital technological changes, such as increased human collaboration, artificial intelligence, and virtual reality technologies.

Wang et al. (2023) suggest a Digital Twin-based solution for addressing safety management challenges in human-centered manufacturing within the context of environmental and security management. This strategy includes machine-readable semantic reasoning frameworks, hazardous state ontologies, and high-reliability virtual Digital Twin workshops. Thakur and Kumar Sehgal (2021) propose a heterogeneous architecture for Smart Cyber-Physical Systems (SCPS) in the context of renewable energy that can be applied in various industries such as petroleum, fertilizer, paper, cement, space exploration, and automobile production.

Under Industry 5.0, Mourtzis et al. (2022) developed an automated tool exchange system for 3D printing design. However, Hein-Pensel et al. (2023) emphasize the importance of maturity assessment in Industry 5.0 adoption, particularly for small and medium-sized businesses with limited resources. This study highlights the need for a more human-centered approach to manufacturing, focusing on sustainability and resilience (Destouet et al., 2023).

To implement Industry 5.0 in Indonesia, concentrating on long-term, flexible, and innovative strategies is crucial. Human centricity, sustainability, and resilience in manufacturing will be critical to successfully transitioning to Industry 5.0 (Destouet et al., 2023). Moreover, efforts to address challenges in workforce skill development and new technology adoption will be essential in implementing Industry 5.0 in Indonesia.

3.7. Global Industry 5.0 Challenges

Industry 5.0 presents several significant challenges that Indonesia must address to adopt and implement this new technology successfully. One primary concern is human-centric manufacturing, which requires a deep understanding of the complex interconnections between humans, machines, and the environment (Wang et al., 2023). Furthermore, Lu et al. (2022) note that there is no common understanding of the nature of human-centered manufacturing, emphasizing the importance of addressing this issue in Industry 5.0.

Another challenge lies in the lack of research on organizational issues arising from human-robot Collaboration (Demir et al., 2019). Implementing technologies such as 3D printing, AR, VR, IoT, and AI in collaborative systems for educational instruction presents obstacles (Mourtzis et al., 2022). Moreover, utilizing Blockchain technology and Federated Learning in the context of Industry 5.0 raises concerns about centralization, privacy, latency, and security risks in industrial IoT infrastructure (Elshenawy et al., 2023).

Industry 5.0 builds upon Industry 4.0, emphasizing the role of humans and technology working together to achieve better outcomes (Coelho et al., 2023). A key aspect of Industry 5.0 is the integration of materials characterization, modeling, and data science to foster

research and innovation in materials manufacturing (Charitidis et al., 2022). This interdisciplinary approach is essential for developing advanced materials and processes that cater to the needs of future industries. Table 3 compares Industry 4.0 and Industry 5.0 in various aspects.

In the Meetings, Incentives, Conferences, and Exhibitions (MICE) industry context, Hur et al. (2022) investigated the readiness of MICE 5.0 by examining technology use through big social media data. This approach highlights the importance of understanding user behavior and technology adoption to implement Industry 5.0 concepts successfully. Khan et al. (2023) proposed a strategic approach to overcome Industry 4.0 challenges by focusing on the changes and improvements brought by Industry 5.0, emphasizing the need for organizations to adapt and evolve by embracing opportunities offered by human-centric manufacturing (Lu et al., 2022).

Table 3. Comparison of Industry 4.0 and Industry 5.0

Aspects	Industry 4.0	Industry 5.0
Main focus	Automation and efficiency	Human-machine Collaboration and sustainability
Key technologies	IoT, big data, AI, robotics	IoT, big data, AI, collaborative robotics, augmented reality, and virtual reality
Environmental impact	Improved energy and material efficiency	Reducing carbon footprint, green energy use
Workforce impact	Job loss due to automation	The increased role of humans in the process
Impact on the production process	Efficient mass production	More flexible and adaptive production

Leng et al. (2022) provided insights into the prospects and retrospects of Industry 5.0, underlining the importance of understanding the historical context and future possibilities. Prassida and Asfari (2022) developed a conceptual model for accepting collaborative robots in Industry 5.0, addressing the need for a human-centered approach to technology adoption. Qahtan et al. (2022) explored integrated sustainable transportation modeling approaches for electronic passenger vehicles in Industry 5.0, emphasizing the importance of considering sustainability and environmental factors in developing and implementing new technologies.

Sachsenmeier (2016) discussed the relevance and implications of bionics and synthetic biology in Industry 5.0, highlighting the potential of these fields to revolutionize various industries by combining the best biological and technological systems. Wagner et al. (2023) presented IndustrialEdgeML, an end-to-end edge-based computer vision system for Industry 5.0, illustrating the role of advanced technologies like computer vision in supporting the transition towards Industry 5.0.

From a knowledge management perspective, Yin and Yu (2022) highlight challenges in integrating digital technology with green innovation. Concerns include promoting digital green knowledge development and managing digital risks and difficulties. Thakur and Kumar Sehgal (2021) argue that implementing their proposed architecture for intelligent heterogeneous systems may present challenges in various sectors.

Workforce skill development and new technology adoption are also significant concerns in Industry 5.0 (Destout et al., 2023). Hein-Pensel et al. (2023) assert that limited resources make it difficult for small and medium-sized enterprises (SMEs) to adopt successful digitalization plans. Ahmed et al. (2022) also emphasizes the potential for increased utility and job completion rates by applying their suggested approach but acknowledge that limited resources pose constraints.

Industry 5.0 represents a new era in which humans and technology work together synergistically to create innovative solutions across various domains. The successful

implementation of Industry 5.0 concepts relies on a deep understanding of the interplay between materials, technology, data science, and human factors, as well as the adoption of sustainable practices and the integration of cutting-edge technologies like bionics, synthetic biology, and computer vision (Charitidis et al., 2022; Coelho et al., 2023; Hur et al., 2022; Khan et al., 2023; Leng et al., 2022; Lu et al., 2022; Prassida & Asfari, 2022; Qahtan et al., 2022; Sachsenmeier, 2016; Wagner et al., 2023).

Table 4. Implementation strategy in Indonesia

Government	Industry	Research Institutes
Policy and regulation	Technology Innovation	Research and development
Infrastructure Support	Adoption of New Technologies	Training and Education
Incentives and funding	Research and Development Investment	Partnership with Industry

Table 5. Strategy collaboration between government, industry, and research institutions

Strategy	Information
Infrastructure development	Improve connectivity, transportation, and access to renewable energy.
Human Resource Development	Train a skilled workforce in Industry 5.0 technology.
Policies and regulations	Implement policies that support the transition and protect workers.
Collaboration between stakeholders	Encourage cooperation between government, industry, and research institutions.

Addressing these challenges will be critical in implementing Industry 5.0 in Indonesia, emphasizing long-term, flexible, and innovative implementation strategies. Human centricity, sustainability, and resilience in manufacturing will be crucial for successfully transitioning to Industry 5.0.

3.8. Industry 5.0 Implementation Strategy In Indonesia

Indonesia's Industry 5.0 implementation strategy encompasses several crucial elements, including infrastructure development and cultivating a skilled workforce. It is essential to foster a comprehensive understanding of the intricate interconnections between humans, machines, and the environment in human-centric manufacturing and establish a common understanding of its core principles. Enhancing the capabilities of adaptable and skilled human resources is necessary to address these challenges. The difficulties small and medium-sized enterprises (SMEs) face in successfully executing digitization plans underscore the need for a supportive infrastructure.

AI-enhanced process and simulation technologies, in conjunction with data analytics within the context of Industry 5.0, can aid the Indonesian industry in achieving more efficient and environmentally friendly production. Adopting these technologies will support implementing the Industry 5.0 strategy, emphasizing energy reduction and effective waste management. Table 2 illustrates the impact of Industry 5.0 in terms of environmental impact, efficiency, and energy conservation.

For a smooth transition to Industry 5.0, governments must establish regulations and policies that protect affected workers while fostering an environment conducive to innovation. Additionally, addressing the challenges of merging digital technology with green innovation requires significant policy support in knowledge and risk management.

Collaboration among government, industry, and research institutions is essential for promoting innovation and research in Industry 5.0. The scarcity of research on organizational challenges stemming from human

collaboration highlights the importance of cooperation among various stakeholders. Furthermore, technologies such as 3D printing, augmented reality, virtual reality, IoT, and AI play a crucial role in developing collaborative educational systems involving robots and addressing centralization, privacy, latency, and security concerns in industrial IoT infrastructure.

Table 4 depicts the implementation strategy of Industry 5.0 in Indonesia. Table 5 outlines the strategy focusing on improving infrastructure, developing a skilled workforce, implementing supportive policies and regulations, and collaboration among stakeholders. By addressing these areas, the industry can successfully transition to Industry 5.0 and thrive in the new era of advanced manufacturing.

In conclusion, implementing Industry 5.0 in Indonesia necessitates a strategy encompassing infrastructure development, skilled workforce enhancement, supportive laws and regulations, and coordination among government, industry, and research institutions. This approach will enable a long-term, adaptable, and innovative transition to Industry 5.0, emphasizing human-centricity, sustainability, and resilience in manufacturing.

4. CONCLUSION

This article examined the strategies and implications of adopting Industry 5.0 in Indonesia, focusing on environmental impact, process technology, and energy conservation. The key findings highlight the importance of embracing Industry 5.0 in Indonesia to promote sustainability, efficiency, and innovation within the industrial sector, aligning with global trends.

Technologies such as 3D printing, AR, VR, IoT, and AI play a crucial role in establishing collaborative systems for educational instruction using robots and addressing centralization, privacy, latency, and security concerns in industrial IoT infrastructure as part of Industry 5.0. A deep understanding of the complex interactions between humans, machines, and the environment is essential for human-centric manufacturing.

Furthermore, infrastructure development and cultivating a skilled workforce are necessary to facilitate Industry 5.0 implementation. Policies and regulations that promote knowledge management and risk management will protect vulnerable workers while fostering an environment conducive to innovation. Collaboration among government, industry, and research institutions is critical for driving innovation and research in Industry 5.0.

In conclusion, the implementation of Industry 5.0 in Indonesia has the potential to significantly improve environmental impact, process technology, and energy conservation. By focusing on infrastructure development, skilled workforce enhancement, supportive laws, and collaboration between government, industry, and research institutions, Indonesia can achieve a sustainable, adaptable, and innovative transition to Industry 5.0.

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