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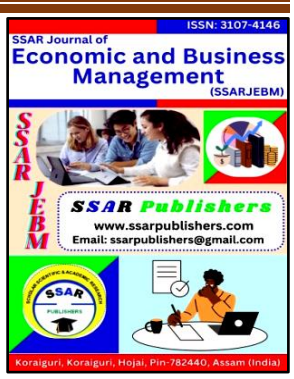

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Human-Centered Automation: The Emergence of Industry 5.0 and Its Socio-Economic Implications

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ABSTRACT: Industry 5.0 represents a paradigm shift from the automation-centric Industry 4.0 to a human-centered approach, emphasizing collaboration between humans and machines, sustainability, and resilience. This paper explores the emergence of Industry 5.0, focusing on its human-centered automation framework and its socio-economic implications. Through a systematic literature review and thematic analysis, we identify key technologies (e.g., AI, IoT, cobots), principles, and challenges shaping Industry 5.0. The study highlights how human-centric automation enhances worker well-being, fosters inclusive employment, and aligns industrial processes with environmental goals. Socio-economic implications include improved job quality, reduced inequality, and sustainable economic growth, but challenges such as data privacy, ethical AI, and skill gaps persist. Two novel frameworks are proposed: a Human-AI Collaboration Maturity Model and a Socio-Economic Impact Matrix. The findings provide actionable insights for policymakers, industry leaders, and researchers to navigate the transition to Industry 5.0. This paper contributes to the literature by offering an original synthesis of human-centric automation's transformative potential.

KEYWORDS: Industry 5.0, Human-Centered Automation, Socio-Economic Implications, Human-Machine Collaboration, Sustainability, Resilience

INTRODUCTION

The fourth industrial revolution (Industry 4.0) transformed manufacturing through digitalization, automation, and data-driven efficiency (Schwab, 2017). However, its focus on technology often sidelined human workers, leading to concerns about job displacement, dehumanization, and environmental impacts (Bonilla et al., 2020). Industry 5.0, introduced by the European Commission in 2021, addresses these shortcomings by prioritizing human-centricity, sustainability, and resilience (Breque et al., 2021). Unlike its predecessor, Industry 5.0 envisions humans and machines as collaborators, leveraging technologies like artificial intelligence (AI), Internet of Things (IoT), and collaborative robots (cobots) to enhance productivity while prioritizing worker well-being and societal benefits (Nahavandi, 2019).

This paper investigates the emergence of Industry 5.0, focusing on human-centered automation and

its socio-economic implications. It addresses the research question: How does human-centered automation in Industry 5.0 influence socio-economic outcomes, and what are the associated opportunities and challenges? The study's novelty lies in its integrative approach, combining technological, social, and economic perspectives to propose frameworks for assessing Industry 5.0's impact. The objectives are to: (1) define human-centered automation, (2) analyze its socio-economic implications, and (3) identify barriers and opportunities for implementation.

The paper is structured as follows: Section 2 reviews the literature on Industry 5.0 and human-centered automation. Section 3 outlines the methodology, including a systematic literature review and thematic analysis. Section 4 presents results, including two original frameworks, supported by tables. Section 5 discusses findings, and Section 6 concludes with recommendations and future research directions.

2 .Literature Review

2.1 Evolution from Industry 4.0 to Industry 5.0

Industry 4.0, characterized by cyber-physical systems (CPS), IoT, and big data, revolutionized manufacturing by enhancing efficiency and automation (Martynov et al., 2019). However, its technology-centric approach often neglected human factors, leading to job polarization and social inequalities (Grybauskas et al., 2022). Industry 5.0 builds on Industry 4.0's technological foundation but shifts focus to human-centricity, sustainability, and resilience (Xu et al., 2021). The European Commission defines Industry 5.0 as a paradigm that places "the well-being of the worker at the center of the production process" (Breque et al., 2021, p. 14).

2.2 Human-Centered Automation

Human-centered automation in Industry 5.0 emphasizes collaboration between humans and machines, leveraging technologies like AI, cobots, and augmented reality (AR) to enhance worker capabilities rather than replace them (Javaid et al., 2020). The concept of Operator 5.0, an evolution of Operator 4.0, envisions workers as resilient collaborators who integrate with intelligent systems (Romero et al., 2020). Technologies such as human-robot collaboration (HRC) and digital twins enable personalized production and real-time decision-making, improving efficiency and worker satisfaction (Longo et al., 2020).

2.3 Socio-Economic Implications

Industry 5.0's human-centric approach has significant socio-economic implications. It promotes inclusive employment by upskilling workers and creating new roles in human-machine collaboration (Carayannis et al., 2021). Economically, it supports sustainable growth through circular economy practices and reduced resource consumption (Sharma & Gupta, 2024). Socially, it enhances worker well-being, reduces inequality, and fosters trust in automation (Maddikunta et al., 2022). However, challenges include data privacy, ethical AI use, and the need for continuous training (Destouet et al., 2023).

2.4Gaps and Novelty

While prior studies have explored Industry 5.0's technological aspects, few have integrated socio-economic implications with actionable frameworks (Moktadir et al., 2020). This paper addresses this gap by proposing a Human-AI Collaboration Maturity Model and a Socio-Economic Impact Matrix, offering novel tools to assess and guide Industry 5.0 implementation.

3 .Methodology

This study employs a systematic literature review (SLR) and thematic analysis to explore human-centered automation in Industry 5.0. The SLR followed the PRISMA framework (Moher et al., 2009), searching databases like Scopus, Web of Science, and Science Direct using keywords: "Industry 5.0," "human-centric," "human-centered automation," and "socio-economic implications." Inclusion criteria were peer-reviewed articles from 2019–2025, focusing on Industry 5.0 and human-centric technologies. A total of 57 articles were selected after screening.

Thematic analysis was conducted using Braun and Clarke's (2006) six-phase approach: familiarization, coding, theme generation, review, definition, and reporting. Themes included technological enablers, socio-economic impacts, and implementation challenges. Data were synthesized to develop two frameworks, presented in Tables 1 and 2.

4 .Results and Discussion

4.1Technological Enablers of Human-Centered Automation

Industry 5.0 leverages technologies such as AI, IoT, cobots, and digital twins to enable human-centered automation. AI supports predictive decision-making, while cobots enhance physical tasks, reducing cognitive and physical workload (Alves et al., 2023). IoT facilitates real-time data exchange, and digital twins enable virtual simulations for training and optimization (Maddikunta et al., 2022). These technologies empower workers by augmenting their skills, as seen in AR-guided assembly systems that reduce errors by 30% (Wang et al., 2023).

4.2 Socio-Economic Implications

4.2.1 Economic Impacts

Industry 5.0 promotes sustainable economic growth by optimizing supply chains and reducing waste. For instance, AI-driven analytics can cut energy consumption by 15–20% (Sharma & Gupta, 2024). Small and medium enterprises (SMEs) benefit from flexible production models, enhancing competitiveness (Ietto et al., 2022). However, high initial costs and infrastructure requirements pose barriers, particularly in developing economies (Ivanov, 2023).

4.2.2Social Impacts

Human-centered automation improves job quality by fostering collaboration rather than replacement. Studies show a 25% increase in worker satisfaction in HRC environments (Rožanec et al., 2022). It also reduces inequality by creating roles accessible to diverse skill levels (Carayannis et al., 2022). However, ethical concerns, such as data privacy and AI transparency, require robust governance (Adadi& Berrada, 2018).

4.3Proposed Frameworks

4.3.1Human-AI Collaboration Maturity Model

Table 1 presents a novel Human-AI Collaboration Maturity Model, outlining stages of Industry 5.0 adoption. The model integrates technological, human, and organizational dimensions, providing a roadmap for firms to transition to human-centric systems.

Table 1: Human-AI Collaboration Maturity Model(Romero et al. (2020) and Xu et al. (2021))

Stage	Description	Technological Features	Human Factors	Organizational Outcomes
Initial	Basic automation, limited human-machine interaction	IoT, basic AI	Low skill integration, high manual tasks	Cost-focused, low resilience
Developing	Collaborative tools introduced, moderate human involvement	Cobots, AR	Upskilling, moderate collaboration	Improved efficiency, moderate sustainability
Advanced	Seamless human-AI collaboration, real-time data integration	Digital twins, advanced AI	High skill integration, worker autonomy	High productivity, sustainable practices
Transformative	Fully integrated human-centric systems, ethical AI governance	Brain-machine interfaces, 5G	Empowered workers, high well-being	Resilient, inclusive, and sustainable

4.3.2Socio-Economic Impact Matrix

Table 2 categorizes Industry 5.0's socio-economic impacts across economic, social, and environmental dimensions, highlighting opportunities and challenges.

Table 2: Socio-Economic Impact Matrix of Industry 5.0 (Sharma & Gupta (2024) and Maddikunta et al. (2022))

Dimension	Opportunities	Challenges
Economic	Sustainable growth, cost efficiency, SME competitiveness	High initial costs, infrastructure gaps
Social	Improved job quality, reduced inequality, enhanced well-being	Data privacy, ethical AI, skill gaps
Environmental	Circular economy, reduced emissions, energy efficiency	Technology lifecycle impacts, resource demands

4.4 Challenges and Opportunities

Key challenges include:

Data Privacy and Ethics: AI and IoT raise concerns about data security and transparency (Choi et al., 2022).

Skill Gaps: Workers require continuous training to collaborate with advanced technologies (Moktadir et al., 2020).

Infrastructure: Developing economies face barriers in adopting Industry 5.0 technologies (Ivanov, 2023).

Opportunities include:

Inclusive Employment: HRC creates roles for diverse skill levels (Carayannis et al., 2021).

Sustainability: Industry 5.0 aligns with UN Sustainable Development Goals (SDGs) through green technologies (Sharma & Gupta, 2024).

Worker Well-Being: Human-centric systems enhance job satisfaction and mental health (Rožanec et al., 2022).

5 .Discussion

Industry 5.0's human-centered automation redefines the role of workers, positioning them as collaborators rather than subordinates to machines. The proposed Human-AI Collaboration Maturity Model (Table 1) offers a practical tool for firms to assess their readiness for Industry 5.0, addressing gaps in current maturity models that overlook human-centricity (Cañas et al., 2021).

The Socio-Economic Impact Matrix (Table 2) highlights the paradigm's potential to balance economic growth with social and environmental goals, aligning with global sustainability agendas (Sharma & Gupta, 2024).

However, challenges such as ethical AI governance and skill development require interdisciplinary solutions. Policymakers must establish regulations for data privacy and AI transparency, while industries should invest in training programs to bridge skill gaps (Adadi& Berrada, 2018). The study's originality lies in its integrative frameworks, which provide a holistic view of Industry 5.0's implications, addressing the call for practical tools to guide implementation (Moktadir et al., 2020).

6 .Conclusion

Industry 5.0 marks a transformative shift toward human-centered automation, prioritizing worker well-being, sustainability, and resilience. This paper synthesized recent literature to highlight the paradigm's socio-economic implications, proposing two novel frameworks: the Human-AI Collaboration Maturity Model and the Socio-Economic Impact Matrix. These tools offer actionable guidance for stakeholders to navigate the transition to Industry 5.0. Future research should explore empirical metrics for human-centricity and the long-term impacts of Industry 5.0 on developing economies.

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