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Original Article

A Study on New Industrial Frontiers through Industry 5.0 with Special Reference to the Region of South Gujarat

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ABSTRACT: *The New Industry Frontiers emerging through Industry 5.0 include the integration of physical systems, artificial intelligence, robotics & sustainable production methods, aiming to achieve inclusive growth by balancing economic progress with environmental responsibility. The evolution of the Industrial Revolution has completely transformed all sectors of society through mechanization, electrification, automation & digitalization. From mechanization in industry 1.0 to mass production in 2.0, with automation in 3.0, and the era of digitalization in industry 4.0, each phase highlights the transformations industries have undergone and how they operate. Today, the emergence of Industry 5.0 is built on the foundation of collaboration between humans and advanced technology, which is a shift from a technology-driven model to a human-centric and more resilient industrial development. A Study on New Industrial Frontiers through Industry 5.0 with special reference to the region of South Gujarat is an exploratory and descriptive study conducted with the help of both Primary and Secondary Data. A total of 23 companies from the South Gujarat region have participated in the survey which was intended to gauge the Industry 5.0 approach at the organisations. The Researchers aimed to understand the concept and significance of Industry 5.0 for organisations. The researchers further aimed to study the Industry 5.0 avenues and challenges for Organisations in the region of South Gujarat. The study recommends the best practices with respect to Industry 5.0 at Organisations. The scope of the study encompasses the domain of the evolution of Industry from the current Industry 5.0. The inferences are indicative in nature and not exhaustive.*

KEYWORDS: *Industry, Industry 4.0, Industry 5.0, New Industrial Frontiers.*

1. INTRODUCTION

The rapid evolution of the Industrial Revolution has completely reshaped the way today's industries function, from the production systems, the workforce dynamics, to evolving technologies and human connectivity. From mechanization in industry 1.0, to production at mass in 2.0, coming with automation in 3.0 & the era of digitalization in industry 4.0, each phase highlights the transformation industries have gone through & how they operate. Today, the emergence of Industry 5.0 is built on the foundation of collaboration between humans & advanced technology, which is a shift from a technology-driven model to a human-centric and more resilient industrial development. While Industry 4.0 focused more on automation and data-driven decisions, emphasizing digitalization to drive the industry, Industry 5.0 seeks to restore the human role in systems through connectivity, creativity, critical thinking & emotional intelligence. The new industry frontiers emerging through Industry 5.0 include integrating physical systems, artificial intelligence, robotics, and sustainable production methods, aiming to achieve inclusive growth by balancing economic progress with environmental responsibility. Industry 5.0 is the future where technological advancements align with ethical, ecological, and human values, redefining industrial practices & strategic priorities, signaling a move from "smart industry" to a "wise industry" one that not only reaps profits & efficiency but also holds responsibility.

2. LITERATURE REVIEW

R Kumar et al. (2021). The evolution of the Industrial Revolution has completely transformed all sectors of society through mechanization, electrification, automation, and digitalization. With challenges persisting, such as job loss, reduced human involvement, and over dependence on automation under industry 4.0, led to the emergence of new revolution of industry 5.0 a human-centered revolution that blends technology with human creativity (Rada, 2015) Industry 5.0 emphasizes on human-machine collaboration, personalization & sustainability integrating advanced technologies such as IoT, AI, blockchain & intelligent automation to enhance flexibility & customization. Key enablers like virtual training, exoskeletons, and manufacturing traceability strengthen the connection between digital tools & human skills. Using the total interpretative structural modeling (TISM) technique, the researchers have studied the relationship between the enablers, developing a diagram to highlight this relationship among different enablers influencing the implementation of Industry 5.0, a new industrial frontier that focuses not only on productivity but also on human empowerment, creativity & sustainable growth.

Golovianko et al. (2023) Industry 4.0 focuses on digital transformation, automation, and smart manufacturing through technologies like IoT, AI, and cyber-physical systems, aiming for efficiency and data-driven operations. Even with this, the model often minimizes human involvement. Industry 5.0, introduced by the European Commission, however, emphasize on human-centric, sustainable, and resilient industrial practices with integration of human efforts and ethical values with technological advancement, promoting humans back into the loop, prompting a model combining the efficiency of Industry 4.0 with the sustainability and human centricity of Industry 5.0. The researchers propose digital cognitive clones as an enabling technology for this hybrid, allowing machines to replicate human decision-making while maintaining human values. The model is further supported by collective intelligence where humans, robots, and AI collaboratively enhance industrial resilience, adaptability & ethical sustainability.

Coelho et al. (2023). The paper explores how the term Industry 5.0 emerged in the scientific literature through systematic bibliographic analysis. It identifies that the concept first appeared in 2016, linking Industry 5.0 with bionics, synthetic biology, and human-robot collaboration. While Industry 4.0 emphasized digital transformation and automation, Industry 5.0 marks a shift to a human-centric, sustainable, and cooperative industry model with the integration of human intelligence with that of advanced technologies. The study also notes that Industry 5.0 is built upon existing Industry 4.0 technologies such as IoT, AI, and CPS without introducing new ones, but redefines their purpose towards societal well-being & ethical manufacturing. The researchers conclude that Industry 5.0 currently represents a value-driven evolution rather than a fully disruptive revolution.

Pilevari & Yavari (2020). The paper highlights Industry 5.0 as the next phase of industrial evolution, emphasizing the collaboration between humans and smart machines. Unlike Industry 4.0, which prioritized automation, data, and efficiency, Industry 5.0 is all about personalization, creativity & sustainable approach through human and robot cooperation. The paper highlights the phases of the industrial revolution from industry 1.0 to industry 5.0. Key studies underline the integration of AI, IoT & robotics with human intelligence to achieve resilient and value-driven manufacturing, transforming from industry 4.0 to industry 5.0, causing changes from mass customized production to personalized production. Industry 5.0 represents a human-centric transformation ensuring both productivity & ethical advancement in the industry.

3. OBJECTIVES OF THE STUDY

The Researchers have considered the following objectives:

- To understand the Concept & Significance of Industry 5.0 for Organisations.
- To study the Industry 5.0 avenues and challenges for Organisations in the region of South Gujarat.
- To recommend the best practices with respect to Industry 5.0 at Organisations.

4. RESEARCH METHODOLOGY AND PROCESS

A Study on New Industrial Frontiers through Industry 5.0 with special reference to the region of South Gujarat is an exploratory and descriptive study conducted with the help of both Primary and Secondary Data. A total of 23 Companies from the South Gujarat region have participated in the survey, which was intended to gauge the Industry 5.0 approach of the Organisations. The Researchers aimed to understand the Concept and Significance of Industry 5.0 for Organisations. The Researchers further aimed to study the Industry 5.0 avenues & challenges for Organisations in the region of South Gujarat. The study recommends the best practices with respect to Industry 5.0 at Organisations. The scope of the study encompasses the domain of the evolution of Industry from the current Industry 5.0. The inferences are indicative in nature and not exhaustive.

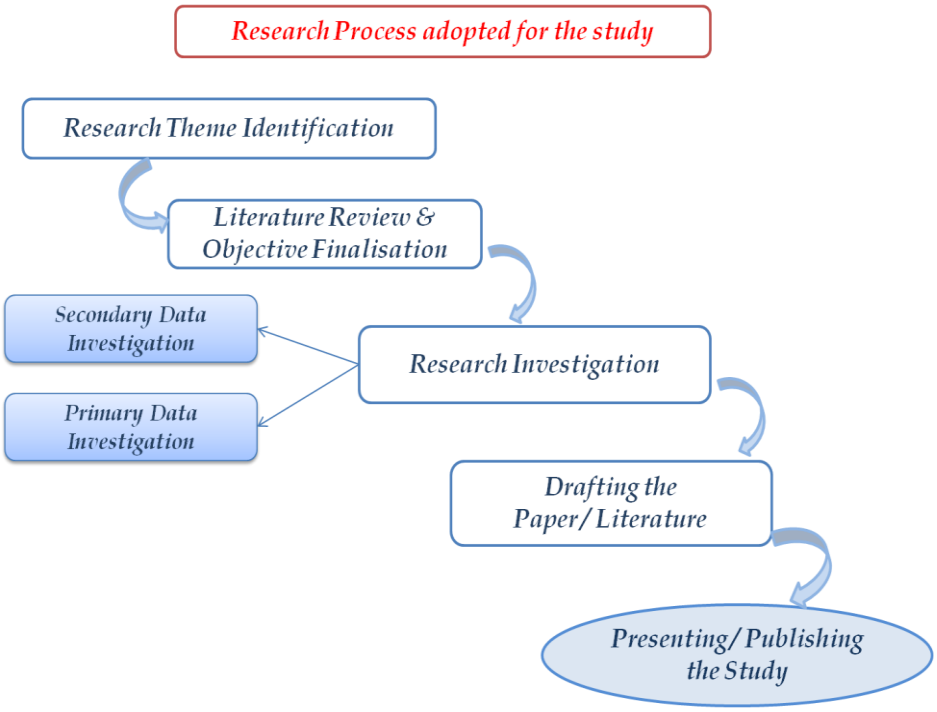


FIGURE 1 Research Process Adopted

Source: *Authors' Understanding*

5. INDUSTRY 1.0 TO INDUSTRY 5.0: THE JOURNEY

The journey of the Industry through 1.0 to 5.0 is pretty exciting. Right from the age of mechanization (1.0) to the era of human-machine collaboration (5.0), the Industry at large has evolved. Here is a glimpse of the journey:

5.1. INDUSTRY 1.0

The first industrial revolution, that is, industry 1.0, focused on the age of mechanization. It emerged in the late 18th century and marked the transition from manual labor to mechanized production. This era came up with the invention of the steam engine, reshaping how manufacturing and transportation functioned. The shift also came with machine-based production from that of handcrafting, enabling increased efficiency and output with mass production. Industries such as textiles, iron, coal & mining witnessed rapid growth, while steam-powered engines and factories helped shape the trade and logistics. Even with this efficient shift, it brought about certain challenges, such as labor exploitation and environmental degradation, which later became a concerning topic for the industries in the future.

5.2. INDUSTRY 2.0

The second era emerged in the late 19th to early 20th centuries. This was the period of industrial expansion driven by assembly line production, electricity, and the combustion engine. The introduction of electrical energy replaced steam as the primary power source, enabling industries to achieve efficient productivity efficiency. Henry Ford's assembly line production standardized production and led to cost efficiency, helping with the mass production of consumer goods. Accordingly, Industry 2.0 laid down the foundation of globalization, corporate structures, and labor divisions, even though challenges mounted for industrial pollution and socio-economic disparities.

5.3. INDUSTRY 3.0

The third era was of digital revolution, that is industry 3.0 it began during the mid 20th century. This phase emphasized the integration of computers, electronics, and information technology (IT) into the industrial processes. The invention of semiconductors, programmable logic controllers (PLC's), and early automation systems transformed manufacturing from mechanical to electronic and software operations. The shift is marked towards automation and process optimization, reducing dependence on human labor for repetitive tasks. This era also saw a rise in multinational corporations (MNCs) and global supply chains, enhancing efficiency and accuracy. However, with the rise of digital dependence, the need for resilient digital infrastructure, adaptability, and a skilled workforce has become apparent.

5.4. INDUSTRY 4.0

The 4th era characterized the age of smart manufacturing by the integration of artificial intelligence (AI), Internet of Things (IoT), big data and cloud computing. This revolution transformed factories into smart factories where decision-making became data-driven, predictive maintenance, customized production technologies like 3D printing, and autonomous robots enhanced

efficiency and traceability. Although with the enhancements of these advanced systems and processes, the over-reliance on technologies raised concerns about the job security, ethical use of data, human creativity, and connection, emphasizing a more balanced and inclusive approach to drive businesses.

5.5. INDUSTRY 5.0

Industry 5.0 is the era of human-machine collaboration; it is the newest phase of industrial evolution, which emphasizes a human-centric, resilient, and sustainable role of technology in businesses. It highlights the value of emphasizing the well-being of the worker at production with the use of technologies that provide profits beyond job respecting resources available on the planet. Instead of replacing humans with machines, Industry 5.0 focuses on collaboration between human intelligence for creation, ethicality, and environmentally conscious production systems. It focuses on co-creation, customization, and sustainability, aligning industrial growth with societal and ecological well-being. The key enablers include cobots, that is, collaborative robots, AI-driven decision systems, blockchain transparency, and green technologies. Unlike the previous revolutions, which emphasized efficiency, Industry 5.0 aspires to become wise industries that are capable of being resilient, ethical, and innovative in their approaches with human empowerment. This era marks a return to human values with industrial progress bridging the gap between digital transformation and social responsibility, that is, a shift from economic value to focus on societal value.

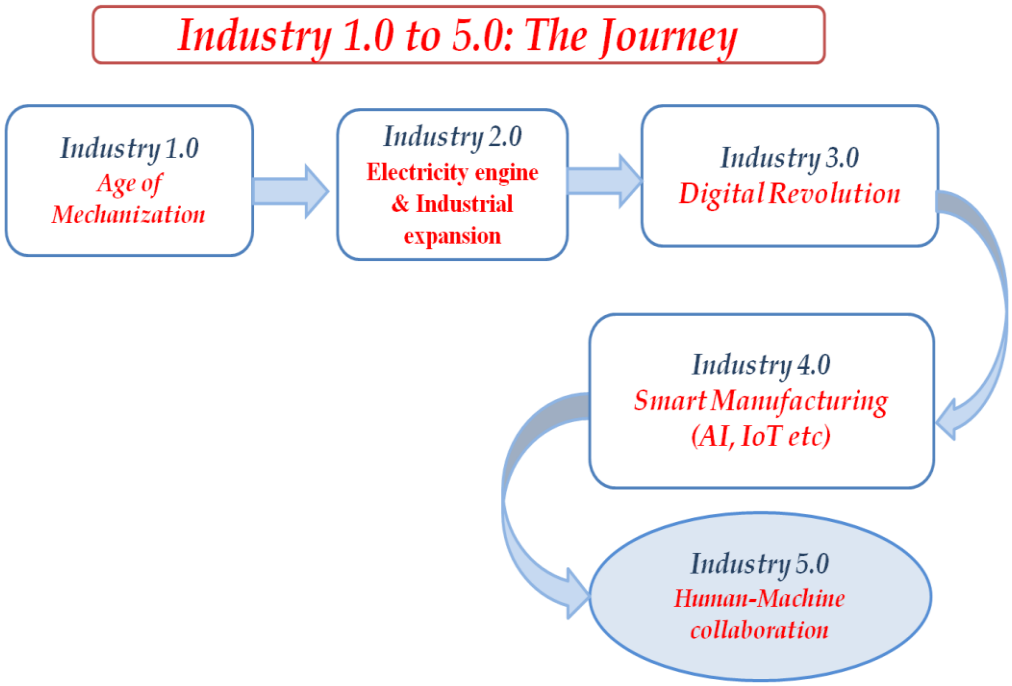


FIGURE 2 The Journey of Industry 1.0 to 5.0

Source: *Authors' Theoretical Understanding*

6. INDUSTRY 5.0: AVENUES

Industry 5.0 creates an era that approaches moving beyond automation towards a human-centric, resilient, and sustainable ecosystem (the three pillars), which makes industry 5.0. The avenues lie in how industries will combine advanced technologies (AI, cobots) with human efforts, that is, creativity, ethics, and well-being. Instead of replacing human efforts, Industry 5.0 becomes an enabler working alongside smart technologies and machines to achieve efficiency, resource utilization, and make the best out of what is available.

6.1. INDUSTRY 5.0 (THREE PILLARS)

FIGURE 3 Three Pillars of Industry 5.0

Source: *Authors' Theoretical Understanding*

Human-centric approach: This pillar focuses on a shift from machines to people, that is, a move from seeing people as "means" to people as "ends". It includes designing a workplace fostering a culture of collaboration and knowledge sharing, where people collaborate with intelligent systems by leveraging advanced technologies, keeping people at the center of innovation by creating training programs to empower employees, providing an ecosystem where employees are not seen as a cost but rather valued as a strategic asset, enabling industries to create personalized products and agile processes.

Resilience: It is the ability to bounce back from uncertain business situations. Industry 5.0 focuses on resilient approaches through technologies, digitalization, and data-driven decisions that can predict risks & uncertainties quickly. Industries here focus not just on achieving profitability, growth, or efficiency but on creating an organization that is proactive, anticipates changes & systematically deals with situations of crisis, enabling sustainable performance.

Sustainability: This pillar ensures that industrial growth is environmentally responsible and aligned with long-term ecological practices. It emphasizes attention to the triple bottom line and 17 SDG's. Rather than focusing on reducing the negative impact, Industry 5.0 with sustainability focuses on creating more positive impacts and outcomes with smart technologies like predictive maintenance, AI, and smart sensors, which can help reduce carbon footprints, waste, and enhance traceability of operations in real time. The goal is to create industries that operate within the available resources, delivering the most out of them economically and socially in an ethical manner.

The deliverables of Industry 5.0 will emphasize

- Integration of digital and physical systems: This will include the integration of digital systems like machine learning and IoT, to optimize operations and predict performance levels, wherein this avenue can enhance the production process, reduce downtime, and focus on improving quality.
- Ethical and Inclusive innovation: This will focus on ensuring the ethicality through data privacy, transparency, fairness, and inclusivity, encouraging industries to innovate responsibly by aligning business goals with those of societal values of trust, equity, and welfare.
- Skill development and human capital development: The integration of technologies and human efforts will open the door for workforce upskilling, cross-functional learning, and developing the competencies enabling a lifelong learning approach for employees.
- New business models and value creation: Industry 5.0 opens avenues for exploring the untapped areas and personalization thinking, and creating out-of-the-box approaches with human efforts and machine intelligence. This will create continuous innovation, better customer service, and retention.
- Worker well-being: One of the main priorities will be on the well-being of the workers through the approach of ergonomic designs, real-time safety monitoring, and integrating technologies in a way that can enhance healthier workplaces. This can support reducing fatigue, stress, and ensuring human-centric industrial operations

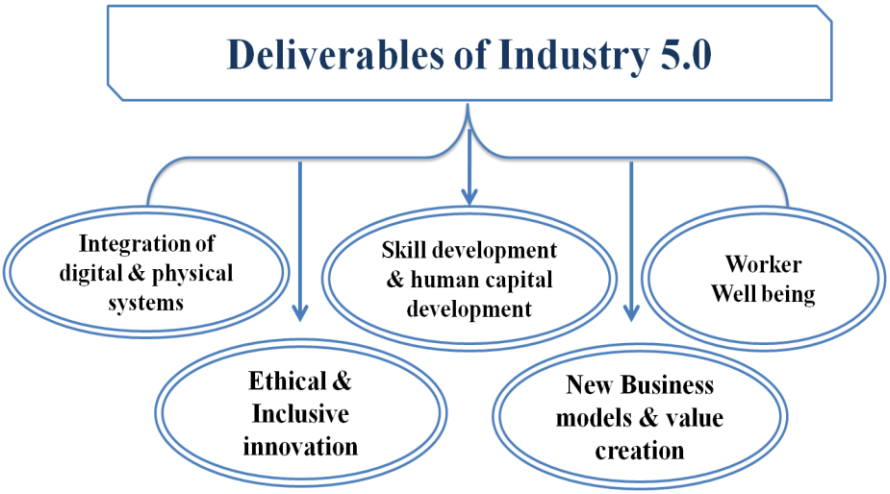


FIGURE 4 Deliverables of Industry 5.0

Source: *Authors' Theoretical Understanding*

7. CHALLENGES OF INDUSTRY 5.0

- Implementation cost: Adapting to Industry 5.0 requires a significant amount of investment for advanced technologies; small and medium enterprises often face difficulty in allocating capital for such transformations.
- Skill gaps: Industry 5.0 demands equipped personnel who have a thorough understanding of technologies like AI, data analytics, human-machine interaction, and hence many of the employees lack these competencies, leading to skill gaps.
- Technology integration: Integrating new technologies with existing systems becomes a complex process, as many of the industries still operate on outdated infrastructure that is not friendly to the integration of such technologies. It becomes an operational challenge for the industries.
- Data privacy risks: Increased reliance on technologies and the exchange of data raises concerns about data privacy, as sensitive and confidential data can be vulnerable to cyber attacks, misuse, and data breaches, which becomes a critical area of concern.
- Sustainability implementation: Wherein, sustainability is a core pillar of Industry 5.0, but implementing eco-friendly practices can be difficult due to high costs, infrastructure issues, and transitioning to sustainability models calls for a higher cost of implementation.
- Resistance to change: Employees and management may resist adopting new technologies due to fear of job loss, lack of understanding, or reluctance to move from traditional means of working, and hence, overcoming these challenges requires strong leadership and clear communication of processes.

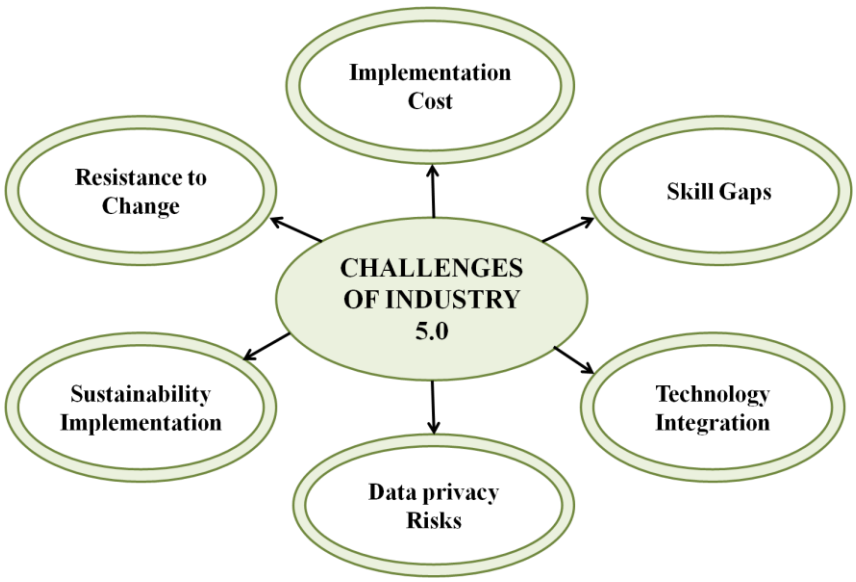


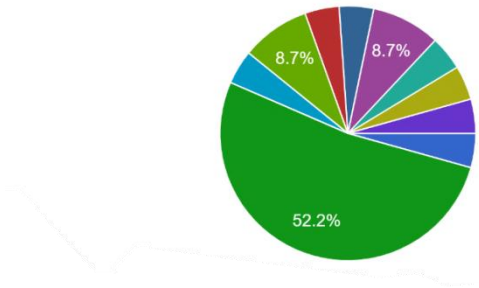
FIGURE 5 Challenges of Industry 5.0

Source: *Authors' Theoretical Understanding*

8. RESULTS AND DISCUSSION

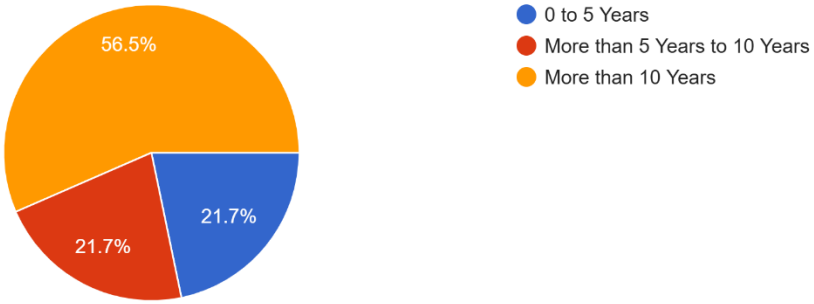
The Researchers have conducted the research in the region of South Gujarat, and 23 companies have participated in the survey. The following are the inferences of the study:

1. Place of Operation



The sample is collected from across the cities in South Gujarat, ranging from Surat, Valsad, Umergaon, to Vapi.

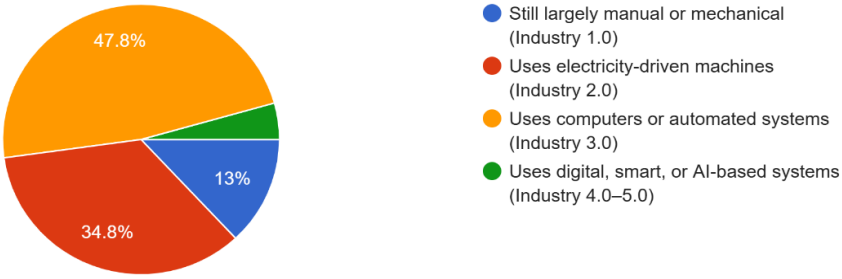
2. Commencement of Operations



2.

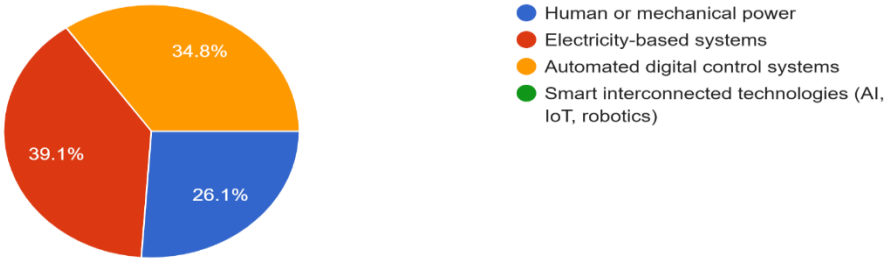
A majority of responding companies (56.5%) have been operational for more than 10 years, reflecting the study's inferences to be from a well-established industrial base.

3. Future of the Company's Production System



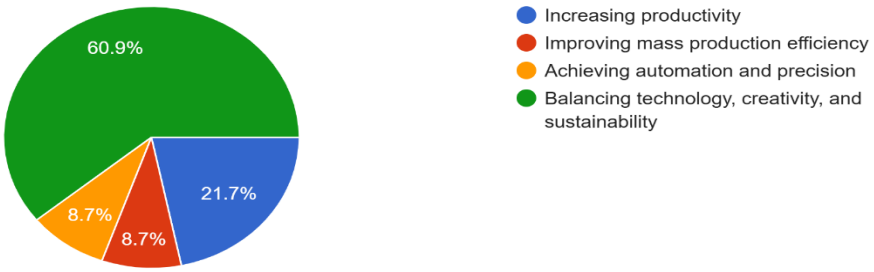
The Researchers understand that most of the responding companies (47.8%) operate at the Industry 3.0 level with notable reliance on Industry 2.0 (34.8%) & minimal adoption of advanced Industry 4.0 & 5.0.

4. Forms of Energy/Power Source



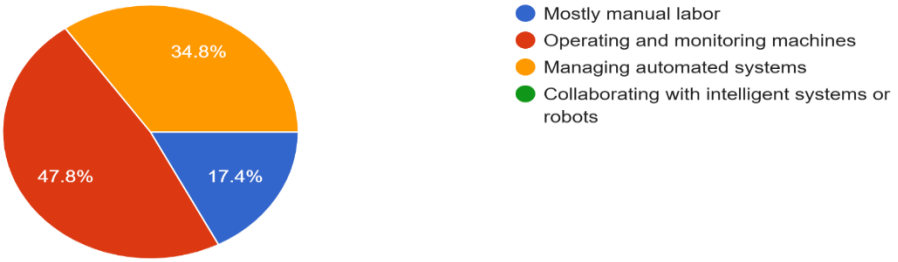
Electricity- based systems dominate (39.1%), followed by automated systems (34.8%), indicating a gradual but incomplete technological transition.

5. Shift in Organizational Focus



The study leads to understanding that a majority of firms (60.9%) focus on balancing technology, creativity, and sustainability, indicating a shift towards advanced industrial priorities, while smaller proportions emphasize productivity (21.7%), mass production efficiency (8.7%) and automation and precision (8.7%).

6. Role of Human Workers

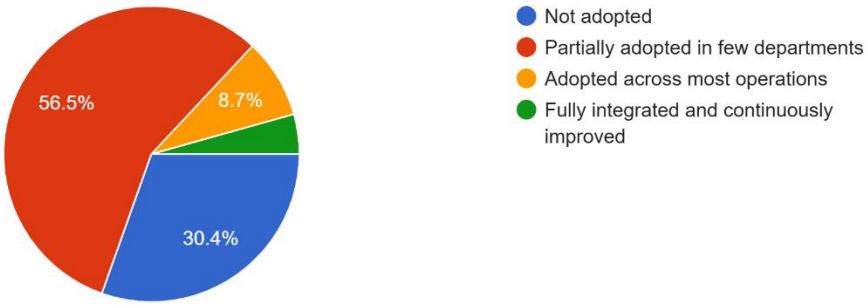


Most workers operate and monitor machines (47.8%), followed by managing automated systems (34.8%), while a smaller proportion is involved in manual labour (17.4%), indicating a shift towards machine-assisted roles.

7. Human- Machine Relationship

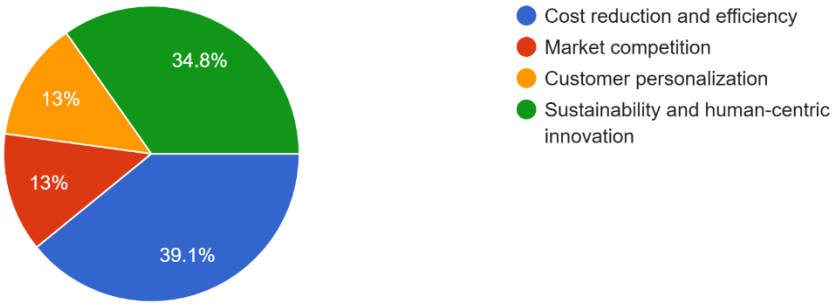
Most organisations (43.5%) view humans and machines as working jointly, followed by machines assisting humans in repetitive tasks (30.4%), while fewer emphasize human-led intelligent support (17.4%) & minimal reliance on machine replacement (8.7%)

8. Adoption of Advanced Technologies



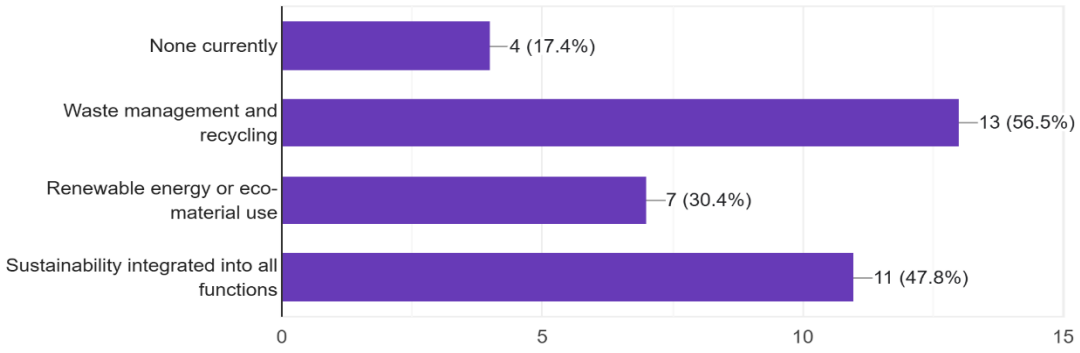
The study leads to the understanding that a majority of firms (56.5%) have partially adopted advanced technologies, while a significant proportion (30.4%) have not adopted them, indicating limited technological integration.

9. Drivers of Innovation Strategy



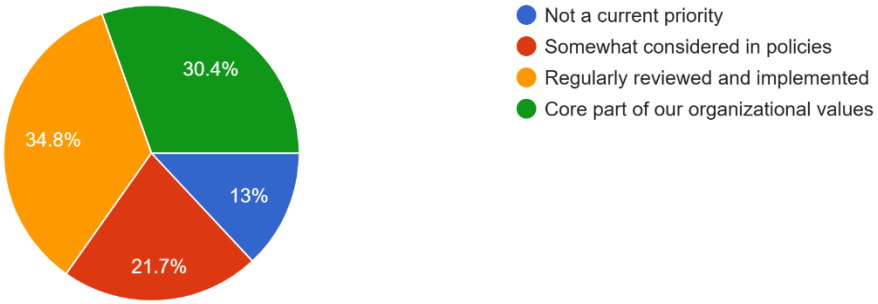
Cost reduction and efficiency (39.1%) are the primary drivers of innovation, followed by sustainability and human-centric innovation (34.8%), with lesser emphasis on customer personalization and market competition (13% each).

10. Sustainability Practices



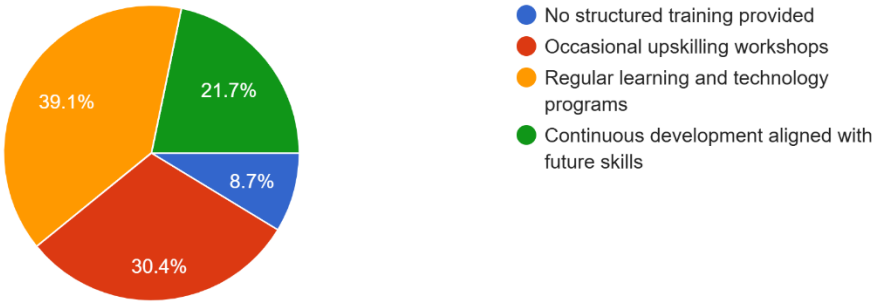
Waste management and recycling are the most common practices (13 responses), followed by sustainability integration (11) and renewable initiatives (7), while very few firms have no sustainability practices (4).

11. Importance of Ethical Technology Use



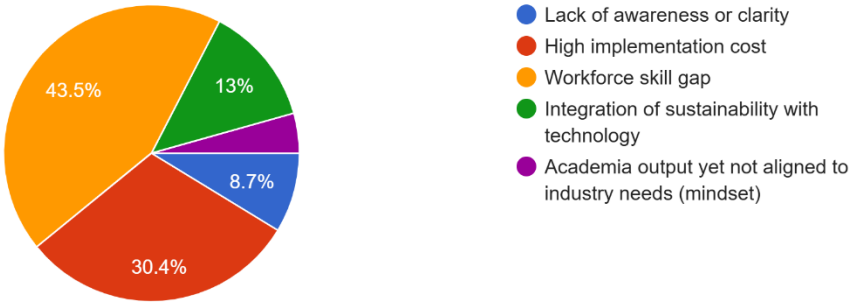
Most organizations either regularly implement ethical practices (34.8%) or consider them core values (30.4%), though some treat them as secondary (21.7%), and a small proportion do not prioritize them (13%).

12. Employee Preparation for Industrial Changes



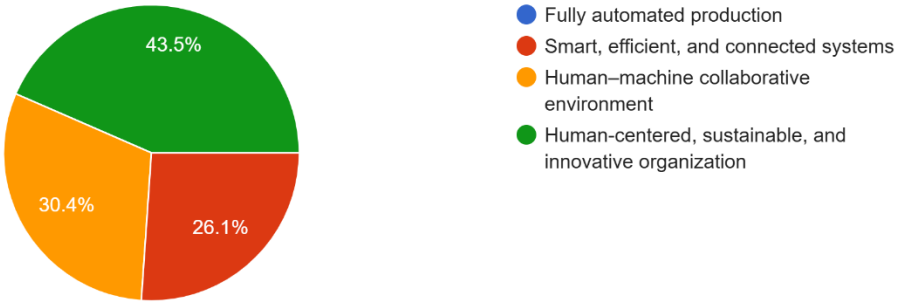
Most organizations (39.1%) rely on regular learning & technology programs, followed by occasional upskilling workshops (30.4%), while fewer emphasize continuous future-oriented development (21.7%) and minimal firms lack structured training (8.7%).

13. Challenges in Adopting Industry 5.0



Workforce skill gap (43.5%) is the most significant challenge, followed by high implementation cost (30.4%), with fewer firms facing issues in integrating sustainability with technology (13%).

14. Future Vision under Industry 5.0



Most organizations envision becoming human-centred, sustainable, and innovative (43.5%), followed by human–machine collaborative environments (30.4%) and smart, efficient systems (26.1%).

9. FINDINGS

- The Researchers find that minimal adoption of Industry 4.0 and 5.0 is experienced, as most of the responding companies (47.8%) operate at the Industry 3.0 level with notable reliance on Industry 2.0 (34.8%).
- The Study leads to the indication that a gradual but incomplete technological transition is experienced among Industries as Electricity- based systems still dominate (39.1%), followed by automated systems (34.8%).
- The study leads to the finding that Industries are yet to experience a full-fledged automation drive. Only 8.7% have shifted to automation and precision. However, there is a shift towards advanced industrial priorities as the majority of firms (60.9%) focus on balancing technology, creativity, and sustainability.
- The study leads to the finding that there is a shift towards machine-assisted roles as responding organisations state that their workers operate and monitor machines (47.8%), followed by managing automated systems (34.8%), while a smaller proportion is involved in manual labour (17.4%).
- The study indicates limited technological integration at the responding companies, as the majority of responding companies (56.5%) have partially adopted advanced technologies, while a significant proportion (30.4%) have not adopted them.
- The study leads to the finding that Cost reduction and efficiency (39.1%) are the primary drivers of innovation, followed by sustainability and human-centric innovation (34.8%).
- The Researchers find that Waste management and recycling are the most common sustainability practices adopted by the responding organisations.
- The responding Organisations have adopted ethical technology use, as a huge 80%+ have responded in this regard.
- The study leads to the findings that Employee preparation for industrial changes largely relies on regular learning and technology programs, followed by occasional up-skilling workshops.
- The Researchers find that the workforce skill gap (43.5%) is the most significant challenge towards implementing Industry 5.0, followed by high implementation cost (30.4%).

- The findings state that with respect to the future vision under Industry 5.0, most organizations envision becoming human-centred, sustainable, and innovative (43.5%), followed by human–machine collaborative environments (30.4%).

10. RECOMMENDATION

The study on the New Industry Frontiers emerging through Industry 5.0 was completed through the inputs from 23 Companies participating in the survey. The Researchers have observed the following set of practices being adopted by these responding companies in order to imbibe the industrial culture of Industry 5.0:

- Cost reduction and efficiency
- Waste management and recycling
- Ethical technology use
- Regular learning and technology programs
- Human-centred, sustainable, and innovative efforts

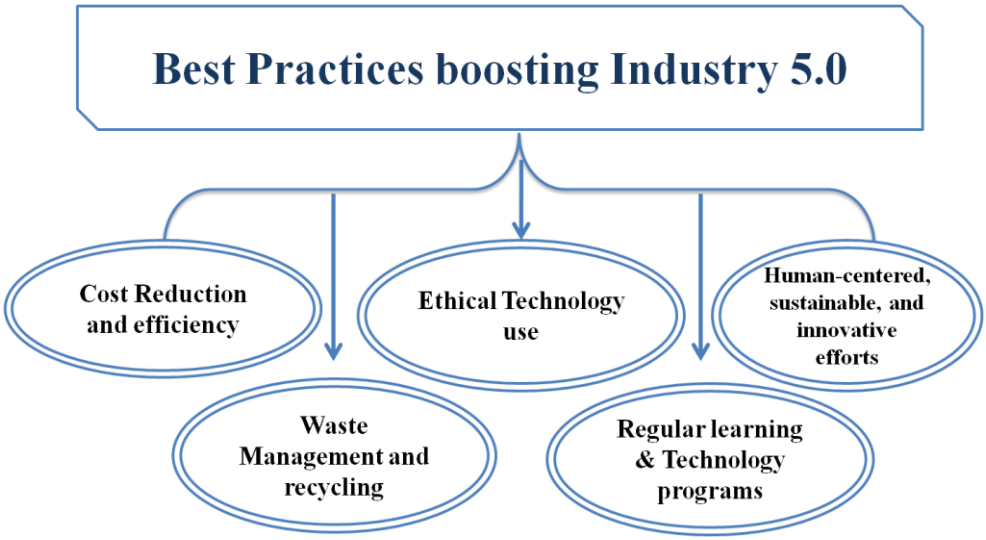


FIGURE 6 Best Practices Boosting Industry 5.0

Source: *Inferences based on survey*

11. CONCLUSION

The study concludes that the New Industry Frontiers emerging through Industry 5.0 include the integration of physical systems, artificial intelligence, robotics, and sustainable production methods, aiming to achieve inclusive growth by balancing economic progress with that of environmental responsibility. The Study leads to the indication that a gradual but incomplete technological transition is experienced among Industries. The study concludes that minimal adoption of Industry 4.0 and 5.0 is experienced. The Industries are yet to experience a full-fledged automation drive. However, there is a shift towards advanced industrial priorities. The study leads to the finding that Cost reduction and efficiency are the primary drivers of innovation. Waste management and recycling are the most common sustainability practices adopted by the responding organisations. The study concludes that largely Organisations have adopted ethical technology use. The study concludes that employee preparation for industrial changes largely relies on regular learning & technology programs. The Study concludes that the workforce skill gap is the most significant challenge towards implementing Industry 5.0. It concludes that with respect to the future vision under Industry 5.0, most organizations envision becoming human-centered, sustainable, and innovative.

12. FUTURE SCOPE OF THE STUDY

- The current study is with respect to the primary survey among the Organisations in the South Gujarat Region. 23 companies participated in the survey.
- The future scope of the study may include further sample sizes from organisations in the region of the study or increasing the radius of the region for the study.
- The researcher may also look forward to a comparative study between various sectors like manufacturing, services, and trading.

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