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Human-centered AI: Beyond algorithms and automation

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Abstract

Artificial Intelligence (AI) has progressed from rule-based systems to sophisticated machine learning models that can automate complex tasks. While these advancements have reshaped industries, the growing dependence on algorithmic decision-making raises concerns about fairness, transparency, and alignment with human values. This paper argues for a paradigm shift toward Human-Centered AI (HCAI), an approach that prioritizes human well-being, ethical responsibility, and collaborative intelligence over pure automation. We examine the shortcomings of automation-driven AI, including issues of bias, lack of interpretability, and reduced human agency. By integrating principles of explainable AI, participatory design, and value-sensitive computing, HCAI ensures that intelligent systems remain trustworthy, inclusive, and aligned with societal goals. Through case studies in healthcare, education, and governance, we demonstrate how Human-Centered AI fosters accountability, improves decision quality, and strengthens human-machine collaboration. Finally, we propose a research roadmap for embedding human values into AI design, moving beyond algorithmic efficiency toward responsible and sustainable innovation.

Keywords: *Human-centered AI, artificial intelligence, explainable AI, automation.*

1. Introduction

Artificial Intelligence (AI) has evolved rapidly from a specialized domain of computer science into a transformative force reshaping industries, societies, and human experiences [1]. From recommendation engines and self-driving vehicles to medical diagnostics and financial forecasting, AI technologies increasingly impact crucial aspects of everyday life. This transformation has been largely fueled by advances in algorithms, the availability of massive datasets, and high-performance computational infrastructure.

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This approach emphasizes embedding principles such as fairness, transparency, inclusivity, and ethical responsibility into AI design. Instead of supplanting human decision-making, HCAI aims to enhance human capabilities and foster cooperation between humans and intelligent systems. This paper investigates the foundations, challenges, and prospects of HCAI [2]. It explores the limitations of automation-driven AI, reviews emerging frameworks that incorporate human values, and presents case studies in healthcare, education, and governance. By underscoring trust, accountability, and inclusivity, this study argues that HCAI is critical for promoting responsible and sustainable innovation in the era of intelligent technologies. The connection between AI challenges and its role in advancing Industry 5.0 lies in understanding how addressing these challenges supports Industry 5.0's human-centric, sustainable, and resilient industrial objectives.

To explore these issues, the study addresses the following research questions:

RQ1. What are the fundamental principles and design approaches defining Human-Centric AI, and how do they align with Industry 5.0 goals?

RQ2. How does Human-Centric AI facilitate human-machine collaboration in Industry 5.0 settings?

RQ3. What are the main global regulatory frameworks governing AI, and how do they address the ethical, legal, and societal challenges associated with HCAI?

RQ4. What are the challenges of aligning HCAI principles with the regulatory requirements of to answer these questions, this study employed a preferred report methodology.

1.1. Significant Contributions of this Study are:

Summarizing existing HCAI design approaches and their connection to Industry 5.0 objectives. Presenting a taxonomy of HCAI collaboration models in Industry 5.0 based on selected studies.   Outlining widely adopted international frameworks governing HCAI. Summarizing the challenges of harmonizing HCAI with Industry 5.0 regulatory demands.
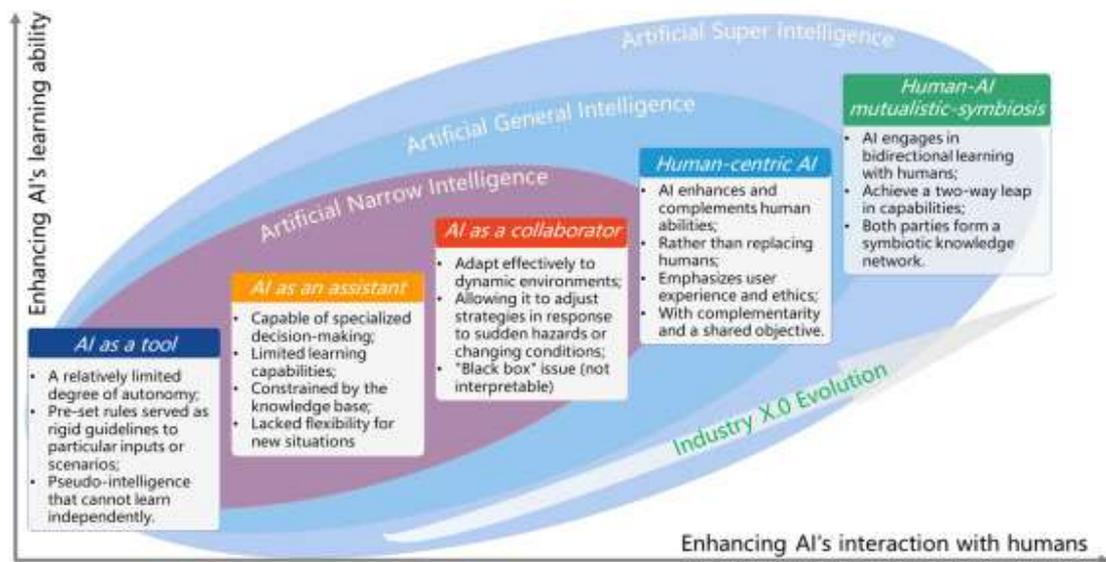

Figure 1. Enhancing AI's interaction with humans

2. Literature review

Human-Centered AI (HCAI) has attracted growing interest in the past decade, emphasizing the integration of ethical principles, human values, and usability into AI system design [3]. Shneiderman (2020) introduced a foundational HCAI framework advocating for AI systems that prioritize human oversight and decision-making over full automation. This framework stresses transparency, accountability, and user control as key principles. Recent research explores HCAI applications across various domains.

In healthcare, HCAI-based diagnostic tools aim to support clinicians by delivering interpretable and actionable insights while minimizing bias and errors. In education, adaptive learning platforms incorporate HCAI principles to ensure equitable access, personalized feedback, and improved Student engagement (Holstein et al., 2019). The connection between HCAI and Industry 5.0 is highlighted in studies focusing on human-robot collaboration and co-creation within industrial contexts. Industry 5.0 emphasizes sustainability, human-centricity, and resilience, closely aligning with HCAI objectives.

Frameworks provide guidance on fairness, transparency, safety, and accountability, ensuring AI systems respect human rights and societal norms. Despite these developments, integrating HCAI with regulatory and industrial requirements presents challenges. Technical complexity, diverse stakeholder expectations, and varying global regulations create obstacles to widespread adoption. Overcoming these issues requires interdisciplinary research, strong governance structures, and continuous evaluation of AI systems in real-world environments.

3. Methodology

This study employs a multi-step qualitative approach to analyze the design, implementation, and governance of Human-Centered AI (HCAI) across multiple sectors [4]. The methodology involves:

Literature Synthesis: Conducting a systematic review of studies on HCAI principles, frameworks, and applications using databases like IEEE Xplore, Scopus, and Google Scholar. Key topics include human-AI collaboration, explainable AI, ethical AI, and Industry 5.0 integration.

Framework Analysis: Evaluating international guidelines governing HCAI (e.g., OECD AI Principles, EU Trustworthy AI Guidelines, IEEE Standards) to identify shared principles, regulatory requirements, and compliance challenges.

Taxonomy Development: Developing a taxonomy of HCAI collaboration models in Industry 5.0 based on the reviewed studies, highlighting methods for incorporating human oversight, AI autonomy, and ethical considerations.

Case Study Selection: Selecting illustrative case studies in healthcare, education, and governance based on criteria like demonstrable human-centered design, ethical compliance, and measurable results.

Qualitative Analysis: Thematically coding and analyzing literature and case study data to identify patterns, challenges, and best practices for implementing HCAI aligned with human values and regulatory standards. This methodology enables a thorough understanding of HCAI design, applications, and governance, providing guidance for embedding human-centered principles into AI systems [5]. Literature reviews serve as a resource for synthesizing existing knowledge, combining explicit and implicit information to address specific research questions. A systematic literature review (SLR) is an evidence-based, reproducible approach to identifying, evaluating, and interpreting prior research.

Table 1. SLR protocols

Elements	Details
Analytical Sample	Published studies
Data Sources	Google Scholar, ScienceDirect, IEEE Xplore, Scopus
Search Combination	("Human-Centric AI" OR "Human-centered Artificial Intelligence" OR "Human-oriented AI") AND ("AI regulations" OR "Artificial Intelligence Governance" OR "AI policy frameworks") AND ("Industry 5.0" OR "Fifth Industrial Revolution" OR "human-machine collaboration")
Exclusive Criteria	a) Scientific paper b) Relevant study c) English language
Inclusive Criteria	Title, abstract, or content related to HCAI and Industry 5.0

From the initial 191 papers identified, 44 were excluded in the first phase. After reviewing titles, abstracts, and relevance, 109 additional papers were removed, while 11 more were added through reference searches. The final dataset included 49 studies. The PRISMA method ensured systematic and transparent selection.
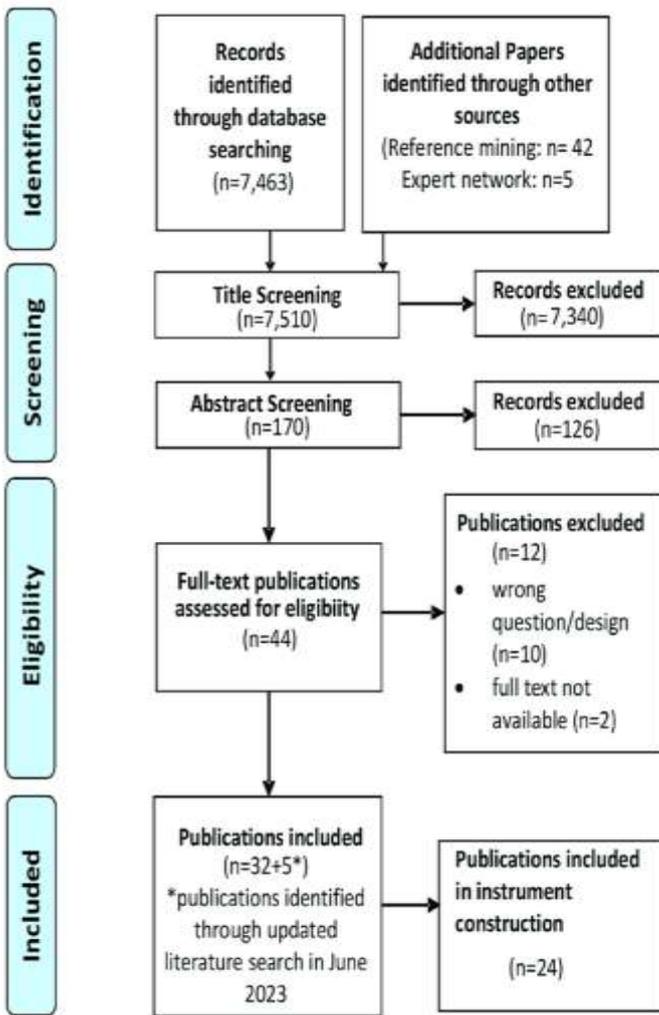
Figure 2. Prisma chart

3.1. Analysis of Results

Research Question (RQ1): What are the core principles and design approaches that define Human-Centric AI (HCAI), and how do they align with the goals of Industry 5.0? Human-Centric AI (HCAI) places human needs, values, and ethical considerations at the forefront of AI design and deployment [6]. It serves as a strategy to ensure AI systems enhance human capabilities instead of replacing them, closely aligning with Industry 5.0 objectives, which focus on human-machine collaboration, sustainability, and overall societal welfare.

3.1.1. Core Principles of Human-Centric AI

Table 2 summarizes the primary principles of HCAI. These principles aim to ensure AI systems are ethical, transparent, fair, and empowering**.**

Table 2. Core principles

Principle	Description	Relevance
Human Empowerment	Extends human capabilities, enhancing decision-making, creativity, and productivity.	Supports Industry 5.0's focus on augmenting human roles rather than full automation.
Transparency	Enables end-users to understand AI operations.	Builds trust and facilitates smooth human-AI collaboration.
Explainability	Provides clarity on AI outputs or recommendations.	Critical for decision-making support in Industry 5.0.
Fairness	Reduces bias and ensures equitable algorithmic outcomes.	Promotes inclusivity and ethical manufacturing practices.
Equity	Ensures AI works well across demographics.	Supports workforce diversity and equal opportunity.
Data Security	Employs robust data practices, protecting user information.	Ensures compliance and protects sensitive industrial data.
Responsibility	Establishes accountability for AI decisions.	Enables human oversight and redress mechanisms.
Autonomy	Respects user control over AI decisions.	Encourages human-in-the-loop design, essential in collaborative environments.
Ethical	Evaluates societal impacts and promotes long-term welfare.	Aligns with sustainability and societal goals of Industry 5.0.

Observation: These principles emphasize that HCAI goes beyond a purely technological approach, representing a value-oriented framework that ensures AI systems remain trustworthy, inclusive, and centered on humans.

3.1.2. Design Approaches of HCAI

Designing HCAI systems requires structured methods to embed human-centric values into AI technologies. Table 3 indicates the design approaches, such as user-centric designs that prioritize user needs, actions, and experiences. Other approaches emphasize adaptability, fairness, and ethical compliance [7].

3.1.4. HCAI Collaboration in Industry 5.0

Industry 5.0 promotes human-AI collaboration, sustainability, and adaptability. Table 5 and Figure 2 outline HCAI's collaborative aspects:

Observation: The design approaches ensure that HCAI is usable, transparent, and aligned with human expectations, making it suitable for collaborative industrial environments envisioned in Industry 5.0.

Table 3. Human-AI collaboration

Aspect	Description	Benefits	Examples
Personalized Interactions	Adjusts to user preferences and capabilities.	Reduces learning time, increases satisfaction.	Employee training
Collaborative Robotics	Works alongside humans, adapting to behavior.	Improves efficiency, reduces errors.	Assembly tasks
Decision Support	Provides real-time insights for decisions.	Enhances precision and quality.	Manufacturing processes, IoT
Job Satisfaction	Monitors and manages job stress.	Improves employee well-being and productivity.	Task management
Flexibility & Adaptability	Assigns tasks dynamically based on demand and expertise.	Enhances operational flexibility and resource utilization.	Production scheduling
Resource Effectiveness & Sustainability	Optimizes resource usage and minimizes waste.	Supports sustainable manufacturing.	Production processes
Transparency & Trust	Implements Explainable AI (XAI).	Builds user confidence and fosters collaborative improvement.	AI-driven decisions
Ethics & Practices	Ensures fairness, confidentiality, and ethical operations.	Promotes ethical workplace culture.	Decision-making processes

3.1.3. Alignment between HCAI and Industry 5.0

- Human Empowerment & Autonomy → Supports human-AI collaboration rather than full automation.
- Transparency & Explainability → Builds trust and informed decision-making in industrial environments.

- Fairness, Equity, and Ethics → Ensures inclusive and responsible AI deployment, essential for social acceptance.
- Data Security & Responsibility → Aligns with ethical and regulatory requirements in Industry 5.0 operations.

- Flexibility, Adaptability, and Sustainability → Enhances operational efficiency and environmental responsibility.

Analysis of Challenges in Aligning HCAI with Industry 5.0 Regulations

Human-Centric AI (HCAI) seeks to enhance human capabilities while promoting fairness, transparency, and ethical adherence in AI systems [8]. Nonetheless, applying HCAI within Industry 5.0 contexts encounters multiple regulatory and operational obstacles, as presented in Table 7, requiring a careful balance between innovation, ethics, compliance, and human-centered objectives.
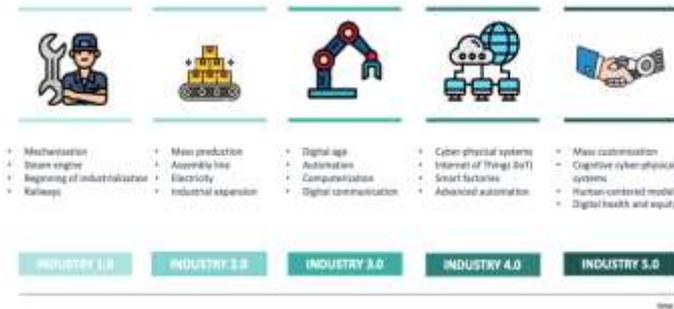

Figure 3. Evolution from industry 1.0 to industry 5.0.

Table 4. Key challenge

Issue	Essence for Industry 5.0	Description	Example
Balancing Innovations with Compliance	Rapid AI innovation can enhance productivity and competitiveness.	Regulatory requirements for ethics and security may slow down innovation.	Healthcare [55]
Cross-Border Regulatory Issues	AI deployment often spans multiple countries.	Differing international regulations create delays and reduce operational flexibility.	Supply chain [56]
Data Privacy and Protection	Essential for human-centric design.	Strict data privacy rules limit data collection, processing, and AI customization.	Adaptive collaboration [57]
Explainability and Transparency	Trust in human-AI collaboration depends on clarity.	Complex AI models (e.g., deep learning) are difficult to interpret, challenging regulatory openness.	Deep learning [58]
Sustainable Development	Supports environmentally responsible Industry 5.0 operations.	Regulatory focus on ethical and sustainable AI increases operational costs.	Waste management [59]
Automation with Job Security	Balances productivity with human participation.	Job protection rules can limit efficiency gains from automation.	Automobile industry [60]
Accountability	Ensures confidence in AI-driven decisions.	Determining responsibility for AI decisions is difficult, especially with minimal human oversight.	Autonomous operations [61]
Bias and Fairness	Promotes inclusivity and equitable human-machine interactions.	Mitigating algorithmic bias is resource-intensive and lacks standardized evaluation metrics.	Recruitment process [62]
Technological Advancements	Industry 5.0 relies on rapidly evolving AI technologies.	Regulators struggle to adapt to new AI capabilities, creating ambiguous or outdated regulations.	New technology [63]
Cost, Complexity, and Compliance	Encourages participation of diverse organizations.	High compliance costs and complexity hinder small and medium enterprises (SMEs) from adopting HCAI.	Small companies [64]

3.2. Analysis and Observations

Regulatory vs. Innovation Tension:

o Regulations, while essential for ethical and human-centric AI, may slow down AI deployment and innovation [9].

o Sectors like healthcare or supply chain face critical trade-offs between rapid adoption and ethical trade – offs between rapid adoption and ethical compliance.

Cross-Border and Data Challenges:

o International AI adoption is hindered by divergent regulations, particularly in data privacy.

o Human-centric AI relies on data personalization, but strict privacy rules can limit AI effectiveness in adaptive and personalized applications.

Transparency and Explainability Issues:

o Highly sophisticated AI models often function as "black boxes," making it difficult to comply with transparency regulations.

o Explainable AI (XAI) becomes essential for trustworthy human-AI collaboration.

Socio-Economic and Ethical Implications:

o Automation may conflict with job security regulations, creating challenges for workforce management.

o Ethical and sustainability requirements increase operational costs, potentially affecting profitability and adoption.

3.3. Technological and Organizational Barriers:

o Rapid advancements in AI can outpace regulatory frameworks, leading to ambiguity and risk of non-compliance.

o SMEs face high costs and complexity in compliance, which could slow inclusive innovation.

3.4. Implications for Industry 5.0: Harmonizing HCAI with regulations is critical for trust, inclusivity, and sustainability in Industry 5.0. Key focus areas include:

• Developing explainable AI to meet transparency standards.

• Establishing international regulatory alignment for cross-border operations.

• Creating flexible compliance frameworks that allow innovation while protecting ethical and human-centric values.

• Supporting SMEs and smaller players with cost-effective compliance strategies.

4. Discussion

This study systematically addressed four research questions (RQs) concerning Human-Centric AI (HCAI) and its integration into Industry 5.0:

4.1. Core Principles and Design Approaches (RQ1)

Tables 2, 3, and 4 present the fundamental principles and design approaches of HCAI. Key findings include: Human Empowerment and Autonomy: AI systems are designed to augment human capabilities, allowing employees to make informed decisions rather than replacing them. Transparency and Explainability: Emphasizing explainable AI (XAI) ensures trust in AI systems, which is critical for human-AI collaboration. Fairness, Equity, and Ethics: Systems are designed to be inclusive, reduce bias, and align with long-term societal welfare.

• *Data Security and Responsibility:* HCAI respects privacy and establishes accountability for AI-driven decisions.

• *Interpretation:* These principles ensure that AI technologies not only enhance productivity but also prioritize human values, aligning closely with the goals of Industry 5.0.

4.2. Human-Machine Collaboration (RQ2)

Table 5 and Figure 2 illustrate how HCAI supports collaboration in Industry 5.0: *Collaborative Robotics:* Machines respond to human actions, enhancing efficiency and safety.

- *Decision Support Systems:* Real-time insights enhance employee decision-making.
- *Flexibility and Adaptability:* AI supports dynamic task allocation, optimizing resources and production processes.
- *Job Satisfaction and Well-being:* Monitoring and mitigating fatigue ensures a human-centric work environment**.**
- *Interpretation:* HCAI enables seamless integration of humans and machines, supporting Industry 5.0's emphasis on cooperation, resilience, and personalized workflows.

4.3. Regulatory Frameworks (RQ3)

Table 6 presents global AI regulatory frameworks, which address ethical, legal, and social challenges:

- *Ethical Compliance:* Ensures fairness, transparency, and accountability.
- *Legal Oversight:* Governs data privacy, security, and liability.
- *Social Considerations:* Encourages equitable workforce participation and inclusivity.
- *Interpretation:* Understanding these frameworks is essential for responsible deployment of HCAI in industrial contexts**,** ensuring legal and ethical compliance while fostering innovation.

4.4. Challenges of Harmonization (RQ4)

Table 7 highlights challenges in aligning HCAI with Industry 5.0 regulations.

- *Balancing Innovation and Compliance:* Rapid AI adoption may conflict with ethical and regulatory requirements.
- *Cross-Border Regulatory Differences:* Hinder international collaboration and deployment.
- *Explainability and Bias Management:* Complex AI models challenge transparency and fairness.
- *Cost and Complexity:* High compliance requirements may restrict SME participation.
- *Interpretation:* Tackling these challenges is essential for scalable and ethically compliant human-AI collaboration in Industry 5.0.

4.5. Analytical Insights (RQ5)

- Word Cloud (Figure 3) and Network Cluster Analysis (Figure 4) Showcase major trends and thematic clusters in HCAI research, reflecting a strong focus on human values, ethics, and collaboration.
- Factorial Analysis (Figure 5) provides deeper insights into interrelationships among HCAI principles, regulatory compliance, and Industry 5.0 objectives, serving as a roadmap for future research [10].

5. Future research directions

The study identifies multiple avenues for further exploration:

1. *Context-Aware and Adaptive AI:* Systems that dynamically respond to human needs in real-time.
2. *Ethical AI Integration:* Embedding ethical frameworks and bias mitigation into industrial AI algorithms.
3. *Generative AI in Industrial Workflows:* Exploring synergies between human ideation and AI creativity.
4. *Reskilling and up skilling Platforms:* AI-driven adaptive learning for workforce development.

5. *Secure Human-Robot Interaction:* Guaranteeing safe and intuitive cooperation within dynamic industrial settings.

6. *Metrics for Human-Centricity:* Creating quantitative indicators to evaluate the effectiveness of HCAI in Industry 5.0.

6. Conclusion

Incorporating Human-Centric AI (HCAI) into Industry 5.0 marks a notable transition from traditional efficiency-driven industrial models toward a comprehensive, human-focused approach. By integrating human values, ethical principles, and collaborative practices into AI systems, Industry 5.0 can potentially transform workplaces and industries, emphasizing human well-being, safety, and societal progress. This study systematically highlighted:

- The fundamental principles and design approaches defining HCAI, ensuring AI systems are transparent, fair, and empowering.
- The ways, in which HCAI improves human-machine collaboration, enabling flexible, adaptive, and inclusive industrial operations.
- The principal global regulatory frameworks guiding AI, along with ethical, legal, and social considerations for responsible deployment.
- The main challenges in aligning HCAI principles with regulatory requirements, including balancing innovation and compliance, maintaining transparency, mitigating bias, and handling cost and complexity.
- Overall, the findings emphasize that HCAI serves as a key enabler of Industry 5.0, promoting workplaces that are efficient, ethical, human-focused, and socially responsible, while offering actionable insights for researchers, policymakers, and industry practitioners to support the future advancement of human-centric industrial AI system.

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