

Innovations and Technological Interventions for Sustainability: Emerging Challenges

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Abstract: This research explores the integration of sustainable practices and technology in the manufacturing industry, highlighting areas for improvement and strategies to overcome implementation challenges. The study examines the Barriers hindering the widespread adoption of sustainable technologies, the current state of sustainable practices in manufacturing Perceived effectiveness of technological interventions on sustainability, Leadership and organizational culture's impact on sustainability, Employee engagement and training in sustainable practices, Insights gathered from 100 participants across five manufacturing enterprises. Key findings indicate are Significant obstacles to adopting sustainable practices exist, Variability in current sustainability initiatives, favorable perceptions of technological interventions, Leadership's crucial role in promoting sustainability, and Essential need for employee engagement and training. This study contributes significantly to enhancing sustainable practices in the dynamic manufacturing sector, providing valuable insights for industry stakeholders.

Keywords: Sustainable Technology, Manufacturing Industry, Innovations, Technological Interventions, Sustainability, etc.

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I. INTRODUCTION

Sustainable development aims to balance current needs with future generations' capabilities, emphasizing two key aspects: addressing global poverty and acknowledging environmental constraints. Integrating sustainability principles into economic and social development goals is crucial, considering a country's development status and Economic system. Sustainable development's interpretation may vary, but a shared understanding of its core concept and strategic framework is essential. A sustainable business prioritizes the well-being of all stakeholders, ensuring long-term viability and positive impacts on the economy, society, and environment. This approach extends beyond environmental considerations, focusing on comprehensive triple-bottom-line effects. As sustainability investments gain importance, businesses embracing sustainable practices enhance their reputation, reduce costs, contribute to local economies, and foster resilient communities, gaining a competitive edge.

Sustainable development requires a collective, long-term perspective, integrating social, economic, and environmental objectives. Manufacturing organizations must recognize their activities' direct and indirect impacts on the environment and society, committing to continuous

sustainable development promotion. While no one-size-fits-all approach exists, common underlying principles emerge.

Sustainable development represents opportunity, progress, and responsibility. It demands transformative improvement, going beyond incremental progress. Commercial success and sustainable development rely on value-creating business practices addressing innovative opportunities, social expectations, and sustainability transitions. Sustainable development offers a framework prioritizing human values and innovation, meeting evolving needs.

Collaborative initiatives, such as Overseas Development Assistance, Foreign Direct Investment, and public-private partnerships, can support sustainable development. Effective leadership harnesses economic and social trends, leveraging global knowledge and expertise to drive enterprise, value creation, and respect.

Key principles, including transparency, learning, corporate social responsibility awareness, and eco-efficiency, foster a conducive environment for sustainability and growth.

➤ Theoretical Framework

Embracing innovation as a catalyst for sustainable development poses a significant challenge. It requires

integrating established management principles to create an effective framework. Innovation encompasses various forms, including novel products, processes, services, management methods, and organizational structures. While constant innovation is demanding, firms must adapt to evolving market demands and competition, ensuring sustained competitive advantage. Innovation remains a vital economic concept for businesses to address societal sustainability challenges.

Corporate sustainability involves meeting stakeholders' needs (shareholders, employees, clients, communities, etc.) without compromising future stakeholders' needs. It entails strategically addressing environmental and social issues while ensuring profitability. Firms must incorporate sustainability's three dimensions into their decisions and activities.

➤ *Innovation Definition and Scope*

Innovation Definition and Scope Innovation involves enhancing existing products, services, or processes through creativity and risk-taking. It can range from minor improvements to comprehensive system overhauls or new market creation. Innovation drives economic growth, and systematic innovation leads to greater success. Key factors contributing to innovation include:

- Strong innovation culture, encouraging employee creativity and risk-taking
- Adequate resources (R&D labs, design teams, management support, funding)
- Clear strategic vision guiding innovation and decision-making
- Successful innovation requires:
 - Identifying market opportunities and customer needs
 - Anticipating trends and experimenting with new ideas
 - Effective implementation and market introduction

Innovation brings benefits like increased profits, faster growth, competitive advantage, improved margins, and groundbreaking discoveries. Innovation is the process of adding value to the already existing product and service. It can be as simple as making a small change or as complex as completely overhauling an entire system or creating new marketing with a new product. Innovation focuses on creativity and risk-taking ability when the situation demands improvement.

The organizations that work systematically to innovate are the most successful in the long run. Innovation often comes from individuals with an idea, but companies also invest heavily in innovation and the creation of new products and services. Innovative culture in an organization is the most important factor for sustainability. We need to develop an ambiance in which the employees feel motivated and encouraged to come out with new ideas. Another critical factor is having the right resources, such as R&D labs, design teams, management support, and funding. Finally, we need to have a clear strategic vision to support innovation and help guide decision-making. To innovate successfully, companies must be able to identify opportunities and seize them.

➤ *Overview of Innovations in Sustainability*

Sustainable innovation encompasses the dynamic process of conceiving and implementing novel products, services, technologies, or business models that yield positive effects on the environment, society, and the economy. Its core objective is to provide inventive and efficient solutions to urgent challenges like climate change, resource depletion, pollution, inequality, and poverty.

This approach is characterized by a commitment to environmental responsibility, striving to reduce resource consumption, minimize waste, and mitigate negative impacts on ecosystems using renewable energy, sustainable materials, and technological advancements. Social impact is another key facet, focusing on equity, inclusivity, and community well-being by addressing challenges such as poverty, and inequality, and improving access to education, healthcare, and clean water. Innovations in renewable energy sources, energy storage, and efficiency play a pivotal role in sustainable innovation, aiming to decrease reliance on fossil fuels and combat climate change. Furthermore, economic viability is emphasized, acknowledging the importance of creating value and generating economic benefits while ensuring long-term profitability through cost savings, market opportunities, increased efficiency, and the development of new markets.

➤ *Technology Innovation for Sustainable Development*

The manufacturing industry's commitment to contributing towards a clean and sustainable environment and continually enhancing its environment-related performance as an integral part of its business philosophy and values can keep the organization ahead of competitors. Strive to integrate its business values ethically and transparently to demonstrate its commitment to sustainable development and to meet the interests of its stakeholders. Create a positive footprint within society to make a meaningful difference in the lives of people by continually aligning their initiatives to the goals for sustainable development. Maintain a commitment to business and people for quality, health, and safety in every aspect.

The manufacturing giant, the steel sector significantly contributes to India's economy pumping 2.5 % into GDP. However, the industry accounts for 12% of India's CO₂ emissions with an intensity of 2.55 Ton per Ton of crude steel produced. India faces the pressing need to adopt such sustainable practices, especially in steel manufacturing, which is an economically vital yet energy-intensive sector. Meeting sustainable development goals will require action on several fronts, including harnessing and maximizing the potential of technological innovation. Examples of such technologies include carbon capture and storage systems called carbon capture utilization and storage (CCUS), an emerging mechanism to mitigate climate-altering GHG emissions. The industry's ambitious plan to decarbonize involves implementing the CCUS mechanism at various stages of production from capturing CO₂ during Iron and steel making to subsequent storage or utilization. India aims to be carbon neutral by 2070 targeting a 45% cut in emissions by 2030 from the 2005 level.

II. LITERATURE REVIEW

Fanny Hermundsdottir et.al (2021) conducts a systematic literature review of 100 peer-reviewed publications to explore the link between sustainability innovations and competitiveness. Most studies suggest a positive relationship, supporting the idea that sustainability innovations can benefit firms, though the relationship is influenced by various contextual factors.

Laura Diaz Anadona et.al (2015) advocate for leveraging technological innovation for sustainable development by recognizing its complex, socio-technical nature. It emphasizes the need for cross-sectoral comparisons, prioritizing underserved populations, and reforming institutions to align with sustainable development goals.

Nina Tura et.al (2019) explores the challenges in utilizing sustainability knowledge for innovation in environmental, social, and economic contexts. Based on data from interdisciplinary workshops and interviews in Finnish companies, it identifies obstacles in knowledge management and examines the potential of digitalization in overcoming these challenges.

Matthew Phillip Johnson explores the integration of environmental and social practices in small and medium-sized enterprises (SMEs) through sustainability management tools like CSR, environmental audits, and stakeholder dialogues. Using Roger's stages of innovation model, a web-based survey of 176 German SME managers investigates awareness, implementation rates, and associated factors.

Opha Pauline Dube (2019) provided the Current Opinion in Environmental Sustainability journal's recent issues (45 and 49) explore emerging technologies and innovations crucial for achieving global sustainability goals. These advancements, akin to historical technological shifts, impact carbon reduction, land management, data handling, and material logistics, prompting collaborative efforts for future sustainable interventions.

Michele Acciaro et.al (2014) explore the growing concern for environmental sustainability in the port industry. It emphasizes the need for advanced conceptual frameworks that consider the multiple stakeholders and interactions involved. The proposed framework, drawing on the InnoSuTra project, assesses the success of innovations in improving seaport sustainability, highlighting the importance of alignment with port actors' demands and the institutional environment.

Catia Milena Lopes et.al (2016) examine how a Brazilian family-owned rubber products company embraces organizational sustainability through knowledge management and open innovation. The study showcases how these strategies, aligned with the OECD's eco-innovation model, drive cultural shifts, fostering sustainable innovations across health, education, and coatings sectors.

B. Baldassarre (2017) focuses on creating sustainable value propositions by integrating principles of sustainable business model innovation and user-driven innovation. It emphasizes a dynamic and iterative approach, involving stakeholders, understanding needs, and developing meaningful solutions for both people and the environment.

Steve Evans (2017) explores the growing interest in sustainable business models (SBMs) and aims to establish a comprehensive theoretical framework for understanding the adoption of SBMs. Drawing on various literature, the study proposes five key perspectives to guide organizations in developing and experimenting with alternative business models that integrate economic, environmental, and social values within a broader value network.

Simonov Kusi-Sarpong (2018) emphasizes the crucial role of sustainable innovation management in sustainable supply chain management (SSCM) for manufacturing companies. It introduces a sustainable innovation criteria framework, utilizing a multi-criteria decision-making model to evaluate and prioritize criteria. Results highlight the significance of 'financial availability for innovation' and aim to guide managers in enhancing sustainability in manufacturing supply chains, paving the way for future research in the field.

Klewitz J et al (2013) explored sustainability-oriented innovations (SOIs) in small and medium-sized enterprises (SMEs) from 1987 to 2010. It identifies SMEs' strategic sustainability behaviors, and innovation practices, and emphasizes the need for a more comprehensive understanding of SMEs' role in industry transformation and sustainable supply chains.

Appio F P et al (2018) The global proliferation of Smart Cities initiatives aims to enhance local competitiveness and citizen quality of life through innovation, improved public services, and environmental sustainability. However, existing research lacks a comprehensive assessment. The special issue explores this through a hybrid framework, offering insights and proposing a new research agenda for informed discourse.

III. THE AIM OF THE STUDY

➤ *The Goal of this Study is to Integrate Sustainable Technology and Practices into the Manufacturing Industry.*

- The research aims to identify and analyze the constraints and problems that are impeding the mainstream adoption of sustainable technology. Understanding these roadblocks is critical for devising successful tactics for overcoming them and promoting sustainable projects.
- The study examines the existing condition of sustainable practices in the manufacturing industry. This entails a thorough review of current programs, adherence to industry standards, and manufacturing organizations' overall commitment to sustainable practices. The research attempts to give insights into areas of strength and areas

that may need development by examining the present landscape.

- The study looks at how people perceive the influence of technological interventions on sustainability analysis of how the incorporation of novel technology affects the environmental, social, and economic components of sustainability within industrial processes. Understanding perceived impact is critical for determining the efficacy of these interventions and their contribution to overall sustainability objectives.
- The research examines the influence of leadership and organizational culture in promoting long-term sustainability in manufacturing organizations. Examining how leadership styles, organizational values, and cultural norms impact the prioritization and implementation of sustainable practices is part of this goal.
- The study intends to look at staff involvement and training for sustainable practices in industrial environments. This includes determining the amount of staff knowledge, involvement, and training possibilities for sustainable practices.
- This study examines adoption barriers, current sustainability practices, the perceived impact of technological interventions, the role of leadership and organizational culture, and employee engagement and training in the manufacturing industry.

By addressing these goals, the research hopes to provide significant insights on how to improve sustainable practices in the changing industrial sector.

IV. SIGNIFICANCE OF THE STUDY

➤ *A thorough Literature Review has been Conducted to Identify key Themes and Concepts related to Innovations and Technological Interventions for Sustainability in the Manufacturing Sector.*

- One of the primary challenges is the looming threat of resource scarcity. Depleting natural resources and escalating demands for raw materials pose a significant hurdle to traditional manufacturing processes. To counteract this challenge, the industry is increasingly embracing circular economy principles, recycling initiatives, and sustainable sourcing practices. These interventions aim to reduce dependence on finite resources and promote a more sustainable resource management model.
- Energy consumption stands out as another formidable challenge. The manufacturing sector historically has been a substantial contributor to environmental degradation and operational costs due to high energy consumption. To address this, interventions include the implementation of energy-efficient technologies, the incorporation of renewable energy sources, and the deployment of smart energy management systems. These measures not only mitigate environmental impacts but also enhance operational efficiency.
- Waste management remains a critical concern, with the generation and disposal of waste posing significant environmental threats. Industry responds by integrating

waste-to-energy technologies, adopting waste reduction practices, and embracing sustainable waste disposal methods. These interventions contribute to minimizing the industry's ecological footprint and fostering a more responsible approach to waste management.

- Carbon emissions from manufacturing processes add to the industry's environmental challenges. The shift towards sustainability involves the adoption of low-carbon technologies, the implementation of carbon capture and storage initiatives, and the embrace of cleaner production methods. These interventions aim to curtail the industry's contribution to greenhouse gas emissions and promote environmentally friendly manufacturing practices.
- Supply chain sustainability emerges as a multifaceted challenge due to the complexity and lack of transparency within global supply chains. Interventions include the integration of sustainable practices throughout the supply chain, leveraging blockchain technology for transparency, and promoting responsible sourcing. These measures seek to create a more ethically sound and environmentally friendly global manufacturing ecosystem. Supply chain transparency remains complex, especially when dealing with global suppliers, requiring ongoing efforts to ensure adherence to sustainability standards. Conducting comprehensive life cycle assessments poses a challenge due to its complexity and resource-intensive nature. Increased consumer awareness and education are essential to meet the growing demand for sustainable products. Global collaboration becomes imperative to address sustainability challenges, requiring coordination among manufacturers, suppliers, governments, and non-governmental organizations.
- A skills gap arises because of rapid technological advancements, requiring the industry to invest in workforce training, collaborate with educational institutions, and promote STEM education. These interventions address the need for a skilled labor force capable of navigating and implementing emerging technologies.
- Technological interventions, such as Industry 4.0, additive manufacturing, robotics, and advanced materials, play a pivotal role in shaping the future of manufacturing. These innovations enhance efficiency, reduce material waste, and promote sustainable practices throughout the production process. Collaborative platforms facilitate better communication and coordination across the supply chain, fostering innovation and sustainability. The adoption of green chemistry further emphasizes the industry's commitment to environmentally friendly materials and processes.
- While these interventions represent significant strides towards sustainability, the industry faces additional challenges. The integration of sustainable materials encounters hurdles related to cost, availability, and performance. The high upfront costs associated with sustainable technologies pose financial challenges for manufacturers. The increasing reliance on data for sustainability initiatives raises concerns about data security and privacy. The lack of standardized protocols hinders the seamless integration of sustainable solutions. Reskilling the workforce becomes imperative for

adapting to advanced technologies, and ensuring regulatory compliance demands continuous monitoring and adjustments.

- The scalability of sustainable solutions is crucial, ensuring that technologies and practices can effectively transition from small-scale success to mass production.
- The management of electronic waste (e-waste) arising from the use of electronic components in manufacturing necessitates effective strategies for disposal and environmental impact mitigation.

➤ *Research Objectives*

This study seeks to:

- Integrate sustainable technologies and practices into the manufacturing industry, identifying and analyzing constraints hindering mainstream adoption.
- Assess the current state of sustainable practices in manufacturing, evaluating programs, industry standards adherence, and organizational commitment.
- Investigate the perceived impact of technological innovations on sustainability, examining environmental, social, and economic effects.
- Examine leadership and organizational culture's influence on promoting long-term sustainability, including leadership styles, values, and cultural norms.

- Evaluate employee engagement and training in sustainable practices, determining knowledge levels, involvement, and training opportunities.

By addressing these objectives, the study aims to provide valuable insights into enhancing sustainable practices in the evolving manufacturing sector.

V. METHODOLOGY

The methodology employed for the study involves a comprehensive approach aimed at gathering insights from middle-level executives within five manufacturing companies. The target respondents for this research consist of 20 employees from each of the selected 5 companies, totaling 100 participants. The questionnaire is divided into sections, covering topics such as the current state of sustainability practices within the manufacturing company, the level of awareness and adoption of innovative technologies, perceived challenges, and suggestions for improvement. The sampling strategy involves selecting a representative sample of middle-level executives from operational departments within manufacturing companies. Descriptive statistics analyze quantitative data, providing a snapshot of trends and patterns.

VI. DATA ANALYSIS

➤ *Findings of the Research Work:*

Table 1 Findings of the Research Work

S. No.	QUESTIONNAIRE	Strongly disagree	Disagree	Strongly agree	Agree	Remarks
1	The current infrastructure in our manufacturing plant poses a significant challenge to the adoption of sustainable technology.	23	36	20	21	About 59% of the population disagree that the current infrastructure poses any challenge to the adoption of sustainable development in their organizations.
2	The perceived risks associated with adopting new technologies hinder the adoption of sustainable technologies and practices	34	29	20	17	A significant level of disagreement (63%) regarding the risks associated with adopting new technologies hindering the adoption of sustainable practices.
3	The manufacturing plant's current sustainability practices align with industry standards.	45	27	15	13	The current practices do not align with industry standards, and we need a more focused approach to improve.
4	The limited availability of sustainable technology solutions in the market is a challenge for our manufacturing plant.	33	34	16	17	The survey findings uncover a significant concern among respondents that realize that technological solutions are available, we need to adopt and innovate as per the practical condition of the manufacturing units.
5	The management actively seeks and implements new sustainable practices in our manufacturing unit.	18	17	31	34	The respondents were very positive about the management's initiatives in the ever-challenging atmosphere of competitiveness. They support the management in seeking and implementing sustainable practices for their units.
6	The manufacturing plant actively engages with stakeholders to enhance sustainability practices.	26	25	22	27	There is a mixed perception regarding the manufacturing unit's

						commitment to sustainability factors through stakeholders.
7	Employees at all levels of the organization are actively involved in promoting and practicing sustainability.	41	33	14	12	A significant portion of the respondents seem to express their strong views that employees at all levels need to be active in promoting and practicing sustainability as of now it is lacking, and major initiatives are needed to bring it into practice.
8	The implementation of technological interventions has significantly improved our manufacturing plant's overall sustainability.	23	16	32	29	The survey findings indicate that technological intervention has significantly contributed to improving the overall sustainability of the manufacturing units. Still, more focus is needed.
9	Sustainable technologies have positively affected the environmental performance of the manufacturing plant.	24	17	29	30	59% of respondents agree that technological developments have positively affected the environmental performance of the organization
10	Sustainability goals are to be integrated into the performance metrics and incentives for leadership.	3	7	60	30	Most of the respondents of the survey have strong views that sustainability goals are to be aligned with a performance matrix and incentives for leadership.
11	Leadership encourages open communication to drive sustainability.	38	27	14	21	The survey results indicate that a major part of respondents does not agree, and they feel a lack of open communication to propagate the culture of sustainability in the organization.
12	The management actively seeks input and feedback from employees regarding sustainability initiatives.	40	36	14	10	The data indicates that there needs to be a proactive approach on the part of management to seek input and feedback from employees regarding sustainability initiatives.
13	The organization provides sufficient resources for employees to implement sustainability initiatives	27	21	25	27	The result of the feedback from respondents shows a mixed response with 52 % agreeing that the organization and management provide sufficient resources to implement sustainability initiatives while 48 % still feel that more initiatives are expected from management.
14	There is a clear communication channel for employees to provide suggestions for improving sustainability	18	27	26	29	The result of the study indicates a mixed response with 55% agreeing that there are initiatives on the part of management for communication to provide suggestions for improving sustainability

- Current infrastructure is adaptive to the adoption of sustainable development
- The present practices and standards are to be raised to align with industry standards in social, economic, and environmental boundaries of sustainability practices.
- The survey indicates that today's well-informed employees are more positive, encouraged, and ready to accept challenges
- The top-down mechanism is the firm route to success in any action-centred leadership practice.
- The manufacturing industry is a nexus of technological innovation and sustainability imperatives. The challenges it faces underscore the need for comprehensive and collaborative interventions.

VII. CONCLUSION

Current infrastructure is adaptive to the adoption of sustainable development. In the competitive and ever-demanding market scenario, the present practices and standards are to be raised to align with industry standards in sustainability practices' social, economic, and environmental boundaries. The survey indicates that today's well-informed employees are more positive, encouraged, and ready to accept challenges to implement sustainable practices in the manufacturing setup. Technological intervention significantly improves sustainability practices in the manufacturing industry. The top-down mechanism is the firm route to success in any action-centered leadership practice. On the same lines, sustainability practices can be successfully implemented by a focused approach of top management. Business activities have a direct and indirect impact on the

environment and society. Every organization should be committed to continuously promoting sustainable development that encompasses environmental, societal, and economic aspects related to its business activities. The manufacturing industry stands at the nexus of technological innovation and sustainability imperatives. The challenges it faces underscore the need for comprehensive and collaborative interventions. By addressing resource scarcity, energy consumption, waste management, carbon emissions, supply chain sustainability, digitalization cybersecurity, skills gap, and other challenges through innovative technological solutions, the manufacturing sector can move forward for a sustainable and environmentally friendly future. Companies that proactively embrace these changes position themselves not only as contributors to global sustainability but also as leaders in a rapidly evolving and conscientious market. Innovations and technological interventions are crucial for achieving sustainability goals. However, addressing the emerging challenges is vital to ensure that these technologies contribute effectively to a sustainable future. Collaborative efforts between governments, industry, and society are essential to overcome these challenges and harness the full potential of sustainable technologies.

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