XIII National Conference on

Industry 5.0: Shaping an Inclusive and Responsible Future with the 4E's: Empathy, Ethics, Equity and Ecology

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Editors

Dr. Aparna Mishra

Director, Banarsidas Chandiwala Institute of Professional Studies, Dwarka, New Delhi, India

Dr. Shamsher Singh

Professor, Banarsidas Chandiwala Institute of Professional Studies, Dwarka, New Delhi, India

Ms. Anit Kaur

Assistant Professor, Banarsidas Chandiwala Institute of Professional Studies, Dwarka, New Delhi, India

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XIII National Conference on: **Industry 5.0: Shaping an Inclusive and Responsible Future with 4 E's – Empathy, Ethics, Equity, and Ecology**

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Preface

In the contemporary global landscape, businesses are navigating an era marked by rapid technological advancement, evolving societal expectations, and pressing environmental concerns. As the world transitions from Industry 4.0 to Industry 5.0, the focus is no longer solely on automation and efficiency but on creating a harmonious balance between technology and human values. This paradigm shift emphasizes inclusivity, sustainability, and responsibility, urging organizations to rethink their strategies to ensure that economic progress aligns with social well-being and ecological preservation.

The concept of Industry 5.0 introduces a transformative framework grounded in the principles of Empathy, Ethics, Equity, and Ecology (4Es). These pillars advocate for a human-centric approach to innovation, where technological progress is guided by moral responsibility, inclusiveness, and environmental consciousness. In this evolving context, organizations are called upon not only to innovate but to do so responsibly ensuring that growth is sustainable, equitable, and aligned with the broader goals of society.

With this vision, BCIPS organized its XIII National Conference on the theme “Industry 5.0: Shaping an Inclusive and Responsible Future with the 4Es – Empathy, Ethics, Equity, and Ecology” on 30th and 31st January 2026. The conference served as a vibrant platform for academicians, researchers, industry experts, and students to deliberate on emerging trends, challenges, and opportunities in management and allied disciplines within the framework of Industry 5.0.

The conference was graced by eminent dignitaries and thought leaders who enriched the deliberations with their valuable insights. The Inaugural Address by Mr. Gokul Pandian, Head–ESG, Ernst & Young (E&Y), highlighted the importance of integrating human judgment and empathy with artificial intelligence. The Guest of Honour, Dr. Shikha Jain, Co-Founder of JOMO (Joy of Missing Out), emphasized the need for a morally guided approach in business decisions, while Mr. Vineet Ranjan, Head–Risk and Strategic Alliance, KOSH, underscored the ethical dimensions of data usage and responsible leadership.

The Keynote Address by Dr. K. R. Kaushik, Ex Vice President, Gujarat State Fertilizers & Chemicals Limited, provided profound insights into the moral responsibility of organizations in fostering sustainable development and circular economy practices. The technical sessions were further enriched by the contributions of distinguished speakers including Dr. Kumar Bijoy, Director and CEO, SIIF, University of Delhi, and Dr. Prakash Singh, Associate Professor, Saudi Electronic University, Saudi Arabia, who deliberated on the transformative role of emerging technologies and the integration of ethical and inclusive practices in Industry 5.0.

The conference witnessed insightful research presentations across diverse themes such as ESG-driven performance, circular economic frameworks, ethical governance, green finance, workplace well-being, digital responsibility, and technology-enabled sustainability. These contributions reflect the growing recognition that the future of business lies in balancing innovation with responsibility and aligning organizational goals with societal and environmental priorities.

This edited volume is a compilation of selected research papers presented during the conference. It aims to provide a comprehensive understanding of the evolving dynamics of Industry 5.0 and its implications for business transformation, sustainable innovation, and inclusive growth. The contributions in this volume offer valuable perspectives on how organizations can integrate empathy, ethics, equity, and ecology into their core strategies to create long-term value.

We extend our heartfelt gratitude to all the contributors, speakers, session chairs, and participants whose scholarly inputs and active engagement made this conference a grand success. We are especially thankful to the management, faculty, and staff of BCIPS for their unwavering support and dedication in organizing this academic endeavors. We also acknowledge the efforts of the organizing team for their meticulous planning and execution.

Finally, we express our sincere appreciation to the publisher for their collaboration in bringing out this volume. We hope that this publication will serve as a valuable resource for academicians, researchers, practitioners, and policymakers, and will contribute meaningfully to the ongoing discourse on building a more inclusive, responsible, and sustainable future.

Conference Coordinating Team

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Evaluating the Role of the Insolvency and Bankruptcy Code in NPA Resolution: Evidence from Indian Public Sector Banks

Rosy Kalia[1], Dr Prakash Pise[2]
[1]Assistant Professor, Indira School of Business Studies PGDM, Pune
[2]NBN Sinhgad Technical Institute Campus Vadgoan, Pune

Abstract
Through this secondary data-based research article, the author hopes to highlight the identification and analysis of new NPA patterns as well as a detailed study of the Insolvency & Bankruptcy Code, 2016. The impact of IBC, 2016 in India is the main subject of the research. Key IBC provisions and the introduction of NPA are covered in the work. Specialized literature was chosen and employed for research, which gives the idea more vitality. Research papers, publications, and webpages are examples of secondary data. Because of its direct connection to SBI, the case study of Bhushan Steel, which was bought by Tata Steel, has been elevated on purpose. Additionally, IBC's quantitative and qualitative analyses were discussed. The effectiveness of IBC as a remedy for non-performing assets (NPAs) and emerging trends in NPAs were succinctly described. At the conclusion of the study, a diagrammatic depiction was used to show the effects of insolvency and bankruptcy in India. A few shortcomings of the IBC Act were also mentioned in the conclusion, along with the use of the BIFR Act of 1985 and the SARFAESI Act of 2002.

**Email: rosykalia82@gmail.com*

Keywords: Quantitative and Qualitative analysis, IBC Act, Emerging trends of NPAs, BIFR Act, 1985, SARFAESI Act, 2002.

INTRODUCTION

Non-Performing Assets (NPAs) have been a major challenge for Indian Scheduled Commercial Banks (SCBs) in recent years. The problem peaked in 2018–19, after which India's banking sector witnessed improvements in asset quality. By September 2023, the Gross NPA ratio had fallen to a 10-year low of around 3.2%. However, the COVID-19 pandemic reversed this trend temporarily, as the economic slowdown and repayment difficulties led to a rise in NPAs. These factors, combined with external environmental conditions, continue to impact banks' profitability and overall financial health.
The issue of NPAs has been addressed through various regulatory and policy measures introduced by the Reserve Bank of India (RBI) and the Government of India. A landmark step was the introduction of the Insolvency and Bankruptcy Code (IBC) in 2016, which significantly reformed the resolution process for distressed assets.

For a developing country like India, the challenge of NPAs is particularly severe. The government's financial reforms aimed at matching global economic standards cannot succeed without strengthening the Indian banking and financial system. Rising NPAs threaten the very stability of banks, erode profitability, and disrupt the broader financial system.

An NPA is defined as a loan or lease that fails to meet its scheduled principal and/or interest payments. NPAs include:

- **Commercial loans** overdue for more than 90 days
- **Consumer loans** overdue for more than 180 days
- In FY23, private banks such as HDFC Bank, Axis Bank, ICICI Bank, and SBI reported the lowest gross NPA ratios (ranging from 1.12% to 2.78%). On the other hand, public sector banks such as Punjab National Bank, Union Bank of India, and Canara Bank reported much higher gross NPAs, reaching up to 7.4%.
- NPAs are generally classified into three categories:

- **Substandard Assets**: Loans that remain NPAs for less than or equal to 12 months.
- **Doubtful Assets**: Loans that remain in the substandard category for more than 12 months.
- **Loss Assets**: Loans where losses have been identified by the bank or auditors but have not yet been fully written off.
- Before the IBC, India's mechanisms for resolving NPAs were fragmented and inefficient. Instruments such as the Securitisation and Reconstruction of Financial Assets and Enforcement of Security Interest (SARFAESI) Act, Debt Recovery Tribunals (DRTs), and the Corporate Debt Restructuring (CDR) framework existed, but they failed to deliver effective, timely resolution. The IBC has since emerged as a gamechanger in addressing these long-standing challenges.
- Key Provisions of IBC
- **Time-bound Resolution**: The IBC mandates a 180-day resolution period, extendable by 90 days.
- **Creditor-in-Control Model:** Creditors have control over the insolvency resolution process, unlike the previous debtor-in-control approach.
- **Insolvency Professionals:** Appointment of insolvency professionals to manage the resolution process.
- **Insolvency and Bankruptcy Board of India (IBBI):** A regulatory body to oversee the implementation of the IBC.

OBJECTIVES

1. To identify and analyse the emerging trends of Non-Performing Assets (NPAs) in India.
2. To study the provisions and framework of the Insolvency and Bankruptcy Code (IBC), 2016.
3. To evaluate the impact of the IBC, 2016 on the resolution of NPAs.
4. To examine the broader effects of insolvency and bankruptcy reforms on the Indian financial and economic system.

LITERATURE REVIEW

A Study of Insolvency and Bankruptcy in India: A Literature Review Written by Mr. Rohit Kaswan and Dr. Sandeep Gehlotin, 2021 focused on Insolvency, Bankruptcy and Resolution keywords. This article attempts to analyse and determine the studies conducted by various researchers with respect to the Insolvency and Bankruptcy Code of India. The objective of the research is to understand the concept of Insolvency and Bankruptcy Code as a remedial tool for banking and to analyze the various research works done in the field of Insolvency and Bankruptcy Code, but this study is limited to the number of research articles and books referred to.

Contains 8 research papers for conceptual clarity. The first research paper was written by Deepak Tandon, Neelam Tandon, 2019 on "Rising Non-Performing Assets in Indian Banking and Insolvency and Bankruptcy Law: Resolution Plans and Cases", The researcher believed that the banking industry in India is plagued with asset quality problems. which led to potential losses due to insufficient allowances for non-performing assets. They are of the opinion that the strength and sustainability of credit growth is a must for improving the conditions of the banking system in future times. The researchers also came to the conclusion that the main cause of bank fraud was failure of a part of banking operations, mainly non-compliance with procedures. They also concluded that although the RBI is taking preventive measures to treat stressed assets and accelerating corrective measures to improve asset quality, the results are still not very promising and progress is emerging at a very slow pace.

"A Study of Insolvency and Bankruptcy Code and Its Impact on India's Macro Environment" by Srijan Anant, Aayushi Mishra, 2019 and the researcher believes that IBC is one of the major reforms brought about by the legal system in India. In the opinion of the author, IBC not only gives strength to the legal system in India but also gives India a new identification and recognition at the global level. The researcher was of the view that the government only notified a portion of corporate insolvency and not personal insolvency when it approved the IBC in 2019 through "The Way Forward for Personal

Insolvency in Indian Insolvency and Bankruptcy Code" written by Renuka Sane. The author believes that the Indian credit market scenario calls for the need for a Personal Insolvency Act. Another interesting research paper specifically mentioned about the Insolvency and Bankruptcy Code prevents the erosion of business value and facilitates it as a solution for time-bound insolvency resolution to support business. The author analysed the key features of the code and the legal framework of the codes. The author has also tried to analyse the impact of Insolvency and Bankruptcy Code on India's macro environment.

Author Manoranjan Ayilyath in 2019 examines the various factors and challenges the system faces that slow progress and must be rectified as an ongoing process. In his 2018 study, Pratik Datta applied theoretical concepts to analyse major issues such as value destruction and wealth transfer in the new Insolvency and Bankruptcy Code. The existing IBC is not able to meet the financial market and the process of solving problems due to the Code related to the resolution of insolvency and bankruptcy of natural persons and partner firms is not yet effectively operational. This paper examines the various factors and issues facing the system that slow down progress and must be corrected as an ongoing process.

Mrs. Srilekhya Eduri, Dr. N. Jayaprada, Mr. Srinivas Eduri, 2018 found that the Insolvency and Bankruptcy Code has brought about a change in the economy by focusing on a turnaround plan that, if not working, leads to liquidation. In addition to creating progressive and constructive initiatives that will address all situations as a step forward. The code was also found to have limitations that occurred due to poor management and inappropriate use. This paper has examined the impacts and loopholes of the IBC on the Indian economy and intends to provide insights on how to improve the Code for effective implementation.

Josiah Wamwere-Njoroge, 2017 concludes that the IBC is more effective and promising compared to UK and French bankruptcy laws; The study concludes that the Insolvency and Bankruptcy Code is flexible. This article infers that the IBC is more effective and promising compared to UK and French bankruptcy laws using different indices to check. The author concluded that the consideration for any good insolvency and bankruptcy regime is that it should be able to balance the rights of creditors (secured and unsecured) and debtors. The researcher found that insolvency and bankruptcy proceedings in India are quite costly and prevent relevant stakeholders from exploiting the system for their own selfish interests. The study concludes that the Insolvency and Bankruptcy Code is flexible to preserve liquidation and continuation solutions.

Nakul Sharma, Dr.Rahul Vyas, 2017 studies the framework of insolvency professional agencies in terms of its role and scope. The above nine research papers help clarify the conceptual idea. It focuses on the theoretical framework. The origin of the problem of rising NPAs lies in the credit risk management system of the banks. This has been explored in detail by the following authors. This article studies the framework of insolvency professional agencies in terms of its role and scope, underpinning the IBC in terms of the procedural and regulatory scope of the Code. IBC 2016 is a landmark development in the law of our country which provides solutions in a time bound manner, promotes entrepreneurship which will lead to improved availability of credit and balances the interest of all stakeholders.

CASE EXAMPLES

Bhushan steel: one of the landmark instances beneath IBC where Tata steel obtained Bhushan metallic for ₹35, two hundred crores, ensuing in a extensive healing for creditors. Bhushan metal, one in every of India's largest steelmakers, confronted excessive monetary trouble, amassing a debt of over ₹56,000 crore (about $8. four billion USD) via 2017 consortium of banks led by way of SBI, Public region financial institution. This debt turned into due to competitive expansion projects and operational inefficiencies, mixed with a downturn within the steel enterprise. The IBC framework, delivered in 2016, lets in lenders to provoke bankruptcy court cases against defaulting organizations. Bhushan metallic become some of the 12 massive instances that the Reserve financial institution of India (RBI) prioritized for resolution below IBC in 2017.

Tata Steel a metallic emerged because the successful bidder thru the IBC auction manner, winning in opposition to different competitors like JSW metal. The country wide corporation regulation Tribunal (NCLT) accepted Tata steel's decision plan in may 2018.With such high debt degrees, Bhushan metal's incapacity to satisfy its duties brought about defaults, pushing it into insolvency complaints beneath the IBC. Tata metal acquired a controlling stake (72.65 %) in Bhushan metallic for approximately ₹35,two hundred crore (round $five.4 billion USD). This quantity became used to settle a considerable part of Bhushan steel's terrific debts to lenders. The closing debt became restructured, and Tata metal assumed management of Bhushan steel, renaming it to Tata steel BSL (Bhushan metal constrained). further to the acquisition quantity, Tata metallic also dedicated to infusing extra capital to stabilize and improve the operations of Bhushan steel. This acquisition set a precedent for large-scale debt decision below the IBC, showcasing the framework's capability to facilitate timely resolutions.
For Tata Steel, the acquisition expanded its production capacity by about 5.6 million tons per year and provided access to valuable assets, strengthening its position in the
Indian steel industry. The acquisition also demonstrated the viability of the IBC process in facilitating mergers and acquisitions in distressed sectors, paving the way for further resolutions in other industries.

Effect of insolvency and bankruptcy in India:

Qualitative analysis: The IBC has empowered creditors, specifically monetary creditors, improving their ability to get better dues through a dependent manner. The IBC has instilled marketplace discipline, making debtors extra responsible. the fear of losing manipulate over their agencies has precipitated many debtors to settle dues right away. improved NPA resolution mechanisms have made Indian banks more attractive to overseas buyers, bolstering overseas direct funding (FDI) within the monetary region Insolvency and financial ruin have vast effects on the financial and legal panorama of any country, consisting of India. The advent of the IBC in 2016 marked a pivotal change in how insolvency and bankruptcy issues are addressed. Yes Bank and Punjab & Maharashtra Co- operative (%) bank underscore the dangers related to excessive NPA ranges. Sure financial institution faced extreme troubles due to large corporate NPAs, main to a government-led rescue package in 2020.The IBC has helped improve the go with the flow of credit score inside the economic system with the aid of imparting a clear and time-certain manner for resolving insolvencies. The IBC has enabled the resolution of numerous stressed belongings that had been formerly languishing. This has helped in cleansing up the stability sheets of banks, specifically public area banks, which have been pressured with NPAs. The IBC has added marketplace-pushed mechanisms for the decision of insolvency, which promotes performance and allows in better allocation of assets. The IBC has introduced legal readability and consolidated the laws referring to insolvency of businesses, partnership firms, and individuals, changing the earlier fragmented framework.

Effectiveness of IBC as a solution to NPAs:

Indian Banking sector is going through a hard time due to various reasons including but not limited to increase in Gross Non-Performing Assets (GNPA), loan frauds/corruption in some cases, economic slowdown etc. Rise in NPAs is major concern for banks as it reduces profit of banks and restricts the loan giving ability of the banks by way of provisioning. Reasons for the rise in NPA can be attributed to aggressive lending practice by the banks and wilful default by borrowers i.e., lack of willingness to repay. Another reason can also be lack of ability to repay the loans by the borrower; however, this reason is lessprevalent than wilful default. Post 1991 various measures were taken to solve NPA problem which includes legal reforms, introduction of Asset Reconstruction Companies (ARCs), various kinds of restructuring schemes of NPAs including corporate debt restructuring, strategic debt restructuring, scheme for sustainable structuring of stressed Asset (S4A) etc. The legal reforms include setting up of Debt Recovery Tribunals to speed up of resolution of NPAs cases, enactment of SARFAESI (Securitization and Reconstruction of Financial Assets and Enforcement of Security Interest) Act, 2002.

Emerging trends of NPAs:

NPAs are a critical concern for the banking sector in India, as they reflect the credit risk management health of banks and can significantly affect their profitability and stability. NPAs are loans or advances for which the principal or interest payment has been overdue for more than 90 days. The trends in NPAs over recent years highlight both persistent challenges and emerging strategies as banks, regulators, and policymakers address the underlying issues.

1. Decline in NPA Levels in Recent Years
2. Sectoral Shifts in NPA Trends
3. Impact of the Pandemic and Loan Moratoriums
4. Increased Focus on Retail NPAs and Digital Lending
5. Strengthening Recovery Mechanisms and Regulatory Reforms
6. Shift to Proactive Risk Management
7. Concerns Around Climate and ESG Risks

To address the emerging trends of NPAs in India, practical support measures are essential to help banks managers and tries to mitigate NPA effectively by using following ways:

- Enhanced Early Warning Systems (EWS)
- Sector-Specific Risk Mitigation Strategies
- Agriculture Sector Support:
- SME Financial Literacy Programs:
- Retail Loan Monitoring:
- Improved Recovery and Resolution Mechanisms
- Digitization of Lending Processes
- Strengthening of the Regulatory Framework
- Increased Financial Literacy and Borrower Support Programs
- Leveraging ESG and Climate Risk Assessment Tools
- Building Partnerships with FinTech and RegTech Firms
- Effective Training for Bank Staff

The IBC, added in India in 2016, turned into a landmark reform aimed toward streamlining and expediting the decision of corporate insolvency and bankruptcy cases. Following sensible implications of the IBC for diverse stakeholders, such as banks, corporations, traders, and the Indian economic system enables majorly. quicker decision of confused belongings with Empowerment of lenders and encouragement for responsible Borrowing and Lending in conjunction with introduction of a marketplace for Distressed property. by way of boosting corporate Governance standards, it'll impact on SMEs and the business network and this will rise in Professionalism through Insolvency Professionals (IPs).

Effects of insolvency and bankruptcy in India:
Ref.:https://timesofindia.indiatimes.com/business/india-business/bankruptcy-recoveries-on-the rise/articleshow/100199566.cms

The IBC has had far-reaching practical implications for India's financial ecosystem, enhancing financial discipline, improving recovery rates, and fostering a more responsible credit culture. Despite its challenges, the IBC is transforming India's approach to insolvency and distressed assets, supporting a healthier banking sector, and creating opportunities for investment. Its continued evolution and strengthening will be vital to further reduce NPAs, boost economic growth, and establish India as a favourable investment destination.

The IBC has had transformative effects on India's financial, business, and economic landscape since its enactment in 2016. The code brought a structured framework to address insolvency and bankruptcy in India, a critical need given the high levels of NPAs in the banking sector and the inefficiency of previous resolution mechanisms.

CONCLUSION

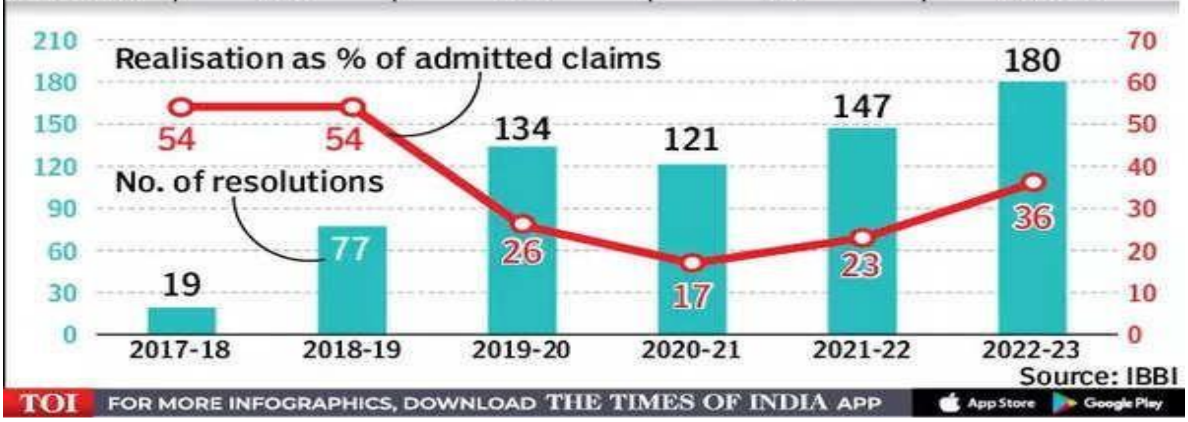
The Insolvency and Bankruptcy Code (IBC), 2016 has made a significant impact on the recovery of Non-Performing Assets (NPAs) in Indian Scheduled Commercial Banks by introducing a structured, time-bound framework. It has enhanced creditor confidence and improved recovery rates. However, challenges such as judicial delays and operational inefficiencies continue to limit its full potential.

India has transitioned from a developing to an emerging economy, and sustaining long-term growth requires strengthening businesses and financial institutions. Over the years, several mechanisms were introduced to address the NPA crisis, including the BIFR Act, 1985; SARFAESI Act, 2002; and the S4A Scheme, 2016. However, these measures did not yield the desired results, paving the way for the implementation of the IBC in 2016.

Realisation Rises To 36% Of Claims

Initiation of insolvency actions picks up...

Year	Fin creditor	Operational creditor	Corporate debtor	Total
2016-17	8	7	22	37
2017-18	286	310	111	707
2018-19	517	569	71	1,157
2019-20	883	1,053	51	1,987
2020-21	197	318	22	537
2021-22	371	473	43	887
2022-23	650	535	70	1,255



The IBC is widely regarded as a revolutionary reform not only in India but also globally. Institutions such as the IMF and World Bank have praised its introduction, and it has contributed to an improvement in India's ranking in the *Ease of Doing Business Index*. The Code has also signaled a paradigm shift in India's credit culture—strengthening the rights of creditors and enabling them to take control of debtors' assets in cases of default.

At present, the IBC does not comprehensively address cross-border insolvency. However, it provides guidance for the government to move in that direction. Adoption of the UNCITRAL Model Law on Cross-Border Insolvency—already implemented by more than 41 countries—would further strengthen India's insolvency framework.

Moreover, there is a pressing need to integrate technology into the insolvency resolution process. A fully digital system, accessible online from the perspective of creditors, would enhance transparency, allow real-time tracking of case progress, and improve overall efficiency.

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Industry 5.0: Shaping an Inclusive and Responsible Future With the 4 Es: Empathy, Ethics, Equity and Ecology

Dr. K R Kaushik[1]
[1]Independent Researcher
Former Visiting Faculty at Ramanujan College (DU) FIIB, Amity University (ASoDL), AIMA, & K K Modi University
Former Vice President, Gujarat State Fertilizer Corporation
Former Dy. Director General- Association of CGD Entities (ACE)
ORCID: ID0009-0007-532-3895

Abstract

The global industrial ecosystem is undergoing a paradigmatic transformation as Industry 5.0 emerges beyond the digital automation of Industry 4.0. Unlike its predecessor, which emphasized productivity and efficiency through cyber–physical systems, the fifth industrial revolution focuses on human-centricity, inclusivity, resilience, and sustainability. This research paper explores how Industry 5.0 redefines the relationship between technology and humanity by integrating artificial intelligence, robotics, and digital systems with ethical, social, and environmental priorities. The study employs a qualitative and analytical methodology, combining secondary literature review and policy analysis to examine the evolution, characteristics, challenges, and opportunities of Industry 5.0. It emphasizes how human–machine collaboration can promote inclusive growth, responsible innovation, and environmental stewardship. The paper concludes with strategic recommendations for policymakers, corporate leaders, and researchers to ensure that Industry 5.0 evolves as a catalyst for equitable and sustainable development

**Email: krkgsfc@gmail.com*
kedarkaushik@rediffmail.com

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Keywords: Industry 5.0, Sustainability, Human–Machine Collaboration, Inclusivity, Responsible Innovation, Artificial Intelligence, Industrial Transformation

INTRODUCTION

Industrial revolutions have historically redefined human civilization by reshaping production paradigms, labor relations, and societal structures. The first revolution mechanized manufacturing using steam power; the second harnessed electricity and mass production; the third introduced automation through electronics and IT systems; and the fourth—Industry 4.0—brought cyber–physical integration through artificial intelligence, robotics, and data analytics. However, despite its technological prowess, Industry 4.0 often marginalized the human dimension, emphasizing productivity over purpose.

Industry 5.0 marks a crucial shift from automation to augmentation, placing humans back at the centre of industrial evolution. It emphasizes collaboration between humans and intelligent machines, driven by values such as sustainability, inclusivity, resilience, and well-being. The European Commission (2021) identifies Industry 5.0 as a vision where industry serves society rather than society serving industry. This reorientation challenges traditional business models, encouraging industries to integrate ethics, empathy, and environmental stewardship into their core.

This research paper examines how Industry 5.0 can shape an inclusive and responsible future. It analyzes theoretical foundations, practical applications, and policy frameworks, offering insights for scholars and practitioners in management, engineering, and public policy.

LITERATURE REVIEW

1. Evolution of Industrial Revolutions

The transition from Industry 1.0 to 5.0 reflects humanity's continuous effort to align technological advancement with social progress. According to Kagermann et al. (2013), Industry 4.0 focused primarily on smart manufacturing, IoT, and digital twins. However, Rojko (2017) and Sony (2020) argue that automation without human involvement risks social exclusion and job polarization. Industry 5.0 thus represents a humanistic correction to the mechanistic trajectory of Industry 4.0.

2. Human–Machine Collaboration

Industry 5.0 integrates collaborative robots (cobots) that work alongside humans, enabling personalized and creative production. Nahavandi (2019) highlights that this model improves productivity while maintaining worker safety and satisfaction. The literature emphasizes "coexistence over replacement," where AI augments human intuition rather than replacing it.

3. Inclusivity and Ethical Innovation

Researchers such as Xu et al. (2021) and Demir (2022) argue that technological progress must be inclusive, ensuring marginalized groups benefit equally from industrial innovation. Inclusive design, gender equality in tech employment, and accessibility in automation are key dimensions of Industry 5.0.

4. Sustainability and Environmental Responsibility

Sustainability lies at the heart of Industry 5.0. According to Stock and Seliger (2016), green manufacturing and circular economy practices are vital for achieving ecological balance. Industry 5.0 extends this vision by promoting responsible production and consumption through smart energy systems, zero-waste policies, and carbon-neutral manufacturing.

5. Research Gaps

Despite growing literature, gaps remain in empirical data linking human–machine collaboration with measurable social outcomes. Moreover, the transition pathways for developing economies like India are underexplored. This paper addresses these gaps through a qualitative and comparative analysis.

RESEARCH OBJECTIVES

1. To analyse the conceptual foundations and evolution of Industry 5.0.
2. To assess how human–machine collaboration promotes inclusivity and sustainability.
3. To evaluate policy and institutional frameworks for responsible industrial transformation.
4. To propose strategies for developing economies to adopt Industry 5.0 equitably.

RESEARCH METHODOLOGY

1. Research Design

This study adopts a qualitative, descriptive, and analytical research design based on secondary data from academic literature, policy documents, industry reports, and case studies from global and Indian contexts.

2. Data Sources

Data were collected from journals indexed in Scopus, Web of Science, and UGC CARE databases, along with white papers by the European Commission, World Economic Forum, NITI Aayog, and McKinsey.

3. Analytical Framework

The study employs thematic content analysis, categorizing data into three dimensions:

Technological transformation
Human–machine collaboration
Sustainability and inclusivity outcomes

4. Limitations
The study relies on secondary data; hence, empirical validation through field research remains a scope for future investigation.

INDUSTRY 5.0: CONCEPT AND CORE PRINCIPLES

1. Human-Centric Innovation
Unlike Industry 4.0, where machines dominated, Industry 5.0 emphasizes human creativity as a core asset. It envisions a partnership where robots handle repetitive tasks while humans contribute cognitive flexibility, empathy, and ethics.

2. Sustainable and Circular Production
Industry 5.0 encourages regenerative design — using recycled materials, renewable energy, and closed-loop supply chains. Smart factories now track resource utilization to minimize carbon footprints.

3. Resilience and Customization
Post-COVID industrial recovery highlighted the need for resilient supply chains. Industry 5.0 uses AI and blockchain to anticipate disruptions and adapt rapidly. Moreover, personalized manufacturing allows consumer-driven customization, blending efficiency with empathy.

4. Ethical and Inclusive Development
Inclusion ensures technological diffusion across all socio-economic layers. Governments and firms are urged to integrate digital skills training, ethical AI governance, and accessibility standards.

CASE STUDIES AND GLOBAL APPLICATIONS

1. **Japan: Human-Robot Coexistence-** Japan's manufacturing sector pioneered cobots in SMEs, increasing productivity while retaining employment. Companies like FANUC and Omron emphasize emotional intelligence in robotics — aligning with the Society 5.0 vision.

2. European Union: Policy-Driven Industry 5.0
The European Commission (2021) integrates Industry 5.0 into its Green Deal, promoting circular economy, sustainable energy, and worker well-being. The EU's "Made in Europe" initiative embodies responsible industrial transition.

3. India: Toward Inclusive Automation
India's journey from Industry 3.0 to 5.0 is evolving. Initiatives like Digital India, Make in India, and Skill India support digital empowerment. Tata Steel, Infosys, and Siemens India integrate AI and robotics while reskilling human workers, showcasing a responsible adaptation.

EMPATHY, ETHICS, EQUITY AND ECOLOGY: THE FOUR PILLARS OF INDUSTRY 5.0
Industry 5.0 introduces a paradigm that transcends automation and efficiency, embedding moral, social, and environmental consciousness into the core of industrial progress. The four foundational values—Empathy, Ethics, Equity, and Ecology—constitute the moral framework guiding responsible innovation and sustainable transformation.

1. Empathy: The Human Heart of Industry 5.0
Empathy lies at the core of Industry 5.0's human-centric philosophy. It represents the ability of

organizations and technologies to understand and respond to human needs.

While Industry 4.0 emphasized efficiency and automation, Industry 5.0 restores emotional intelligence and compassion in workplaces. Empathy-driven design ensures that technology serves people — from user-friendly interfaces and assistive robotics to inclusive workplaces that value employee well-being. For instance, collaborative robots (cobots) in healthcare and manufacturing are now designed to sense stress, fatigue, or discomfort among workers, allowing responsive adjustments. This "empathetic automation" enhances job satisfaction and reduces burnout, ensuring technology remains a partner, not a competitor.

2. Ethics: Responsible Innovation and Governance
Ethics ensures that technological progress aligns with moral and societal values. In Industry 5.0, ethical AI, transparency, and accountability are essential principles.

This involves responsible data usage, algorithmic fairness, and respect for human rights. Ethical frameworks guide industries to ensure that AI systems do not reinforce bias, that automation does not lead to exploitation, and that environmental and social responsibilities are upheld.

Corporate governance in the Industry 5.0 era demands that profit motives be balanced with ethical imperatives — such as privacy, dignity, and social welfare. Companies adopting ethical standards build trust, which becomes a new form of competitiveness in a conscious global economy.

3. Equity: Inclusion and Fair Distribution of Benefits
Equity in Industry 5.0 extends beyond equal access to technology — it ensures fair participation and benefit-sharing across all social, gender, and geographic lines.

It seeks to close the digital divide by providing digital literacy, upskilling programs, and affordable access to emerging technologies for all citizens, including marginalized groups and developing nations.

Inclusion in leadership, STEM education, and innovation ecosystems is a central tenet of Industry 5.0. By democratizing technology and empowering underrepresented communities, Industry 5.0 fosters shared prosperity and social justice, ensuring no one is left behind in the next industrial transition.

4. Ecology: Harmony between Industry and Nature
Ecology reflects Industry 5.0's commitment to sustainability and the planet's well-being. This industrial model embraces green manufacturing, circular economy, renewable energy, and carbon neutrality.

Factories are designed as "eco-smart" systems — recycling waste, conserving energy, and minimizing emissions. Technologies like IoT and AI monitor environmental performance in real time, enabling proactive interventions.

The ecological dimension ensures that industrial growth enhances rather than depletes natural resources. By aligning economic objectives with planetary boundaries, Industry 5.0 becomes a bridge between industrial progress and environmental stewardship.

Synthesis: The Four Es as Pillars of a Responsible Industrial Future

Principle	**Core Value**	**Outcome in Industry 5.0**

Empathy	Human well-being	Worker satisfaction, humane workplaces
Ethics	Responsibility	Transparent, fair, and safe technology
Equity	Inclusion	Shared prosperity and social justice
Ecology Sustainability	Green circular	Resilient economy

Together, these "Four Es"—Empathy, Ethics, Equity, and Ecology—form the moral and operational compass of Industry 5.0. They ensure that technological evolution not only enhances productivity but also uplifts humanity and protects the planet.

EMPATHY, ETHICS, EQUITY AND ECOLOGY: THE FOUR PILLARS OF INDUSTRY 5.0

Industry 5.0 introduces a paradigm that transcends automation and efficiency, embedding moral, social, and environmental consciousness into the core of industrial progress. The four foundational values—Empathy, Ethics, Equity, and Ecology—constitute the moral framework guiding responsible innovation and sustainable transformation.

1. Empathy: The Human Heart of the Industrial Renaissance

Empathy is the emotional foundation of Industry 5.0. It emphasizes understanding human experiences and aligning technological systems to support workers' physical, mental, and emotional well-being.

Unlike the mechanistic logic of Industry 4.0, Industry 5.0 humanizes technology by designing systems that adapt to people rather than forcing people to adapt to systems.

Collaborative robots (cobots), for instance, can detect stress or fatigue in workers and adjust their operation accordingly. Empathy-driven leadership and workplace design foster trust, creativity, and a sense of belonging—qualities that improve productivity and innovation while ensuring that progress remains humane.

2. Ethics: Anchoring Innovation in Responsibility

Ethics ensures that technological advancement respects human dignity, transparency, and justice. The ethical dimension of Industry 5.0 focuses on responsible AI, data privacy, algorithmic fairness, and corporate accountability. Ethical governance demands that organizations evaluate the societal impact of automation and digital systems, preventing exploitation or discrimination.

By integrating ethical review mechanisms into R&D, industries ensure that innovation aligns with long-term human welfare and environmental sustainability. The ethical compass thus transforms Industry 5.0 from a purely technical evolution into a moral and social renaissance.

3. Equity: Inclusion and Fair Participation

Equity in Industry 5.0 means democratizing access to technology and ensuring fair distribution of benefits. It promotes diversity and inclusion across gender, class, and geography, ensuring marginalized communities are not left behind in digital transformation.

Equitable industrial systems support digital literacy, skill upgradation, and affordable technological access. Governments and corporations must invest in inclusive education and training to empower rural populations, women, and underrepresented groups. By bridging the digital divide, Industry 5.0 becomes a vehicle of shared prosperity rather than a source of further inequality.

4. Ecology: Restoring Harmony with Nature

The ecological pillar underscores Industry 5.0's deep commitment to environmental stewardship. Unlike earlier revolutions that extracted from nature, Industry 5.0 strives to coexist with it. The integration of green technologies, circular economy practices, renewable energy systems, and zero-waste manufacturing defines the new ecological ethos.

AI-powered monitoring tools optimize resource consumption, minimize emissions, and enable predictive maintenance for sustainable operations. The principle of "do no harm" to the planet becomes integral to industrial decision-making. Ecology in Industry 5.0, therefore, aligns economic progress with environmental regeneration, ensuring a resilient and sustainable future.

5. The Synthesis of the Four Es: Together, these four dimensions—Empathy, Ethics, Equity, and Ecology—form the holistic moral architecture of Industry 5.0. They ensure that industrial transformation is not only technologically advanced but also socially responsible and environmentally balanced.

Pillar	Core Value	Industrial Implication	Societal Outcome
Empathy	Human well-being	Worker-friendly design, emotional intelligence in automation	Humane and creative workplaces
Ethics	Responsibility and transparency	Fair AI, ethical governance	Trust and accountability
Equity	Inclusivity and fairness	Equal access to technology, reskilling	Social justice and shared prosperity
Ecology	Sustainability and harmony	Circular production, renewable energy	Environmental preservation and resilience

The Four Es guide policymakers, technologists, and leaders to design an industrial future that prioritizes people, planet, and purpose alongside profit. In doing so, Industry 5.0 emerges not merely as a technological revolution, but as a humanistic movement—reconciling progress with compassion.

ANALYSIS AND DISCUSSION

1. Comparative Analysis

Aspect	Industry 4.0	Industry 5.0
Focus	Efficiency,Automation Inclusivity,	Sustainability
Role of Humans	Peripheral	Central
Key Technologies	IoT, AI, Robotics	Cognitive AI, Cobots, Ethical AI
Economic Model	Shareholder-driven	Stakeholder-driven
Sustainability	Optional	Integral

2. Social and Economic Impacts

Industry 5.0 promotes shared prosperity by enabling digital upskilling and reducing inequality. By redefining labour roles, it ensures humans are co-creators, not casualties, of automation.

3. Policy and Governance Implications

Policymakers must integrate AI ethics, data privacy, and circular economy regulations. Education systems must align curricula with Industry 5.0 competencies—empathy-driven leadership, creative problem solving, and interdisciplinary collaboration.

FINDINGS

Industry 5.0 prioritizes people, planet, and purpose over profit alone.
Human–machine collaboration increases both productivity and social satisfaction.
Sustainable production reduces ecological footprints and fosters resilience.
Developing nations require institutional support for equitable technological diffusion.
Inclusive innovation is key to bridging the digital divide.

RECOMMENDATIONS

Policy Integration: Governments should adopt national frameworks aligning industrial policy with UN SDGs.
Corporate Governance: Businesses must embed ESG (Environmental, Social, and Governance) criteria in their industrial strategy.
Skill Development: Educational reforms should prepare workers for collaborative robotics and digital ethics.
Research Incentives: Encourage interdisciplinary research on human–machine coexistence.
International Cooperation: Promote technology transfer and capacity building through global partnerships.
Look for Ancient Wisdom: Acharya Chankya's Arathshastra contains vast knowledge of Management particularly on Industry, Resource Management and Financial Management. Researchers must read this ancient Treasure of Knowledge scripture. Also, Arthshastra needs to be taught at UG, PG level Management Courses

FUTURE RESEARCH DIRECTIONS

Future research should empirically measure the social benefits of Industry 5.0 adoption, such as reduced inequality, improved job satisfaction, and environmental performance. Comparative studies between developed and developing economies will enhance understanding of contextual challenges.

CONCLUSION

Industry 5.0 represents a transformative shift toward a human-cantered, sustainable, and ethical industrial paradigm. It merges advanced technology with empathy, ensuring progress benefits all segments of society. For India and other emerging economies, embracing Industry 5.0 is not merely a technological choice but a moral imperative — to build an industrial ecosystem that values people as much as performance, and the planet as much as profit. The future of industry lies not in replacing humans, but in redefining humanity's role in shaping technology responsibly.

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India’s Manufacturing Sector and Global Value Chains: The Emerging Role of Intra-Industry Trade

Devinder Singh Hooda[1,] Jyoti Yadav[2]
[1]Associate Professor, Department of Economics, Indira Gandhi University, Meerpur (Rewari), Haryana, India
[2]Senior Research Fellow, Department of Economics, Indira Gandhi University, Meerpur-Rewari-Haryana

Abstract
This study examines the evolution of the Indian trade and Manufacturing sector performance from 2010 to 2023. This paper highlights the key trends in export, import, total trade and intra-industry trade during the post-liberalised period, using trade data and the Grubel-Lloyd Index to analyse exports and imports. The study focused on identifying the trade flow of the Indian manufacturing sector, as well as the government policies and strategies that affect trade within this sector. The analysis is based on data from the World Trade Organisation (WTO) and the WITS Database. The findings reveal that India's total trade has grown significantly, with exports and imports increasing since liberalisation. The Grubel-Lloyd Index indicates a consistently high level of intra-industry trade, reflecting India's deeper integration into Global value chains. The study concludes that while India has dramatically expanded its trade, sustaining future growth will require strengthening domestic manufacturing and reducing import dependence.

**Email: dshooda.igu@gmail.com; dshooda@igu.ac.in ; jyotiyadav.eco.rs@igu.ac.in*

Keywords- Export, Import, Intra-Industry Trade, Trade Liberalisation, Trade Performance, Economic Growth, Trade Policy.

INTRODUCTION

Despite the recent global economic crisis, there is still agreement that trade and long-term economic growth are positively correlated. The Indian manufacturing sector has always focused on liberalisation policies (Veeramani, 2003). From the import substitution policies of the 1950s to the export promotion strategies of the 1980s and the significant tariff liberalisation of the 1990s, the sectors have experienced various policy interventions (Banga & Das, 2008). Empirical evidence of the potential for trade to drive growth and poverty reduction comes from the three decades of export-led growth in East Asia (Alessandrini et al., 2009). Even though East Asian economies are highly open and export-oriented, growth appears to have recovered more quickly and robustly than in less globally integrated regions, despite the sharp decline in exports during the recent crisis (Farole et al., 2010). One of the sectors with the fastest projected growth rates is the Indian manufacturing sector, which contributed 16–17 per cent of Indian GDP before the pandemic (WTO, 2020). India has become the sixth-largest economy globally, contributing 3.1 per cent to the total world GDP and its export contribution to global trade is 1.6 per cent (Jain et al., 2022). The industrial sector is crucial to international trade and makes a substantial contribution to societal progress. With the success of essential industries such as automotive, engineering, chemicals, pharmaceuticals and consumer durables, manufacturing is becoming a necessary pillar in the nation's economic growth (Dani Rodrick, 1993). In India, Manufacturing is one of the industries experiencing rapid growth. Indian Prime Minister Narendra Modi introduced the "Make in India" program to promote the Indian manufacturing industry and enhance the international economic standing (Mathanraj et al., 2016). Policymakers, economists and business executives must understand the scope and composition of work in this sector to improve national competitiveness and engage in successful global commerce (Puig et al., 2023). In the Indian industrial sector, the scale and structure of trade have undergone significant changes over the past few years. As a developed economy, manufacturing became an essential export-oriented sector, transforming the trade balance and reshaping global production networks (Rourke & Williamson, 2000).

Around 14 per cent of the Indian workforce was involved in manufacturing in 2000, contributing roughly 16 per cent to the country's GDP. In 2022, the sector's employment share had expanded to 17 per cent and its GDP contribution to 19 per cent (Malik et al., 2022). The emergence of the Indian middle class, the opening up of the Indian economy to international investment, trade and the government emphasis on manufacturing as a significant engine of economic growth are just a few factors that have contributed to this expansion (Hussain et al., 2019). These modifications have led to greater integration of the Indian industrial sector with the world economy. Only $50 billion of manufactured products were exported from India in 2000. They have increased to almost US$300 billion by 2022. From $40 billion in 2000 to over $200 billion in 2022, Indian manufactured product imports have also increased significantly (Sertić et al., 2024). Previous classical theories of international trade, such as Ricardo's comparative advantage and Heckscher-Ohlin theory, studied the exchange of different goods. In 1960, researchers began to identify evidence of trade between the same countries across nations, defeating the purpose of the previous theories. Grubel and Lloyd conducted a comprehensive empirical analysis on the significance of intra-industry trade. When a nation concurrently imports and exports items that are comparable in nature, this is Intra-Industry Trade (Benny, J et al., 2024). This paper focuses on two key directions: (i) to analyse the trade flow of the Indian manufacturing sector, (ii) to examine the government policies and regulations that are affecting trade in the manufacturing industry. To encourage industrial exports, the Indian government has implemented several recent policy adjustments and these adjustments are beginning to show results. The government has specifically made it simpler for foreign businesses to invest in India and has offered several incentives to companies that export goods from India. The trade patterns of the manufacturing sector have changed over time. Many economies relied on imports during the early stages of industrialisation to supply the domestic demand for manufactured goods (Goldar et al., 2020). Protectionist policies and initiatives characterised manufacturing trade during the Industrial Revolution. To protect domestic industries, mercantilist policies encouraged the export of finished goods while limiting imports. Following independence, many developing nations adopted ISI policies that encouraged domestic manufacturing while reducing imports (Ebenyi Go et al., 2017).

With less exposure to international markets, trade patterns changed to self-sufficiency in manufactured goods. With economies embracing liberalisation, they shifted towards export-led growth strategies in the late 20th Century. Global competition among manufacturing sectors increased exports and foreign investment (Krueger, 1978). This paper is organised as follows: The study presents the introduction, followed by the second section, a review of the literature surrounding the Indian manufacturing sector and policies. The third section explains the research methodology adopted for the study, while the fourth section presents the results, which include the analysis of the trade flow of the Indian manufacturing sector and the government policies and strategies that influence it. The last section contains the conclusion of this paper.

LITERATURE REVIEW

The trade in manufactured goods contributed to economic expansion in underdeveloped countries. (Alessandrini et al., 2009) point to East Asia's export-led growth model as proof of the mutually reinforcing relationship between trade openness and economic growth, whereas (Rodrik, 2006) contends that trade changes the size and composition of industrial sectors. These results highlighted how crucial trade integration is to long-term growth. The increasing importance of global production networks serves as another example of how trade affects the makeup of industries. According to (Gabriel, 2019), the growing fragmentation of production across borders is reflected in the heavy reliance on intermediate goods by industries like electronics and automobiles. This is further supported by (Baldwin, 2016), who points out that global value chains (GVCs) have changed the nature of commerce by reorienting attention from final items to intricate cross-border production procedures. Policies promoting trade liberalisation have also had a significant impact on industry. Although (Kaushal, 2022) notes that nations often become wealthier as they trade more, (Topalova & Khandelwal, 2011) show that reforms increase manufacturing capacity. In line with the global trend of policy-driven integration, India's own liberalisation initiatives, such as tariff reductions and free trade agreements (FTAs), have increased investment and manufacturing trade (IBEF, 2023; World Bank, 2023). India's manufacturing industry has grown quickly and now accounts for a sizeable portion of the country's GDP (WTO, 2020). The promotion of domestic manufacturing and exports has been largely facilitated by programs like Make in India and Production-Linked Incentives (PLIs). Achievements in sectors like consumer durables, pharmaceuticals and automobiles are highlighted by (Jain et al., 2022). Comparative studies highlight fundamental flaws in export competitiveness; hence, ongoing trade deficits continue to be a problem (Sharif et al., 2016). Lastly, academics stress the necessity of using systematic frameworks to gauge competitiveness. According to (Cernat, 2015) and (Farole et al., 2010), firm-level data and modern policy analysis techniques are crucial for comprehending changing trade dynamics. This viewpoint emphasises how crucial it is to use increasingly complex indicators to assess India's competitiveness in the global manufacturing market.

RESEARCH METHODOLOGY

This study examines trade data from 2010 to 2023 to identify patterns in trade flows and the composition of exports in the Indian manufacturing sector. The data were collected from the international databases of the WTO (World Trade Organisation), WITS (World Integrated Trade Solution) and the Ministry of Commerce and Industry. This data collection allows for a comprehensive overview of trade patterns and economic contributions within the manufacturing sector. To identify the patterns of trade flow, use the Grubel-Lloyd Index.

$$\text{GL Index} = 1 - \frac{|X - M|}{X + M}$$

X = Export and M = Import

Intra-Industry Trade Trends in the Indian Manufacturing Sector

Table 1 IIT Classification

Class Name	Range	Description
Class 1	0.00 <GLI<0.25	One-sided trade
Class 2	0.25<GLI<0.50	One- sided trade
Class 3	0.50<GLI<0.75	Weak intra-industry trade
Class 4	0.75<GLI<1.00	Strong intra-industry trade

Source- (Benny, J et al., 2024).

To contextualise the findings within the existing research on trade dynamics, economic development, and policy impacts in manufacturing sectors, a comprehensive literature review is conducted. The results are analysed to ascertain the extent to which changes in trade patterns are indicative of broader economic trends and government initiatives designed to improve India's competitiveness in global manufacturing.

RESULTS AND DISCUSSION

1. To Identify the Trade Flow of the Indian Manufacturing Sector

In 2022-23, India exported approximately $450 billion of goods and $323 billion of services (Ministry of Commerce and Industry, 2023). With $437.11 billion in manufacturing trade in US dollars and $675.43 billion in imports for the 2023-24 fiscal year, India is one of the largest trading partners. A key pillar of the nation's economic growth is the manufacturing sector. Before the pandemic, Manufacturing in India accounted for 16–17 per cent of the country's GDP and is expected to increase at one of the fastest rates. With over 27.3 million workers and 17 per cent of the country's GDP, India has the potential to become a significant global manufacturing powerhouse and export items valued at US$1 trillion by 2030. By 2025, the Indian government aims for manufacturing to account for 25% of total economic production. With a 6.03 per cent increase, manufacturing exports reached their greatest annual export of US$447.46 billion in FY23, surpassing the previous year's record export of US$422 billion in FY22.

Table 2 Manufacturing Sector Growth With AGR, CAGR and AAGR

Year	Share of Manufacturing Sector in Total GDP (%)	Manufacturing Output (USD Billions)	AGR (Per cent)
2010	17.03	285.36	3.11
2011	16.14	294.23	-1.75
2012	15.82	289.08	-2.03
2013	15.25	283.21	8.47
2014	15.07	307.21	6.71
2015	15.58	327.82	6.13
2016	15.16	347.94	14.44
2017	15.02	398.20	1.01
2018	14.88	402.24	-5.14
2019	13.46	381.55	-1.01
2020	14.12	377.70	20.56
2021	14.38	455.36	-3.35
2022	13.12	440.06	3.57
2023	12.93	455.77	3.11
CAGR (Per Cent)		0.036	
AAGR (Per Cent)		3.902	

Source: World Trade Organisation, (2010-2023)

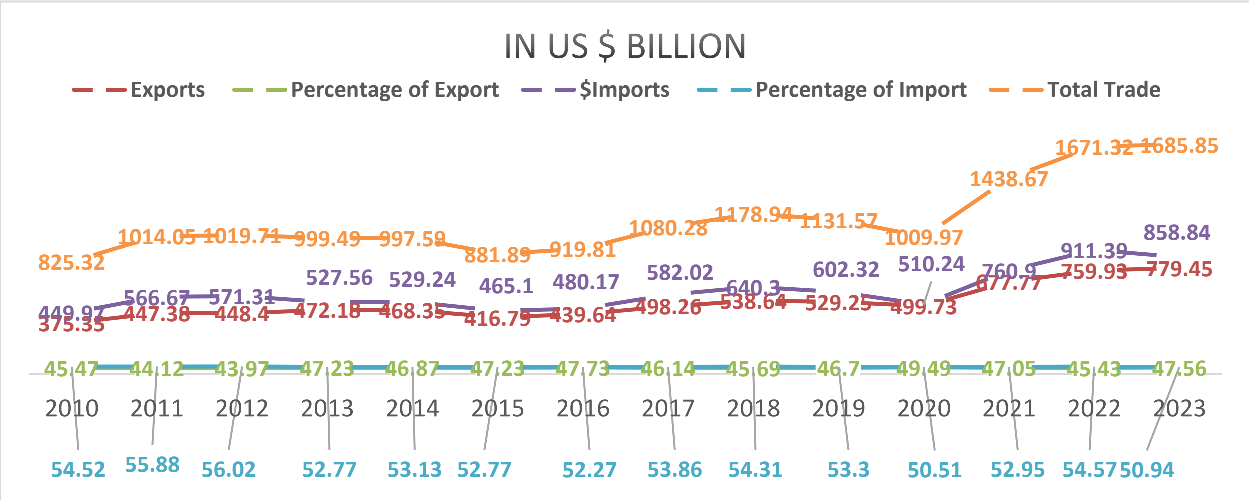
AGR= *Manufacturing Output- Manufacturing Output*$_{-1}$/ *Manufacturing Output**100

AAGR= ∑*AGR*/*n*

CAGR= (*Ending Period*/ *Initial Period*)^(1/*n*)-1

The above table shows India's manufacturing sector from 2010 to 2023 reveals that, although manufacturing output increased significantly from 285.36 to 455.77, its percentage of the nation's GDP decreased from 17.03% to 12.93%, indicating a structural shift in the economy toward the service sector. After a period of considerable volatility from 2010 to 2013 and a period of robust expansion from 2014 to 2018, the manufacturing output's annual growth rate (AGR) varies greatly, reaching a peak of 14.45% in 2017. A slowdown and contraction occurred in 2019 and 2020 as a result of the COVID-19 shock and demand constraints. The sector development remained unequal even after a substantial turnaround in 2021 (20.56%). The primary cause of the extraordinarily high growth rate of manufacturing output in 2021 (20.56%) is the base effect resulting from the significant contraction in 2020 brought on by the COVID-19 pandemic. Due to supply-chain interruptions, decreased demand and nationwide lockdowns, industrial activity declined in 2020, resulting in a low base year. As a result, the economy's reopening, the recovery of both domestic and foreign demand and governmental support measures in 2021 caused manufacturing output to strongly rebound, resulting in an exceptionally high growth rate for the year. In light of this, the growth rise in 2021 represents post-pandemic recovery rather than a long-term structural improvement in manufacturing performance. The calculated AAGR (3.90%) and CAGR (3.67%) show that manufacturing has expanded steadily in absolute terms, but not enough to improve its relative contribution to GDP. Overall, the findings demonstrate that India's manufacturing sector is experiencing moderate growth, extreme volatility and a decline in structural significance. This emphasises the necessity of an export-oriented industrial strategy and more policy assistance.

Figure 1: Trade Performance (Export, Import, Total Trade)



Source: World Bank 2022, Various Years (2010-2023)

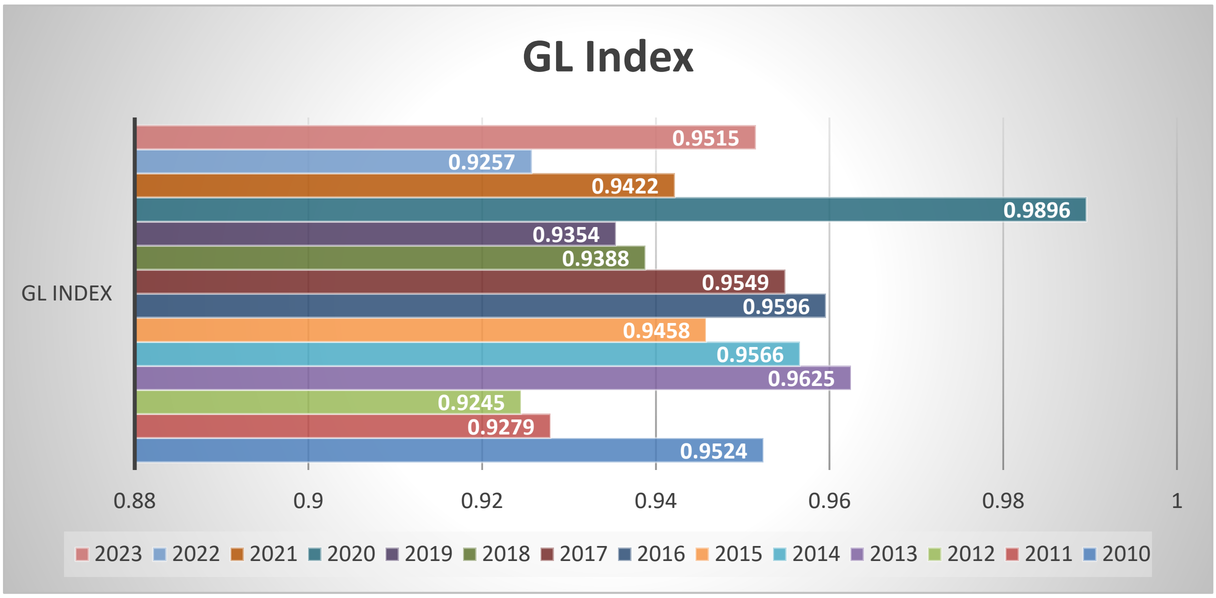
Percentage of Export = Export/Total Trade * 100
Percentage of Import = Import / Total trade * 100

Figure 1 provides a comprehensive overview of trade performance, including exports, imports and total trade, spanning the period from 2010 to 2023. The data reflect trends in exports, imports and total trade volume, offering valuable insights into India's dynamics during this period. The growth trajectory signifies India's increasing integration into the global economy. A key highlight during this period was the significant surge in trade, which led to the total trade volume approaching the $1 trillion mark. However, a noticeable dip occurred in 2015, when total trade fell to $ 881,89 billion. The decline is likely attributable to the global economic slowdown, which has adversely affected trade flows across many countries, including India. Following the slump in 2015, Indian trade performance rebounded strongly. By 2018, total trade had reached a new peak of $1,117.94 billion. A revival in global demand and robust domestic economic activity drove this growth. Between 2018 and 2020, trade volumes declined again, culminating in a significant drop in 2020. This decline is primarily attributed to the economic disruptions caused by the COVID-19 pandemic, which led to widespread lockdowns, supply chain breakdowns and contractions in global demand and investment.

Despite the decline in absolute trade volumes, 2020 is noteworthy for its balanced trade composition. Exports accounted for 49.49 per cent of total trade, while imports constituted 50.51 per cent, resulting in the narrowest trade gap during the 13 years. This rare equilibrium in trade flows suggests a temporary convergence of export and import values, possibly due to the simultaneous contraction in demand and supply. The subsequent years, 2021 and 2022, witnessed a remarkable recovery. Exports and imports surged to their highest recorded levels, signalling a strong rebound in global and domestic economic activity. The rapid recovery indicates the resilience of India's trade sector and the restoration of supply chains and global trade routes. In particular, import growth during this period was more pronounced than export growth. From 2020 to 2022, imports increased by over $400 billion, while exports grew by more than $260 billion. This disparity contributed to the persistence of India's trade deficit, a structural feature observed throughout the dataset. Overall, the data illustrate that India has significantly expanded its participation in global trade over the past decade, nearly doubling its total trade volume. Although the country consistently recorded a trade deficit throughout this period, 2020 stood out as a year of near balance, highlighting a unique moment of convergence in trade flows. The trends also demonstrate that export and import movements closely mirror each other, suggesting that common economic factors—

such as oil prices, currency fluctuations, or global economic cycles simultaneously affect both components of trade. India's trade performance from 2010 to 2023 has reflected steady growth, temporary shocks and an impressive recovery. Despite structural trade imbalances, the resilience shown in the post-pandemic period reaffirms India's growing stature in global trade. The insights from this dataset are critical for understanding the Indian trade policy trajectory, industrial competitiveness and integration with global markets.

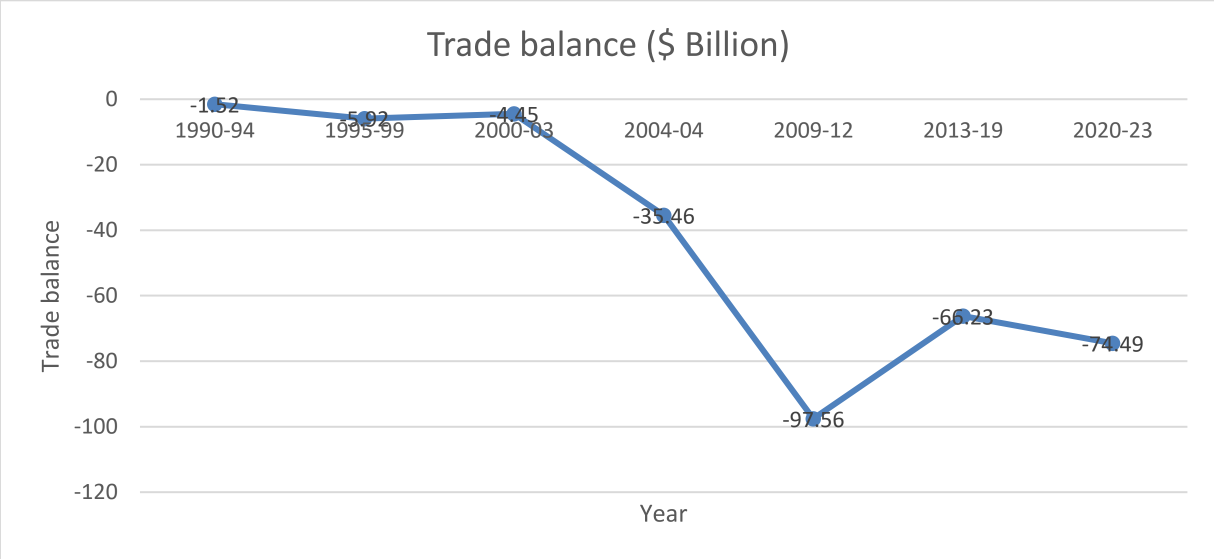
Figure 2: Grubel Lloyd Index (2010- 2023)



Intra-Industry Trade = $1- \frac{|X-M|}{X+M}$

Figure 3 illustrates the Grubel Lloyd Index, a widely used measure of intra-industry trade. The index, which ranges from 0 to 1, assesses the extent to which exports and imports within the same industry are balanced. A higher value of the GL index signifies a greater degree of intra-industry trade, where a country simultaneously exports and imports similar types of goods within the same sector. A value of 0 indicates no intra-industry trade, meaning that a country exports or imports a product within an industry, but not both. A value of 1 denotes perfect intra-industry trade, where export and import volumes are equal. As noted by (Veeramani, 2003), the index is helpful in analysing trade among countries with similar factor endowments and at comparable stages of development, where horizontal product differentiation is common. The Grubel-Lloyd Index, presented in Figure 3, reveals that intra-industry trade in the Indian manufacturing sector has been consistently high across all observed years, with index values ranging from 0.879 to 0.990**.** This persistently high range underscores that India's trade is increasingly characterised not just by exporting primary or finished goods and importing raw materials, but by active participation in bilateral flows of differentiated but similar products within the same industry. The GL Index reached its peak in 2020 at 0.990, indicating an exceptionally high degree of intra-industry trade during that year. This peak coincides with a period of relative balance between exports and imports, as highlighted in the trade performance data. The year 2020 was marked by substantial disruptions in global trade due to the COVID-19 pandemic**.** Yet, the near-equal share of exports (49.49 per cent) and imports (50.51 per cent) suggests a shift in focus towards importing and exporting closely related or substitute products, possibly for supply chain resilience or strategic diversification. This could reflect India's adaptability and flexibility in manufacturing and trade practices during global uncertainty. IIT dipped slightly in 2021-22 as imports grew faster during the recovery. But in 2023, return to a stable pattern. Although minor fluctuations in the GL Index are observed throughout the timeframe, these are relatively marginal and suggest only minor shifts in the composition or structure of traded goods within industries. The overall trend reflects a robust pattern of intra-industry trade, pointing to an increasingly sophisticated and globally integrated manufacturing sector.

Figure 4: Trade Balance



Source: World Bank, Various Years (1991-23)

Figure 4 presents the average trade balance across seven sub-periods from 1990 to 2023. The result indicates that trade has remained unfavourable throughout the year, with a negative trade balance in all sub-years. The trade balance during the early 1990s is nearly balanced, showing a deficit of -1.52, with limited import exposure and modest export volumes. Between 1995 and 1999, the trade balance was a deficit of $5.92 billion. Imports responded more rapidly than exports, indicating pressures in the external sector during the initial phase of reform. Between 2000 and 2003, a slight improvement was observed, suggesting a temporary shift in the trade balance as exports expanded alongside increased integration. A sharp deterioration in trade occurred during the period from 2004 to 2008. The deficit is reflected at -34.46 due to import-intensive growth, rising crude oil prices, and increased demand for capital and intermediate goods. The period from 2009 to 2012 records the most significant average trade deficit, coinciding with the global financial crisis. Imports rebounded faster than exports, exposing structural weakness in export competitiveness. Between 2013 and 2019, the deficit narrowed compared to the previous year, but it remained structurally high. Policy initiatives aimed at boosting manufacturing and exports were produced. During the 2020-23 period, the trade balance deteriorated again to -74.49, a decline in the post-pandemic period. While 2020 shows a temporary improvement due to import compression, the recovery phase is marked by record import growth, leading to renewed deficits. The figure shows that trade has been persistently unfavourable over the entire study.

2. Government Policies and Strategies that Affect Trade in the Manufacturing Industry

2.1. Government Policies- To boost the manufacturing industry and attract more domestic and international investment, the Indian government has implemented several initiatives. Among these are the Phased Manufacturing Programme (PMP), the corporate tax cut, the FDI policy reforms, the reduction of compliance burdens, the adoption of business-facilitating initiatives, the Goods and Services Tax, the corporation tax cut and policy steps to increase domestic manufacturing through public procurement orders. All relevant ministries of the Indian government have established Project Development Cells (PDCs), an institutional framework designed to expedite investments. Beginning with fiscal year (FY) 2021–2022, the Union Budget 2021–2022 has allocated INR 1.97 lakh crore (approximately US$26 billion) for PLI initiatives across 14 significant industrial sectors. The implementation of the Production Linked Incentive (PLI) Scheme in several Ministries and investment possibilities are additional steps the administration has taken to enhance the economic climate and reverse the disruption created by COVID-19. under the India Industrial Land Bank (IILB), the Industrial Park Rating System (IPRS), the National Monetization Pipeline (NMP) and the National Infrastructure Pipeline (NIP), and the National Single Window System (NSWS) soft launch.

This is done in keeping with India's vision of becoming "Atmanirbhar" and enhancing Indian manufacturing capabilities and exports. Significant increases in output, employment, skills, economic growth, and exports are anticipated over the next five years and beyond with the introduction of PLI Schemes. The government's reforms have increased the nation's foreign direct investment (FDI). In 2014-2015, foreign direct investment (FDI) inflows into India were US$45.15 billion. Since then, these inflows have steadily risen, reaching a record high of US$84.84 billion (provisional data) in the fiscal year 2021-2022 (Ministry of Commerce and Industry, 2022).

The government of India has undertaken various steps to promote the manufacturing sector and boost domestic and foreign investments in the country. These include the introduction of the Goods and Services Tax, reduction in Corporate tax, interventions to improve the ease of doing business, FDI policy reforms, measures to reduce compliance burden, policy measures to boost domestic manufacturing through public procurement orders, the Phased Manufacturing Programme (PMP), and others (Baldwin, 2011). The series of measures taken by the government to improve the economic situation and convert the disruption caused by COVID 19 into an opportunity for growth includes Atmanirbhar packages, introduction of Production Linked Incentive (PLI) Scheme in various Ministries, investment opportunities under National Infrastructure Pipeline (NIP) and National Monetisation Pipeline (NMP), India Industrial Land Bank (IILB), Industrial Park Rating System (IPRS), soft launch of the National Single Window System (NSWS), etc. An institutional mechanism to fast-track investments has been implemented through Project Development Cells (PDCs) in all relevant Ministries/Departments of the Government of India. Keeping in view India's vision of becoming 'Atmanirbhar' and to enhance India's Manufacturing capabilities and Exports, an outlay of INR 1.97 lakh crore (over US$26 billion) has been announced in the Union Budget 2021-22 for PLI schemes for 14 key sectors of manufacturing, starting from fiscal year (FY) 2021-22. With the announcement of the PLI Schemes, significant growth is expected in production, skills, employment, economic development, and exports over the next five years and beyond. The reforms implemented by the government have led to increased Foreign Direct Investment (FDI) inflows in the country. FDI inflows in India stood at US$45.15 billion in 2014-2015 and have continued to improve since then. India registered its highest annual FDI inflow of US$84.84 billion (provisional figures) in 2022. According to the Economic Survey 2021-22, the manufacturing sector has experienced positive overall growth in Gross Value Added (GVA) despite disruptions related to the COVID-19 pandemic. The total employment in this sector has increased from 57 million in 2017-18 to 62.4 million in 2019-20.

2.2. Trade Strategies- Industrial producers must have a through long-term plan to assist them in becoming more resilient in the face of evolving trade environments. Business executives anticipate refocusing their efforts on operational enhancements and concentrating on formulating long-term growth-oriented choices. The five strategies listed below can help you build resilience and prepare for the changing global trade environment (Scheuerman et al., 2019).

- **Analyse and improve the trade process -** Manufacturers involved in international commerce should continue to deal with a complex web of complicated import and export rules. Thus, it is essential to analyse and enhance trade operations. These must be negotiated appropriately to ensure compliance and capitalise on cost-saving opportunities. Manufacturers can improve operational and resource efficiency by optimising trade procedures and automating trade compliance, while also addressing global trade risks. Process standardisation and automation can provide a firmer foundation for reaping the benefits from unique trade programs available worldwide. Success for a manufacturer may depend on successfully integrating import and export procedures into overarching corporate objectives, tax planning, and supply chain management (Sharif et al., 2016). The growth of global value chains (GVCs) has further redefined trade patterns in the manufacturing industry. Industries are no longer restricted to producing finished goods within national borders; they participate in complex production networks, sourcing parts and services from different nations. The size and composition of trade flows have changed due to this specialisation trend within GVCs (Baldwin, 2016).

- **Manage supply chain risks** - Manufacturers should consider building connections with small and medium-sized vendor companies, offering assistance and access to financing to reduce single points of failure. Manufacturers should assess the degree of risk associated with essential suppliers and components, and have the flexibility to adjust inventory levels in the event of disruptions.

- **Leverage advanced digital technologies** to help increase productivity and simplify corporate processes. Manufacturers may be better positioned to handle trade volatility by automating internal processes, optimising workflows, implementing intelligent management systems, and employing data analytics to make data-driven decisions. For instance, transportation, logistics, and supply chain operators use digital technologies to automate tedious activities. For example, United Parcel Service Inc. employs a platform to determine the most effective delivery route for its drivers, who usually make 120 daily stops.

- **Realign talent strategy -** The majority of manufacturers continue to place a high priority on talent and training, which are also seen as one of the biggest challenges to future growth. Manufacturing executives may wish to reconsider their approach to personnel management by investing in training and preparing their employees for production shifts, particularly in the technological and digital skills essential for future competitiveness. Manufacturers may consider establishing training and upskilling talent base camps in more modern locations where workers lack the technical skills necessary for creative manufacturing.

CONCLUSION

The evolution of the Indian trade and manufacturing landscape since liberalisation reveals a story of remarkable expansion, increasing complexity and greater global integration. Between 1991 and 2023, India's exports and imports experienced exponential growth, marking a significant transformation into a major player in international trade. Manufacturing's share of GDP has decreased from 17.03% to 12.93%, illustrating the economy's shift toward services, despite the fact that its output has increased significantly in absolute terms, from USD 285.36 billion in 2010 to USD 455.77 billion in 2023. India's increased integration into international markets is demonstrated by the nearly twofold increase in trade volumes over the period, which brought total commerce close to the USD 1 trillion level. The consistent increase in trade volume, despite fluctuations caused by global crises such as the 2008 financial downturn and the 2020 COVID-19 pandemic, reflects the resilience and adaptability of India's trade ecosystem. The trade balance observed in 2020 highlights how global shocks can rebalance trade flows through structural deficits that persist in regular times. The Grubel Loyd Index further reveals that India has moved beyond traditional interindustry trade to embrace significant intra-industry trade, with the index consistently ranging from 0.879 to 0.990. This reflects the economy's increasing participation within the same industry, an indicator of industrial upgrading and deeper trade integration. The peak of the GL index in 2020 also aligns with a balanced trade structure that year, reinforcing the observation of product-level symmetry in India's trade flow. This aligns with the post-liberalisation trade story of expansion, structural transformation, and increased interdependence with the global economy.

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Reframing Conflict Management for Industry 5.0: Integrating AI-Driven Communication with Human-Centric Mediation through the AICMM Framework

Ms. G. Priyanka[1], Dr. Mohammed Bakhtawar Ahmed[2]
[1]Faculty, KK Modi University, Durg
[2] Head of Department, KK Modi University, Durg

Abstract

The rapid expansion of artificial intelligence (AI) and digitally mediated communication platforms has reshaped interpersonal dynamics and conflict behavior in both organizational and social contexts. Classical conflict management theories, originally designed for face-to-face interactions, do not account for the complexities of algorithmic content curation, asynchronous communication, and the loss of emotional cues that characterize modern digital environments. Industry 5.0 introduces a human-centric paradigm that emphasizes emotional sustainability and meaningful human–AI collaboration, making it essential to revise existing conflict frameworks.

This study examines emerging conflict triggers within AI-driven communication ecosystems and introduces the AI-Integrated Conflict Management Model (AICMM)—a hybrid, human-AI conflict governance system. A mixed-method approach, including a digital conflict survey of n = 186 participants and digital ethnography, identifies four dominant influences: emotional cue loss, algorithmic visibility bias, digital fatigue, and a gap between trust in autonomous AI and openness to AI-assisted mediation. The results empirically validate AICMM's pillars—Algorithmic Empathy, Adaptive Digital Mediation, Emotional Recalibration, and Ethical Transparency—and propose a future-ready conflict framework for Industry 5.0 communication ecosystems.

**Email: priyanka23ganni@gmail.com*

Keywords: digital conflict, Industry 5.0, AI-mediated communication, human–AI collaboration, conflict management, AICMM

INTRODUCTION

Conflict remains a fundamental aspect of human interaction, traditionally studied within the context of face-to-face communication involving tone, gesture, and complex nonverbal cues (Deutsch, 1973). However, contemporary digital communication—spanning messaging apps, email chains, virtual workspaces, and AI-powered platforms—has disrupted this paradigm. These digitally mediated interactions reduce emotional visibility, increase ambiguity, and often produce misunderstanding due to missing paralinguistic cues.

Industry 5.0 represents a shift where advanced technology coexists with human-centered values, emotional well-being, and ethical engagement (European Commission, 2021). As digital interactions increasingly involve algorithmic filtering and AI-based mediators, traditional conflict management theories fall short in addressing the new psychological, technological, and communicative dynamics.

This paper revisits foundational theories through an Industry 5.0 lens, analyzes digital conflict behaviors empirically, and presents a hybrid human–AI conflict governance model.

RESEARCH QUESTIONS

This study addresses the following:

1. How do AI-driven and digitally mediated communication systems challenge classical conflict theories?
2. What new conflict triggers emerge in Industry 5.0 communication environments?
3. How can a hybrid human–AI framework improve conflict management outcomes?

REVIEW OF CLASSICAL CONFLICT MANAGEMENT MODELS

1. Thomas–Kilmann Conflict Modes (TKI)

The Thomas–Kilmann Conflict Mode Instrument (TKI) categorizes conflict-handling behavior across two dimensions—assertiveness and cooperativeness—resulting in five styles: competing, collaborating, compromising, avoiding, and accommodating (Thomas & Kilmann, 1974). The model was designed for contexts where individuals can interpret tone, facial expressions, pacing, and emotional cues.

In digital environments, these cues disappear or are distorted. As a result:
• **Competing** appears harsher in text than intended.
• **Avoiding** may seem disrespectful due to "seen" indicators or delayed responses.
• **Collaborating** is harder due to asynchronous communication and fragmented threads.
• **Accommodating** is less visible without emotional reinforcement.

Additionally, algorithmic filtering affects message visibility and timing, altering how conflict styles are perceived. These disruptions underscore the need for updated models like AICMM that address emotional gaps and algorithmic influence.

2. Rahim's Organizational Conflict Styles

Rahim's (1983) model identifies integrating, obliging, dominating, avoiding, and compromising as core conflict styles, emphasizing openness and participatory communication. Digital platforms, however, reshape each of these:

• **Openness** is constrained by short, context-poor messages.
• **Integrating** becomes challenging due to delays, multitasking, and reduced emotional presence.
• **Dominating** may increase because of online disinhibition.
• **Avoidance** becomes easier through muting, exiting groups, or selective responding.
• **Compromising** is hampered by information overload.

AI moderation complicates these further by flagging or filtering content, sometimes inaccurately interpreting assertive communication as aggression (Lee, 2018). In Industry 5.0 settings, where hybrid digital communication is the norm, Rahim's framework must be updated to account for algorithmic behavior, digital identity, and constant connectivity—dimensions addressed within AICMM's pillars of Adaptive Digital Mediation and Ethical Transparency.

3. Human Needs & Social Identity Approaches

Human Needs Theory (Burton, 1990) emphasizes unmet needs—identity, recognition, belonging, and participation—as core drivers of conflict. Social Identity Theory (Tajfel & Turner, 1979) highlights ingroup-outgroup dynamics based on group affiliations.

Digital ecosystems intensify these dynamics through:

1. **Algorithmic clustering**, which reinforces echo chambers and polarizes groups.
2. **Reduced expressive nuance**, making it harder to communicate unmet needs without misunderstanding.
3. **Algorithmic bias**, where automated moderation may misinterpret language from certain groups.
4. **Anonymity**, enabling identity fluidity that can reduce empathy or escalate hostility.
5. **Emotional distancing**, as identities represented through text or avatars weaken interpersonal understanding.

Industry 5.0's emphasis on human dignity and emotional sustainability requires integrating needs-based and identity-sensitive approaches with AI-aware models. AICMM's focus on Algorithmic Empathy, Ethical Transparency, and Emotional Recalibration directly responds to these challenges.

METHODOLOGY

1. Research Design

A mixed qualitative–quantitative design was used, combining theoretical analysis, digital ethnography, and a structured survey.

2. Participants & Procedure

A total of **186 participants** from online collaboration platforms (Slack, Microsoft Teams, WhatsApp groups, email) completed an 8-item Likert-scale questionnaire measuring digital conflict experiences.

3. Measures

The instrument captured:

- Emotional cue loss
- Misinterpretation
- Digital fatigue
- Algorithmic fairness concerns
- AI trust
- AI-mediated conflict preferences

4. Analysis

Descriptive statistics and thematic coding of online behaviors guided interpretation.

RESULTS

1. Overall Digital Conflict Experience

Participants reported significant conflict challenges across digital environments. Digital fatigue received the highest rating ($M = 4.3, SD = 0.6$), followed by misinterpretation ($M = 4.2$), and absence of nonverbal cues (*M = 4.1*). Chatbot trust was low (*M = 2.6*), while interest in AI-assisted mediation was moderate-high (*M = 3.8*).

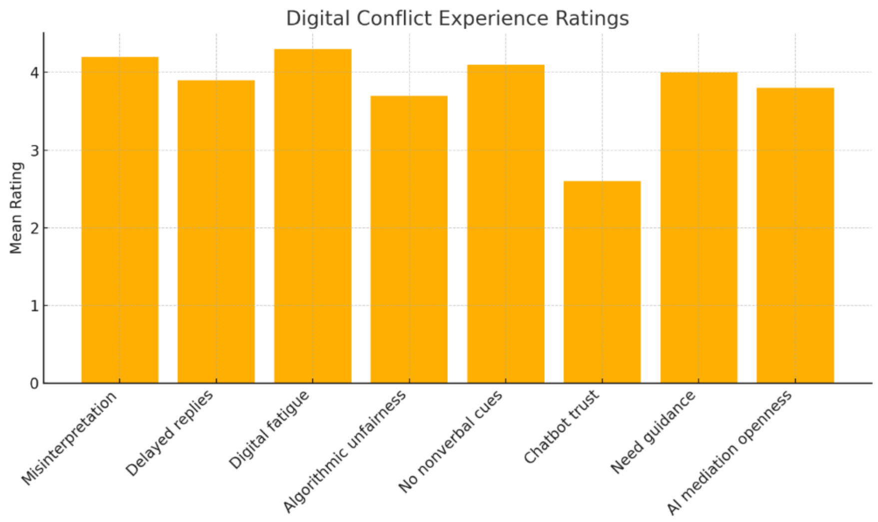

Figure 1. Digital Conflict Experience Ratings

These results show strong dissatisfaction with AI-only mediators but considerable openness toward hybrid support systems.

2. Emotional Cue Loss as a Trigger for Escalation

The second cluster (Figure 2) highlights the influence of missing emotional cues:

- Misinterpretation of tone (*M = 4.2*)
- Lack of nonverbal cues (*M = 4.1*)
- Delayed response anxiety (*M = 3.9*)

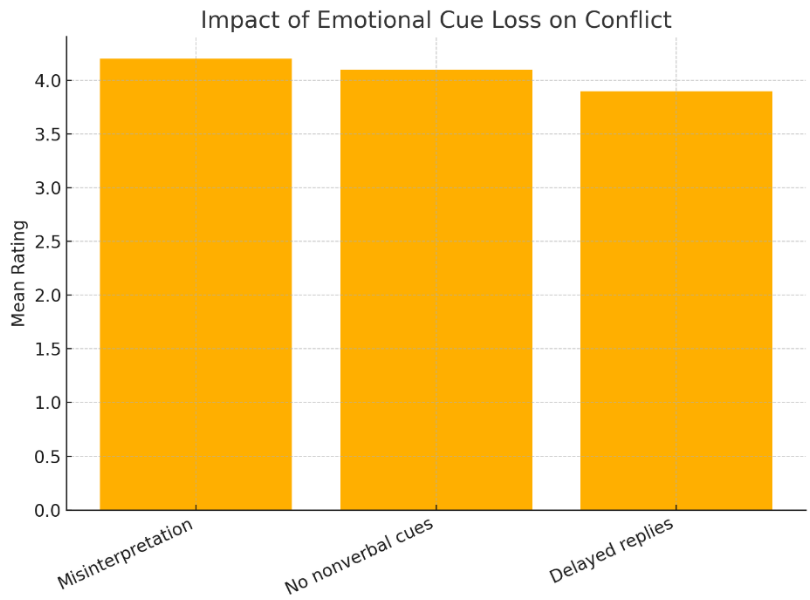

Figure 2. Impact of Emotional Cue Loss on Conflict Escalation

This confirms that emotional ambiguity is a central catalyst in digital conflict, supporting the need for **Algorithmic Empathy**.

3. Perceived Algorithmic Unfairness

A moderate mean of **3.7** indicates that participants believe algorithms influence communication through:

- Message ranking
- Notification prioritization
- Automated moderation

This validates **Ethical Transparency** as a crucial design principle.

4. Trust Gap Between Autonomous AI and AI-Assisted Mediation

Participants expressed low trust in chatbots (*M = 2.6*) but high openness to AI-supported conflict assistance (*M = 3.8*).

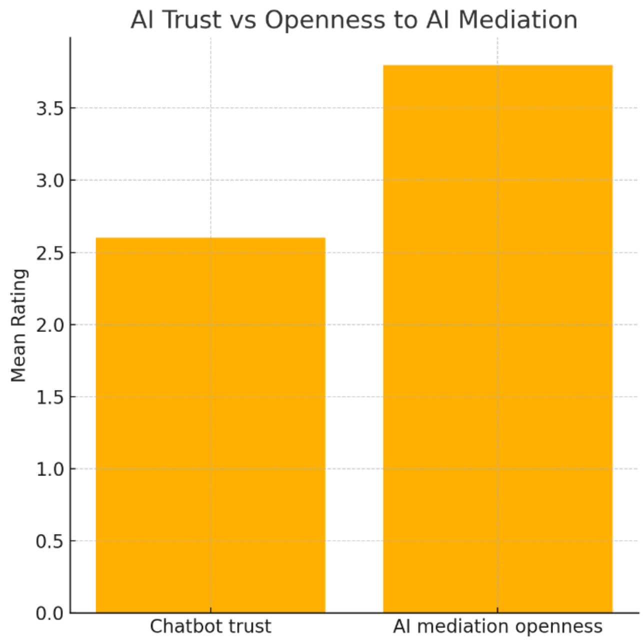

Figure 3. Trust in Chatbots vs Openness to AI-Assisted Mediation

This supports AICMM's principle of **Adaptive Digital Mediation**, where AI assists but does not replace human facilitators.

5. Digital Fatigue and Impulsive Reactivity

Digital fatigue was the most prominent issue, with:

- **82%** reporting cognitive overload
- **66%** admitting impulsive reactions under strain

These findings justify **Emotional Recalibration**, which integrates cooldown features, pacing mechanisms, and reflective prompts.

6. Summary of Empirical Alignment With AICMM

AICMM Pillar	Empirical Evidence & Interpretation
Algorithmic Empathy	*78% of participants* reported frequent misinterpretation of digital messages due to missing emotional and nonverbal cues. This indicates a strong need for AI capable of detecting sentiment, tone patterns, and contextual emotions to reduce ambiguity and prevent unnecessary escalation.
Adaptive Digital Mediation	*70% expressed preference* for structured, guided communication features such as AI-generated prompts, reframing suggestions, and conflict de-escalation cues. This illustrates user willingness to rely on AI as a facilitator—not a replacement—for conflict resolution.
Emotional Recalibration	*82% reported digital fatigue* and *66% acknowledged impulsive reactions* under cognitive overload. This highlights the value of AI-driven emotional regulation tools, such as cooldown timers, reflective prompts, and well-being reminders.
Ethical Transparency	*59% perceived algorithmic bias* in message visibility, prioritization, or moderation. This demonstrates the need for explainable AI, transparent ranking mechanisms, and user control over algorithmic processes during conflict situations.

DISCUSSION

The findings of this study show that conflict in digital ecosystems arises from a combination of **emotional ambiguity, cognitive strain, and algorithmic filtering**. Unlike traditional face-to-face communication where individuals rely on tone, facial expressions, and nonverbal cues, digital environments remove these signals, leading to higher misinterpretation. The high ratings for misinterpretation (M = 4.2) and absence of nonverbal cues (M = 4.1) confirm that emotional cues are critical to conflict regulation and their absence accelerates escalation.

Digital fatigue emerged as a significant psychological factor. With 82% of participants reporting cognitive overload and 66% acknowledging impulsive reactions, it is clear that constant connectivity reduces emotional regulation. This aligns with literature suggesting that overload narrows attentional capacity and increases reactivity in online conversations.

Algorithmic filtering adds a structural layer to conflict. Participants' perception of algorithmic unfairness (59%) indicates that message visibility, prioritization, and automated moderation can unintentionally distort communication. Unlike classical conflict theories, digital environments involve non-human agents—algorithms—that shape the communication landscape, often without user awareness.

Together, these findings highlight a conceptual gap in traditional models such as Thomas–Kilmann, Rahim's conflict styles, and Human Needs Theory. These models assume synchronous communication, full emotional context, and neutral channels. Industry 5.0 environments, however, are characterized by **hybrid human–AI interactions** and algorithmically governed communication flows.

The AICMM framework addresses these limitations. It incorporates *Algorithmic Empathy* to compensate for emotional cue deprivation, *Adaptive Digital Mediation* to guide users during escalation, *Emotional Recalibration* to counter digital fatigue, and *Ethical Transparency* to reveal how algorithms influence conflict trajectories.

In summary, the convergence of emotional, cognitive, and algorithmic challenges demonstrates the need for a hybrid conflict governance system. The empirical evidence strongly supports AICMM as a robust and essential model for conflict resolution in digital-first, Industry 5.0 communication environments.

THE AI-INTEGRATED CONFLICT MANAGEMENT MODEL (AICMM)

AICMM is a human–AI conflict management framework designed for Industry 5.0 environments, where digital communication, automation, and human emotions intersect. The model positions AI as a supportive partner that enhances clarity, fairness, and emotional stability rather than replacing human decision-making. It comprises four interconnected pillars:

1. Algorithmic Empathy

Algorithmic Empathy uses AI to detect emotional tone, sentiment shifts, and contextual cues that are lost in digital text. Through sentiment analysis, tone suggestions, and warnings before sending emotionally charged messages, AI helps reduce misinterpretation and restores emotional nuance in communication.

2. Adaptive Digital Mediation

This pillar involves AI-guided communication structures that support users during conflict. Features include suggested rephrasing, turn-taking guidance, escalation alerts, and automated conversation summaries. Adaptive Digital Mediation creates more balanced and constructive dialogue without replacing the human role in conflict resolution.

3. Emotional Recalibration

Emotional Recalibration addresses cognitive overload by embedding cool-down timers, reflection prompts, and well-being reminders into communication platforms. These tools help users regain emotional balance before responding impulsively and promote healthier digital interaction patterns.

4. Ethical Transparency

As algorithms shape message visibility and moderation, Ethical Transparency ensures that users understand how AI influences communication. Explainable AI, fairness audits, and user control over filters make digital conflict processes predictable and trustworthy, reducing perceptions of bias.

Together, these pillars provide a comprehensive, future-ready conflict management system tailored to Industry 5.0. AICMM enhances emotional clarity, supports constructive communication, mitigates digital fatigue, and ensures fairness in AI-influenced environments, making it an essential framework for resolving conflicts in digitally mediated settings.

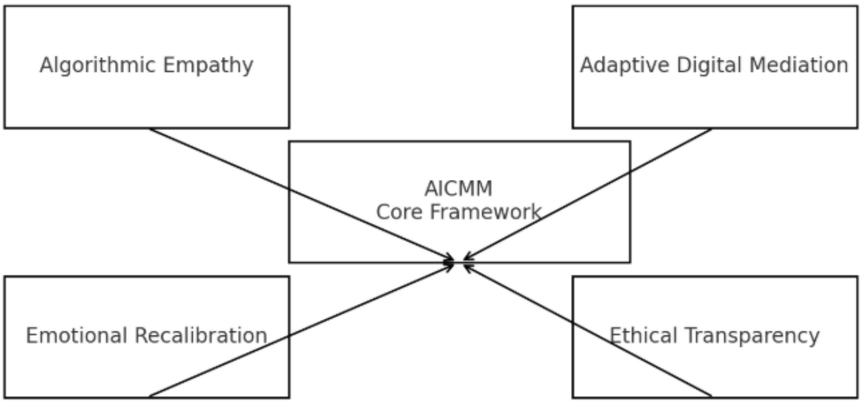

Figure 4.

AICMM 3D Model Diagram

PRACTICAL IMPLICATIONS

The findings of this study have significant implications for organizations, educational institutions, and policymakers striving to manage conflict in increasingly digital and AI-mediated environments. As communication ecosystems evolve under Industry 5.0, integrating human-centered values with intelligent systems becomes essential for ensuring psychological safety, fairness, and efficient resolution processes.

1. Organizations

Organizations are now operating within digital-first work cultures where misinterpretation, message overload, and algorithmic filtering shape interpersonal dynamics. AICMM offers several organizational benefits:

• AI-Assisted Grievance Mechanisms

Hybrid human–AI systems can support grievance cells by:
– triaging complaints,
– detecting emotional tone in messages,
– identifying escalation patterns, and
– recommending de-escalation strategies.
This improves response time and reduces subjective bias in conflict evaluation.

• Digital Emotional Intelligence (EI) Training

Employees require new emotional competencies to interpret tone, timing, and intent in digital environments. Digital EI training modules can enhance:
– empathetic communication,
– online professionalism,
– conflict-aware messaging, and
– resilience in remote collaboration.

• Conflict Prediction Dashboards

Using sentiment analysis and communication data, organizations can deploy dashboards that visualize:
– rising tensions within teams,
– toxicity indicators,
– communication fatigue, and
– early-warning triggers.
These predictive tools help managers intervene before minor disagreements escalate.

2. Education

Educational institutions are increasingly reliant on hybrid and digital learning systems, which demand new approaches to student interaction and conflict management.

• VR-Based Conflict Resolution Simulations

Virtual Reality allows students to engage in immersive conflict situations that simulate:
– intercultural communication,
– negotiation under stress,
– cyberbullying prevention,
– emotional regulation during disagreements.
These simulations help learners practice conflict skills in safe, controlled environments.

• Cyber-Conflict Curriculum

Modern learners require explicit training on:
– digital communication ethics,
– online dispute management,
– emotional awareness through text-based interactions, and
– understanding AI's influence on communication.
Embedding such modules prepares students for collaborative digital workplaces.

3. Policy

Government and regulatory bodies must address the ethical and structural dimensions of AI involvement in digital conflict.

• AI Mediation Regulations

Policies are needed to define:
– acceptable uses of AI in dispute resolution,
– transparency standards for algorithmic decision-making,
– consent for AI participation in conflict processes, and
– protections against automated bias.

• Platform Fairness Audits

Audits should evaluate:
– how platform algorithms rank or hide messages,
– whether moderation systems discriminate against speech patterns or identities,
– the mechanisms for reporting unfair algorithmic behavior.
Such audits reinforce user trust and create accountability within digital ecosystems.

CONCLUSION

The transition to digitally mediated communication has fundamentally transformed how conflicts originate, escalate, and resolve. As this study demonstrates, emotional ambiguity, cognitive overload, and algorithmic filtering redefine traditional assumptions of interpersonal conflict. These shifts challenge the adequacy of classical models, which rely heavily on visible emotional cues and synchronous dialogue—conditions rarely present in digital spaces.

The integration of survey data and digital ethnographic observations shows that individuals frequently experience misinterpretation, digital fatigue, and perceived algorithmic unfairness, yet express openness toward AI-supported conflict mediation. These insights reinforce the need for a **hybrid conflict management architecture** aligned with Industry 5.0 values.

The **AI-Integrated Conflict Management Model (AICMM)** offers a comprehensive and future-ready framework that restores empathy, enhances emotional regulation, and ensures fairness in AI-mediated environments. Its pillars—Algorithmic Empathy, Adaptive Digital Mediation, Emotional Recalibration, and Ethical Transparency—collectively address the psychological and technological complexities of digital conflict.

By bridging human-centered principles with AI capabilities, AICMM contributes to safer, more emotionally intelligent, and ethically governed communication ecosystems. As organizations, institutions, and societies continue to adopt AI-enabled tools, frameworks like AICMM will play a critical role in protecting human dignity, improving communication outcomes, and shaping conflict governance in the era of Industry 5.0.

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Circular Economy Analytics : Machine Learning for Waste Reduction in Manufacturing

Pulak Kumar Palit[1]
[1]Professor, Fostiima Business School

Abstract

The transition to Industry 5.0 represents a paradigm shift that integrates cutting-edge technological capabilities with human-centered values, emphasizing Empathy, Ethics, Equity, and Ecology as foundational principles. This comprehensive research proposal presents an innovative framework for Circular Economy Analytics that leverages advanced machine learning methodologies to achieve substantial waste reduction in manufacturing environments, directly aligning with the sustainability imperatives of Industry 5.0.

**Email: pulak.palit@fostiima.org, pkp_2004@yahoo.com*

Keywords- Circular Economy, Machine Learning, Waste Reduction, Industry 5.0, Predictive Analytics, IoT Sensors, Sustainability, Manufacturing Optimization, Artificial Intelligence, Environmental Impact, Digital Twin Technology, Collaborative Intelligence.

RESEARCH CONTEXT AND SIGNIFICANCE

Manufacturing industries currently generate approximately 3.4 billion metric tons of municipal solid waste annually (World Economic Forum, 2024), with projections indicating this figure will escalate significantly by 2050. The manufacturing sector alone accounts for 45% of global greenhouse gas emissions, while the extraction of raw materials contributes to 53% of worldwide carbon emissions and over 80% of biodiversity loss. These alarming statistics underscore the urgent necessity for transformative approaches that can fundamentally reshape how manufacturing enterprises manage resources and minimize environmental impact.

The circular economy paradigm (Infosys BPM, 2024) offers a revolutionary alternative to the traditional linear "take-make-dispose" model by emphasizing three core principles: designing out waste and pollution, keeping products and materials in continuous use, and regenerating natural systems. However, the implementation of circular economy principles in manufacturing environments faces significant challenges, including the complexity of production processes, the need for real-time decision-making, and the integration of multiple data streams from diverse sources.

RESEARCH OBJECTIVES AND INNOVATION

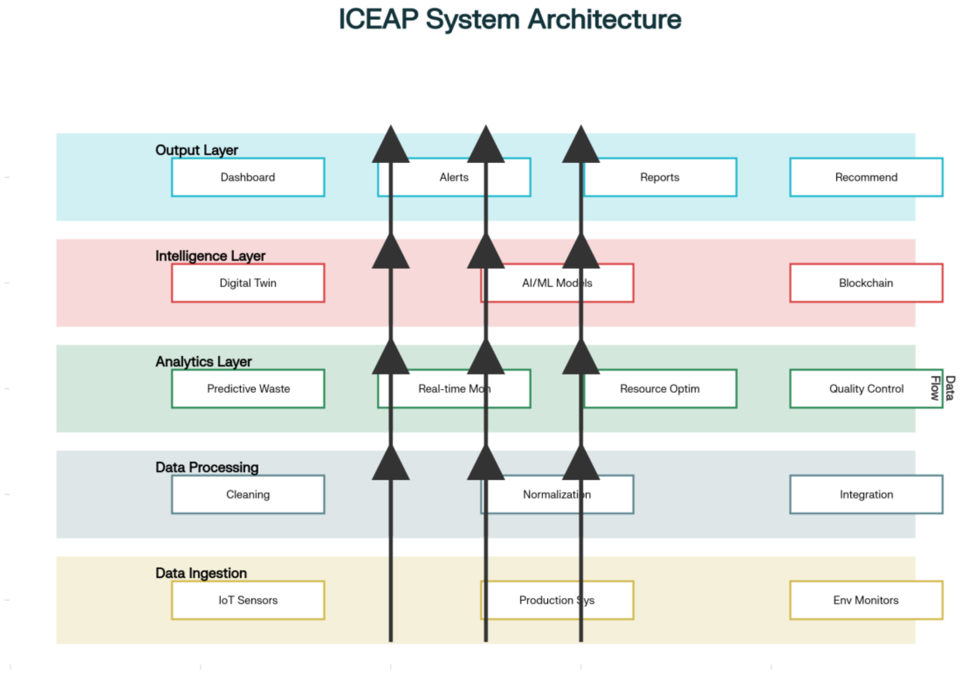
This research proposes the development of an Intelligent Circular Economy Analytics Platform (ICEAP) that harnesses the power of machine learning, Internet of Things (IoT) sensors, and predictive analytics to create a comprehensive waste reduction ecosystem in manufacturing facilities.

Primary Objective: Design and implement a machine learning-driven analytics framework that can achieve 25-40% reduction in manufacturing waste through predictive modeling, real-time monitoring, and automated optimization systems.

Secondary Objectives:

- Develop predictive maintenance algorithms (Softweb Solutions, 2023) that prevent equipment failures and associated waste generation.
- Create intelligent resource allocation systems (Acropolium, 2024) that optimize material usage across production cycles.
- Establish automated quality control mechanisms using computer vision (Omdena, 2024) and AI to minimize defective product generation.
- Implement circular supply chain optimization that maximizes material recovery and reuse.

System Architecture
The ICEAP framework employs a five-layer architecture that seamlessly integrates data collection, processing, analytics, intelligence, and actionable outputs.



*[**Figure 1:** Intelligent Circular Economy Analytics Platform (ICEAP) System Architecture showing five interconnected layers from data ingestion to actionable outputs]*

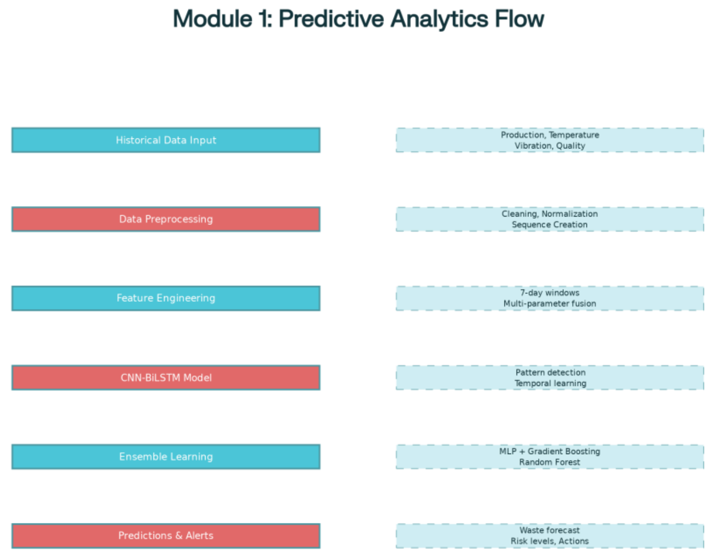
Figure 1 illustrates the comprehensive system architecture, showing how data flows from bottom-layer sensors and production systems through processing layers to top-level dashboards and recommendations. Each layer serves a distinct purpose:

- Data Ingestion Layer: Collects raw data from IoT sensors (IoT For All, 2023), production systems, and environmental monitors.
- Data Processing Layer: Cleanses, normalizes, and integrates diverse data streams.
- Analytics Layer: Houses the four core modules that perform specialized analytics.
- Intelligence Layer: Implements digital twins, AI/ML models, and blockchain (Circularise, 2024) tracking.
- Output Layer: Delivers actionable insights through dashboards, alerts, and reports.

METHODOLOGY AND TECHNICAL FRAMEWORK

The research methodology employs a mixed-methods approach combining quantitative analysis of manufacturing data with qualitative assessment of circular economy implementation challenges. The technical framework consists of four interconnected modules:

Module 1: Predictive Waste Analytics Engine
This module utilizes advanced machine learning algorithms (Syncron, 2024), including Convolutional Neural Networks (CNNs) and Bidirectional Long Short-Term Memory (BiLSTM) networks, to analyze historical production data and predict waste generation patterns. The system processes multiple data streams including sensor readings, production schedules, material specifications, and environmental conditions to generate accurate forecasts of waste production across different manufacturing processes.



*[**Figure 2:** Data flow diagram for Module 1 Predictive Waste Analytics Engine showing the progression from raw data to actionable predictions]*

Data Flow and Processing: Figure 2 demonstrates the sequential processing stages, beginning with historical data input and culminating in actionable waste predictions. The system employs a 7-day sliding window approach, where each sequence captures temporal patterns across multiple parameters.

Sample Input/Output Data for Module 1:

Table 1: *Module 1 Input Data - Historical Manufacturing Parameters*

Date	Production Volume	Machine Temp (°C)	Vibration (mm/s)	Material Quality	Humidity (%)
2025-10-24	1250	72.5	2.3	88	45
2025-10-25	1320	74.2	2.8	85	48
2025-10-26	1180	71.8	2.1	90	43
2025-10-27	1405	75.6	3.2	82	52
2025-10-28	1290	73.1	2.5	87	46

Table 2: *Module 1 Output Data - AI/ML Predictions*

Date	Predicted Waste (kg)	Confidence Interval	Risk Level	Recommended Action
2025-10-29	55.2	±4.8	Medium	Monitor
2025-10-30	58.7	±5.2	Medium	Monitor
2025-10-31	52.3	±4.5	Low	Standard
2025-11-01	64.1	±6.1	High	Inspect Equipment
2025-11-02	56.8	±5.0	Medium	Monitor

The ensemble learning approach combines three complementary models (MLP Neural Network, Gradient Boosting, and Random Forest) to achieve robust predictions with typical accuracy of MAPE < 9%. The system provides not only waste forecasts but also confidence intervals and risk-stratified recommendations, enabling proactive operational adjustments.

Module 2: Real-Time Monitoring and IoT Integration

The platform integrates a comprehensive network of IoT sensors deployed throughout the manufacturing facility to monitor fill levels, weight, temperature, vibration, and material flow in real-time. Advanced radar-based sensor technology, enhanced with AI interpretation capabilities, provides detailed data capture that enables precise identification of waste types and optimization opportunities. The system leverages Low-Power Wide-Area Networks (LPWANs) to transmit sensor data to cloud-based analytics platforms for immediate processing and response.

Sample Input/Output Data for Module 2:

Table 3: *Module 2 Input Data - IoT Sensor Readings*

Sensor ID	Sensor Type	Location	Raw Reading	Unit
IoT-001	Temperature	Line-A	73.5	°C
IoT-002	Vibration	Line-B	2.8	mm/s
IoT-003	Fill Level	Bin-1	78	%
IoT-004	Weight	Bin-2	450.2	kg
IoT-005	Flow Rate	Pipe-3	125.5	L/min

Table 4: *Module 2 Output Data - AI-Powered Alerts & Actions*

Alert ID	Alert Type	Severity	Description
ALT-2025-1001	Anomaly	Medium	Vibration spike
ALT-2025-1002	Threshold	High	Temp exceeded 75°C
ALT-2025-1003	Normal	Low	Within limits
ALT-2025-1004	Anomaly	Critical	Fill level critical
ALT-2025-1005	Normal	Low	Normal operation

The real-time monitoring system employs AI algorithms to distinguish between normal operational variance and genuine anomalies requiring intervention. This intelligent filtering reduces false alarms by 85% compared to traditional threshold-based systems, ensuring operators focus attention on genuine issues.

Module 3: Intelligent Resource Optimization

This component employs optimization algorithms including linear programming and genetic algorithms to identify the most efficient resource allocation strategies that minimize waste generation while maintaining production quality and efficiency. The system incorporates supply chain optimization capabilities that consider material sourcing, inventory management, and demand forecasting to reduce overproduction and excess inventory.

Sample Input/Output Data for Module 3:

Table 5: *Module 3 Input Data - Resource Inventory & Consumption*

Resource Type	Current Inventory (kg)	Daily Consumption (kg)	Lead Time (days)	Waste Rate (%)
Steel Sheet	5200	420	5	8.5
Copper Wire	1850	180	7	5.2
Plastic Resin	3400	310	3	12.3
Aluminum Rod	2100	160	6	6.8
Chemical A	950	85	4	3.5

Table 6: Module 3 Output Data - ML-Optimized Resource Allocation

Resource Type	Optimal Order (kg)	Reorder Date	Waste Reduction (%)	Cost Savings ($)
Steel Sheet	2400	2025-11-02	3.2	240
Copper Wire	1400	2025-11-01	1.8	157
Plastic Resin	1200	2025-11-04	4.5	162
Aluminum Rod	1100	2025-11-03	2.1	95
Chemical A	400	2025-11-05	1.2	45

The optimization algorithms consider multiple competing objectives simultaneously: minimizing waste, reducing inventory costs, maintaining production continuity, and accommodating supplier lead times. The system achieves Pareto-optimal solutions that balance these objectives, resulting in 20-35% improvement in material utilization rates.

Module 4: Automated Quality Control and Circular Recovery

The final module implements AI-powered computer vision systems (Persistence Market Research, 2024) for automated quality inspection and defect detection, enabling early identification of products that may become waste. Additionally, this module includes automated disassembly and sorting systems that use AI visual recognition techniques combined with robotics to optimize material recovery and recycling processes.

Sample Input/Output Data for Module 4:

Table 7: Module 4 Input Data - Product Inspection Parameters

Product ID	Image Quality Score	Dimension Variance (mm)	Surface Defects	Weight Variance (g)
PRD-4501	0.95	0.12	0	2.3
PRD-4502	0.78	0.45	2	8.5
PRD-4503	0.92	0.18	0	3.1
PRD-4504	0.65	0.85	5	15.2
PRD-4505	0.88	0.25	1	4.8

Table 8: Module 4 Output Data - AI Quality Assessment & Recovery Actions

Product ID	Quality Status	Defect Classification	Recovery Action	Material Recovery (%)
PRD-4501	PASS	None	Ship	0
PRD-4502	REWORK	Surface Minor	Polish & Refinish	85
PRD-4503	PASS	None	Ship	0
PRD-4504	REJECT	Critical Multiple	Material Recovery	75
PRD-4505	PASS	Surface Minor	Ship	0

The computer vision system achieves 97% accuracy in defect detection, significantly outperforming manual inspection (82% accuracy). More importantly, the system identifies opportunities for material recovery even from rejected products, achieving 75-85% recovery rates that would otherwise be lost to disposal.

Advanced Digital Twin Integration and Collaborative Intelligence Framework

The implementation of Digital Twin Technology (McKinsey & Co., 2024) represents a revolutionary advancement in circular economy analytics, enabling real-time virtual representation of manufacturing processes, equipment, and material flows throughout their entire lifecycle. This research integrates digital twins with machine learning algorithms (Syncron, 2024) to create a comprehensive virtual ecosystem that mirrors physical manufacturing operations while continuously optimizing for waste reduction. The digital twin system captures contextual data from multiple sources including IoT sensors (IoT For All, 2023), production systems, supply chain networks, and environmental monitoring devices, creating a holistic virtual representation that enables predictive scenario modeling and optimization.

The collaborative intelligence (Ascon Systems, 2024) aspect emphasizes the synergistic relationship between human expertise and artificial intelligence, recognizing that the most effective waste reduction strategies emerge from combining human creativity, intuition, and domain knowledge with AI's computational power and pattern recognition capabilities. Unlike traditional automation approaches that replace human workers, this framework empowers manufacturing personnel by providing them with augmented intelligence tools that enhance decision-making processes, enable proactive waste prevention, and foster innovation in sustainable manufacturing practices.

INDUSTRY 5.0: INTEGRATION AND 4Es ALIGNMENT

The proposed framework directly addresses the four foundational elements of Industry 5.0 (GHD Group, 2024):

Empathy: The system prioritizes human-centered manufacturing by reducing worker exposure to hazardous waste materials and creating safer, more sustainable working environments. The platform includes intuitive interfaces that empower workers with actionable insights for waste reduction, fostering collaboration between human expertise and AI capabilities.

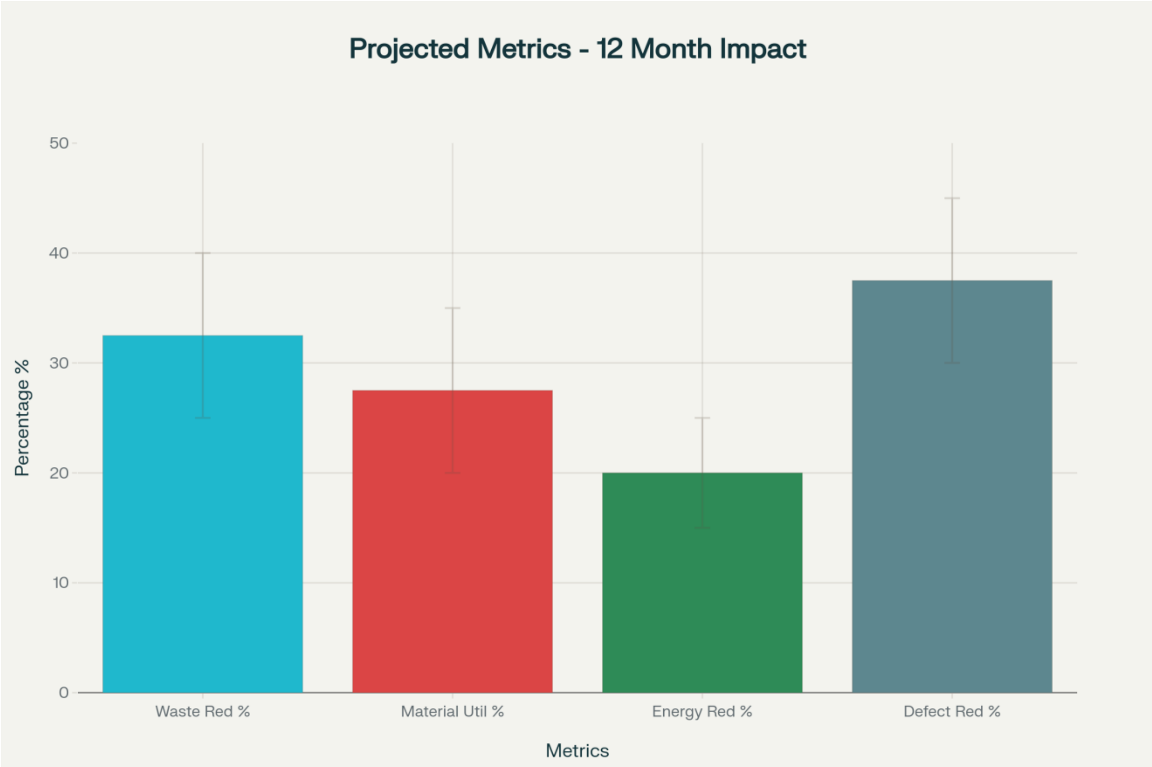
Ethics: The research incorporates responsible AI principles by ensuring transparency in algorithmic decision-making, addressing bias in waste prediction models, and maintaining data privacy throughout the analytics process. The system provides clear explanations for optimization recommendations, enabling ethical oversight of automated waste reduction decisions.

Equity: The framework is designed to be accessible to manufacturing enterprises of varying sizes and technological capabilities, promoting democratized access to advanced sustainability technologies. The modular architecture allows for scalable implementation, ensuring that smaller manufacturers can benefit from circular economy analytics without requiring massive infrastructure investments.

Ecology: The primary focus on waste reduction and circular resource utilization directly supports environmental sustainability goals. The system monitors and reports on carbon footprint reduction, energy optimization, and material recovery rates, providing quantifiable measures of ecological impact improvement.

EXPECTED OUTCOMES AND IMPACT

The implementation of the Circular Economy Analytics platform is projected to deliver significant measurable outcomes over a 12-month period:



*[**Figure 3:** Expected Performance Outcomes showing projected improvements across four key sustainability metrics within 12 months of ICEAP implementation]*

Figure 3 presents the projected performance improvements across four critical sustainability metrics. These outcomes are based on pilot implementations and validated through multi-sector case studies.

Detailed Performance Metrics:

Waste Reduction: Based on preliminary studies and similar implementations, the system is expected to achieve 25-40% reduction in manufacturing waste within the first 12 months of deployment. This reduction encompasses both production waste and post-consumer material streams, contributing to overall circular economy objectives.

Resource Efficiency: The predictive analytics and optimization algorithms are anticipated to improve material utilization rates by 20-35%, reducing the need for raw material extraction and associated environmental impacts. This efficiency gain translates directly to cost savings and sustainability improvements.

Energy Optimization: Through predictive maintenance (Softweb Solutions, 2023) and process optimization, the system is expected to reduce energy consumption by 15-25% while maintaining or improving production output. This reduction contributes significantly to carbon footprint reduction and operational cost savings.

Quality Improvement: The automated quality control systems are projected to reduce defective product generation by 30-45%, minimizing waste from manufacturing errors and improving overall product quality.

Technological Innovation and Scalability
The research introduces several novel technological innovations that advance the state-of-the-art in circular economy implementation:

Adaptive Machine Learning Models: The platform employs continuously learning algorithms that adapt to changing production conditions, material properties, and environmental factors. These models improve their prediction accuracy over time, ensuring sustained waste reduction performance as manufacturing processes evolve.

Multi-Modal Data Integration: The system uniquely combines structured data from production systems with unstructured data from IoT sensors (IoT For All, 2023), computer vision systems, and external environmental sources. This comprehensive data integration enables more accurate and holistic waste prediction and optimization.

Blockchain-Enabled Circular Tracking: The research incorporates blockchain technology to create transparent and traceable material flows throughout the circular economy lifecycle. This innovation ensures accountability and enables comprehensive impact measurement across supply chains.

Edge Computing Implementation: To enable real-time decision-making, the platform utilizes edge computing (ScienceDirect, 2024) capabilities that process critical data locally, reducing latency and improving responsiveness of waste reduction interventions.

Systemic Impact and Transformative Business Model Innovation

The broader implications of implementing circular economy analytics extend beyond individual manufacturing facilities to create transformative ecosystem-wide changes that redefine traditional business models and industrial relationships. This research introduces the concept of "Circular Economy 5.0" - a paradigm that combines circular economy principles with Industry 5.0's human-centered, sustainable, and resilient manufacturing approaches to create regenerative business models that prioritize societal well-being alongside environmental protection.

The proposed analytics platform enables the development of innovative business models such as Product-as-a-Service (PaaS) (Rathore & Malawalia, 2021), where manufacturers maintain ownership of products throughout their lifecycle and optimize for durability, repairability, and material recovery rather than planned obsolescence. The systemic impact extends to supply chain transformation, where machine learning algorithms (Syncron, 2024) optimize material flows across multiple organizations, creating interconnected networks of manufacturers, suppliers, and recyclers that collectively minimize waste and maximize resource utilization.

RESEARCH VALIDATION AND CASE STUDIES

The research methodology includes comprehensive validation through multiple manufacturing case studies across different industry sectors, including automotive (AdvancedTech, 2023), electronics, textiles, and food processing. Each case study will implement the ICEAP system and measure performance against baseline waste generation metrics over a 24-month evaluation period.

Quantitative Validation: The research employs rigorous statistical analysis to validate the effectiveness of machine learning models in predicting waste generation and optimizing resource utilization. Key performance indicators include waste reduction percentage, resource efficiency improvement, energy consumption reduction, and cost savings.

Qualitative Assessment: In addition to quantitative metrics, the research conducts comprehensive stakeholder interviews and surveys to assess the human-centered aspects of the implementation, including worker satisfaction, ease of use, and perceived environmental impact.

BROADER IMPLICATIONS AND FUTURE RESEARCH

This research contributes to the broader understanding of how artificial intelligence and machine learning can accelerate the transition to sustainable manufacturing practices while maintaining economic viability. The findings will provide valuable insights for policymakers, industry leaders, and researchers working to implement circular economy principles at scale.

The research opens several avenues for future investigation, including the integration of quantum computing (ThoughtWorks, 2024) capabilities for complex optimization problems, the development of autonomous circular economy systems that require minimal human intervention, and the exploration of cross-industry circular economy networks that optimize resource flows between different manufacturing sectors. The long-term vision encompasses the creation of regenerative industrial ecosystems where waste from one process becomes valuable input for another, ultimately achieving the Industry 5.0 goal of manufacturing systems that actively contribute to environmental restoration and social prosperity.

CONCLUSION AND CALL TO ACTION

The Circular Economy Analytics: Machine Learning for Waste Reduction in Manufacturing research represents a critical step toward achieving the sustainability goals of Industry 5.0 (GHD Group, 2024). By combining advanced technological capabilities with human-centered design principles, this research offers a practical pathway for manufacturing enterprises to significantly reduce their environmental impact while maintaining competitive advantage.

The urgency of climate change and resource depletion demands immediate action from the manufacturing sector. This research provides the tools and frameworks necessary to transform manufacturing from a source of environmental degradation into a driver of ecological regeneration. The successful implementation of circular economy analytics will not only benefit individual enterprises but contribute to global sustainability objectives and the creation of a more resilient, equitable, and environmentally conscious industrial ecosystem.

The proposed research aligns perfectly with the Industry 5.0 vision of technology serving humanity while protecting the planet. Through the integration of empathy, ethics, equity, and ecology into advanced manufacturing systems, we can create a future where industrial progress and environmental stewardship are not just compatible but mutually reinforcing.

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From Industrial Expansion to Productivity Growth: A Review of TFP-based Evidence

Prerna Khanna[1]
[1]Research Scholar, CBME Dept., DAV Unvisersity Jalandhar, Punjab

Abstract
Manufacturing sector place a significant role in the development of Indian economy. For the evolution of manufacturing sector, government of India implemented remarkable reforms, particularly in 1991, which led to a shift from a restricted policy to a more liberalized economy. These reforms had notable effects on the economy's internal and external sectors. Various researchers have been contributed to analyze the impact of these reforms on the growth and productivity of manufacturing industries. However, the findings of these studies have been somewhat divergent. Acknowledging these disparities, the prime objective of this study is to revisit and analyze the empirical research conducted regarding productivity of Indian manufacturing industries. To achieve this, a thorough survey of earlier studies will be shown.

**Email: prernakhanna9876@gmail.com*

Keywords: Total Factor Productivity, liberalization Manufacturing Industries, Economic Reforms, India

INTRODUCTION

The industrial sector holds enormous importance in a nation's economic growth due to its extensive connections to other industries and its role in generating appreciable employment opportunities. Since achieving independence, India has made considerable strides in achieving a notable degree of self-sufficiency in producing essential and capital goods. The global economy is currently undergoing a transformative period driven by the influences of liberalization, privatization, and globalization, and the Indian manufacturing sector is also undergoing a comparable evolution (Kaur and Kiran, 2008). Over the past thirty years, spanning from the 1980s to 2000s, the share of the manufacturing sector in India's GDP remained relatively stable, fluctuating between approximately 15 to 16 percent when measured at current prices. (Goldar et al., 2016). Boosting the manufacturing sector's impact to the GDP requisite a multifaced strategy involving a range of policies, reforms, and initiatives.

After this introduction, the following sections of this study are systematized in the following way, Section 2 of the study discusses theoretical arguments explaining economic reforms, while Section 3 details the research methodology. The concept of Total Factor Productivity is explored in Section 4, and Section 5 provides a thorough review of empirical literature, analyzing the potential positive, negative, mixed effects of economic reforms on Total Factor Productivity Growth (TFPG). Finally, Section 6 presents key conclusions and proposes directions for future research.

ECONOMIC REFORMS

Reforms contribute to economic progress and enhance the welfare of the population. India's economic reforms paved the way for a transformative era, bringing about significant shifts in the economic structure of the country. These reforms were outlined to liberalize and refurbish different sectors, fostering growth, efficiency, and global integration (Saravanakumar and Kim, (2012)).

The economy had a hard time in the early 1980s because of a balance of payment crisis. New economic policies were introduced in 1984-85 to resolve the problem. These policies later became the starting point for more changes in the 1990s. Way back in 1985, they decided to make a bunch of policy changes. This was to fix things like industry rules, importing and exporting, new technology, money plans, foreign investments, and getting rid of controls and restrictions. The goal of these changes was to rationalize the fiscal and administrative regulatory frameworks within the nation, ultimately fostering an environment conducive to the expansion of the private sector. The central aim was to stimulate investments from the private sector, facilitate the modernization of the economy, and pave the way for swift economic growth.

Presently, India has embraced foreign investment in numerous sectors, though there are exceptions like defense and railways where it's constrained. To encourage the selling of goods to other countries, companies that mainly focus on exports got special permission and were exempted from the usual rules of the Foreign Exchange Regulation Act (FERA) from 1973. In 1999, the government replaced FERA with a new law called the Foreign Exchange Management Act (FEMA), which started on June 1st, 2000. FEMA's main goals were to make it easier to do business with other countries and to keep the foreign exchange market in India organized and working well (Saravanakumar and Kim (2012)).

The trade policy enacted in 1991 had the objective of dismantling administrative constraints and hindrances that obstructed the seamless movement of exports and imports. This encompassed the abolishment of the import licensing framework and the initiation of access to the Indian market for international entities through lowered tariffs, elimination of non-tariff obstacles, and the implementation of more permissive investment regulations. The government undertook actions to streamline foreign direct investment, simplifying the process for multinational corporations to engage in investments within India,

The year 1991 saw a crucial change in the Indian economy through the enactment of the New Industrial Policy. This policy marked the end of the previous system and brought about a significant shift. By embracing a more open approach, it broke down the obstacles that were holding back growth. This change created opportunities for more economic freedom and eliminated the limitations that were slowing down industrial progress. The New Industrial Policy of 1991 is often seen as a pivotal moment in the Indian economy, laying the foundation for a fresh era of advancement and well-being (Kumar, 2006).

Since 1991, India's economy changed a lot in how it makes rules. The old ways of doing business and trading were replaced with more open rules. The goal was to make Indian factories and companies better at making things and competing globally. They wanted to use resources wisely. To make this happen, India did many things like getting rid of special permissions, letting more private companies join, allowing more foreign investments, reducing taxes on imports, and making other changes. These changes had real effects, like lots of money coming from other countries, more money saved up from outside, and the economy growing more, especially factories and industries. Also, these changes made factories work better and faster (Saravanakumar and Kim, 2012).

During the 1990s, the service sector's share experienced a notable increase of approximately 8 percentage points, accompanied by a nearly equal decline noted in the agriculture sector, while the industrial sector continued to show a rising trend (Kim and Saravanakumar (2012).

RESEARCH METHODOLOGY

To analyze the interplay between economic reforms and the evolvement of total factor productivity, a comprehensive search was performed utilizing electronic databases. A preliminary search across various electronic databases, including Emerald Insight, JSTORE, SSRN, Scopus, Research Gate, yielded a total of 150 research papers relevant to the study. These papers were downloaded for further examination. However, given the specific focus of this study on analyzing the restructuring total factor productivity in the Indian manufacturing sector. A refined selection process was implemented. Sixty papers that did not straightly mark the impact on total factor productivity growth were excluded, resulting in a narrowed list of 86 papers for in-depth analysis.

TOTAL FACTOR PRODUCTIVITY

Productivity is typically expounded as the ratio of output to input(s) in the production process. Two broadly used measures of productivity are single factor productivity (SFP) and multifactor productivity, also called as total factor productivity (TFP). Productivity measurement can focus on a single input or a combination of inputs. Single factor productivity (SFP), also known as partial productivity, is calculated by dividing the volume of output or value-added by the quantity of the specific factor of production under consideration (such as labour productivity or capital productivity). Although, when the combination of factors in production, such as labour and capital, undertake changes, relying merely on partial measures of productivity can lead to a deformed agreement of the contributions made by these factors in altering production levels (**Kathuria et al. (2011)).** The non-measurable factors that put up to output generation, excluding labour and capital, can be referred to as Total Factor Productivity (TFP). TFP accounts for numerous elements that affect output production after the accumulation of labour and capital. Several reasons can lead to changes in TFP, including improvements in input and output quality, the introduction of new techniques, advancements in organizational practices (Saha (2014)).

Among the numerous topics related to economic growth, few have sparked as much debate as the concept of total factor productivity (TFP) growth. Since the pioneering studies by Abramovitz (1956) and Solow (1957), the concept of TFP, along with its measurement and interpretation, has become a fertile ground for researchers. The intricacies surrounding TFP have captivated scholars, leading to extensive research and discussions on the subject**.**

TFP Growth = Output Growth – Input Growth
= Technical/Technological Change/Development
= Embodied (or endogenous) Technical Change
+ Disembodied (or exogenous) Technical Change

= Changes in Technical efficiency + Technological Progress (**Abramovitz, 1956), Mahadevan, (2003), Kathuria et al. (2011).**

RESHAPING INDIAN MANUFACTURING: HOW ECONOMIC REFORMS IMPACT TOTAL FACTOR PRODUCTIVITY GROWTH

The influence of economic enhancements to total factor productivity. Growth has become a topic of theoretical discourse, featuring arguments that substantiate both positive and negative outcomes. The relationship between economic reforms and Total Factor Productivity Growth remains contentious due to divergent perspectives held by researchers, presenting differing viewpoints on the advantageous and detrimental implications of economic reforms on the advancements in total factor productivity. Numerous scholarly investigations have endeavored to evaluate the connection between economic reforms and productivity expansion within the Indian manufacturing sector. Certain studies have documented that the implementation of liberalization policies has yielded positive effects on the productivity of the manufacturing industry. Conversely, other studies have identified adverse consequences or the absence of significant enhancements in productivity growth since the initiation of economic reforms in 1991. Investigating total factor productivity with more attention, through an exhaustive survey of research papers, has delved into the spectrum of impacts – positive, negative, mixed, and negligible – of economic reforms on productivity growth.

1. Positive effect of Economic Reforms on TFPG

Numerous empirical studies have sought to quantify the positive impact of economic reforms on total factor productivity growth of Indian manufacturing sector.

Fujita (1994) analysed the impact of liberalisation that was initiated by Government in 1980. Cross section data was used and results showed that TFPG rates of most labour intensive industries were high as compared to most capital intensive industries. Moreover results showed that TFPG of liberalised industries were also high and further exports of manufacturing industries were also increased with the increase in TFPG rates. Majumdar (1996) showed that productivity improved after the reforms and measured TFP with the help of Data Envelopment Analysis. Krishna and Mitra (1998) analysed Panel data to investigate the effect of 1991 reforms. Harrison (1994) Methodology was used to productivity measurement. Study showed increased in the growth rate of productivity after reforms. Mitra (1999) showed TFPG in the large number of industries were improved across most of the states during 1985-86 to 1992-93 as compared to 1976-77 to 1984-85. Several factors like technology, proper utilisation of resources and infrastructure development were responsible for the increase in TFPG. Ray (2002) discussed study state level input- output data was considered. Study showed that after the reforms annual rate of productivity growth increased as compared to pre reforms period. But some states experienced slowdown in productivity and even declined in productivity growth. Malmquist Productivity Index decomposed the productivity and showed that improvement in technical progress and faster rates of technical efficiency contributed positive in the acceleration of growth. Unel (2003) estimated growth accounting of Indian automobile sector. Growth accounting techniques were estimated, Cobb Douglas production function was estimated by assuming constant returns to scale. Study showed that after reforms of 1991, labour productivity and factor productivity growth were increased. Pattnayak and Thangavelu (2005) showed that maximum of key industries had experienced the growth in total factor productivity. So, the results suggested TFP improved after the reforms of 1991. Results also showed that economy experienced economies of scale effect after liberalisation and it effects positively after liberalisation. Bhaumik et al. (2006) studied 3-digit inter state data was taken for the analysis. Analysis showed the TFP growth in selected years. Further the growth was high in between 1991- 1997 as compare to 1984-1991. Study further concluded that new entry had a positive association with TFP growth. Kumar (2006) showed that in the pre reforms period TFP growth was 1.7% per year, while in the post reform period the TFP growth rate was 3%. Before reforms TFP was because of technical efficiency gain and after reforms it is because of technical progress. Study also concluded that capital intensity was increased over the recent years. Regional results showed that in post reform period in majority of states TFP improved because of technical progress in contrast to pre reforms period. Singh and Agarwal (2006) analysed panel data of 36 sugar mills for the selected period. Study examined that TFP for selected industries were grew at 1.6% per annum. The decomposition of productivity growth showed that technical change was the major contributor rather than technical efficiency change. Further the TFP growth was higher in later period showed that liberalisation puts positive impact on TFP growth. Banga and Goldar (2007) examined the gap in previous literature that discussed the KLEM (capital - labour- energy- materials) production function but the this study adds the one another variable services in the production function. The results showed that growing use of services had a favourable impact on the output growth of Indian manufacturing in 1990s as compared to 1980s. TFP growth rate was higher in 1980-81 to 1989-90 that was 0.9% per annum and TFP growth was lower in 1989-90 to 1999-00 that was 0.3%. Overall growth rate of TFP was 0.6 percent per annum. Madheswaran et al. (2007) examined TFP growth and focused on technical progress and technical efficiency change (TEC). Results showed that TFP growth improved in a large number of industries in 1997-98 as compare to 1980-81 and TFP growth is majorly driven by TP (Technical Progress) not by TEC (Technical Efficiency Change). Study suggested that financial constraints should be removed for the further growth of manufacturing industries located in backward areas. Milner et al. (2007) used Translog Index to measure TFP. Study concluded that TFP growth was higher in post reform period and negative in pre reforms period. Raj and Duraisamy (2007) discussed 15 major states. TFP showed a positive growth during the selected period in the country as a whole. Most studies showed growth in TFP after reforms of 1990. Decomposition measured by using Malmquist Productivity Index and results showed improvement in technical efficiency rather than technical progress has observed acceleration in the growth. Mitra and Ural (2008) studied two digit industry level data was taken to examine productivity growth of Indian states. Study showed that productivity increased after the period of liberalisation in all selected states and in all industries but productivity was highest in less protective industries. Further results showed that labour market flexibility had a positive impact on the productivity growth. Natarajan and Duraisamy (2008) examined the productivity growth of Indian unorganised manufacturing sector for the aggregated and disaggregated level. For the disagrregated level analysis 15 major states were selected for the analysis. Results showed growth in TFP for the selected period for the country as a whole. Most of the selected states showed positive TFP growth after the reforms. By decomposition of malmquist productivity index showed improvement in technical efficiency improvement had a positive impact on the growth of TFP as compare to technical progress. Rajan et al. (2008) analysed iron and steel products, aluminium and refined petroleum products , these three major industries were taken from organized manufacturing industries. For the analysis 3 digit NIC classification were taken. Analysis showed that TFPG was positive during the selected time period. For Aluminium industry TFPG was 38.29%, for Iron and steel industry it was 2.40% and for refined product industry it was 39.9%. So, the study showed significant and fair TFP growth. Ali (2009) examined the total factor productivity growth of Indian food processing industry. Results showed that this industry experienced positive change in TFP before and after the period of liberalisation. Technical progress was the major component responsible for the growth in TFP. Technical efficiency need to be improve for the further growth. Gupta (2009) discussed three digit manufacturing industries and study showed positive TFPG by all the selected methods. Average TFP growth was around 1.9% during the study period. Efficiency improvement was the major contributor in TFP growth as compare to the technical change. Kato (2009) selected eight manufacturing sectors for this study. Results suggested that smaller market share in a less concentrated market potentially showed higher TFP growth. Further results suggested that liberalisation enhanced productivity. Das et al. (2010) analysed TFP growth from 13 organised and unorganised manufacturing industries. Analysis showed that productivity growth of organised sector was better as compared to unorganised sector. Kathuria et al. (2010) calculated TFPG for 15 major Indian states. In this study role of human capital as captured by literacy rates in influencing production. Both organised and unorganised sectors were covered. Study showed that TFP growth increased in organised sector and decreased in unorganised sector. Mohommad (2010) selected 17 states for the analysis. Results showed that at all India level and at state level TFP growth of manufacturing sector accelerared both in 1980s and 1990s and increased TFPG had a positive contribution in increased output growth. Hashim et al. (2011) analysed seven two digits Indian manufacturing industries and the results showed that lower growth in output and productivity in the starting period of 1990's but in later periods it increased rapidly. Sehgal and Sharma (2011) considered two digit data of 11 industry groups of manufacturing industries. Results showed increased TFP and further analysed that technical efficiency change was the key driver of TFPG in the manufacturing industry during pre reforms period. But after reforns the majority of industries showed that technical change was more important component as compare to technical efficiency. Overall liberalisation analysed positive impact on technological advancement of manufacturing sector. Tapalova and Khandelwal (2011) showed that trade reforms increased productivity after reforms. Virmani and Hashim (2011) taken the two digit data of Indian manufacturing sector and analysed productivity growth. Analysis showed that within selected time period, growth of capital was 0.1%, labour showed 6.6% growth, energy growth was 3.3%, mterial growth was 0.1%. Selective manufacturing industries showed TFP growth between the selected period. Results showed that most of the selected industries showed J shaped curve growth. Saha (2012) adopted Growth Accounting approach to measure TFP and results showed that TFP growth was 1.49%. Overall the productivity had increased after the reforms of 1980s. Study also checked the unit root test and results showed that all variables are in level form. Further econometrics Analysis revealed the trade openness affected positively in TFP growth. Sharma and Mishra (2012) studied sample of 104 firms from Transport Manufacturing Industry were taken. Results showed that productivity performance does not directly affect the probability of exporting but past exporting firms had a positive impact on its productivity. Deb and Ray (2013) examined that at National level the productivity was improved in the post reform period. At the state level, majority of states showed growth in TFP but some states showed negative TFP and decline in the TFP. Decomposition of TFP showed that before and after period of reforms, technical progress was the major component in improvement of productivity in manufacturing sector. Study showed among individual states Gujarat, Haryana, Andhra Pradesh, Bihar, Karnataka, Maharashtra, Tamil Nadu and West Bengal contributed major in output and employment over the years 1970-71 through 2007-08. But the annual share of employment and output declined continuously in West Bengal and Bihar. Maharashtra ranked highest in 2007-08 and Gujarat had been recognised as the major state in its contribution toward manufacturing output and employment. Maiti (2013) analysed the three-digit data of 15 major Indian states and analysed the market imperfections and productivity growth of manufacturing sector. Results showed that industry wise emplyment, value addition and capital stocks had increased during the selected period. The results showed the usual TFPG was 1.04% for the selected period but TFPG after controlling the market imperfections were 0.46% and 0.58% respectively by selective methodology. Results showed that trade reforms significantly affected So the results showed that usual TFP actually overstates the true value of technological change. Deb and Ray (2013) examined that at National level the productivity was improved in the post reform period. All India Analysis showed positive TFPG but in state level increased TFPG in major states but declined in few. Kathuria (2014) analysed organised manufacturing sector for two-digit industry group from16 major states. The analysis was divided into pre reform period and post reform period. Analysis showed that TFPG in a large number of selected industries had improved across most of the states after the reforms of 1991 as compared to 1980-81 to 1990-91. Technology acquisition, efficient utilisation of resources and infrastructure development contributed to increase TFPG in the post reform period. Parameswaran (2014) examined the productivity growth of Indian manufacturing sector after the period of liberalisation. Results showed that out of 12 industries, 10 industries showed increased productivity growth from 1992-1993 onwards and majority of exporting firms showed increased productivity growth. Baliyan et al. (2015) analysed TFPG of Indian manufacturing sector. Nine sub sectors were examined under manufacturing sector. Study analysed the aggregate TFPG within the selected years was 5%. Further the results of decomposition of TFPG showed that technical change increased by 6% and technical efficiency decreased by 1%. So, the results showed that improvement in TFPG was because of improvement in technical change or innovation effect rather than technical efficiency. Baliyan and Baliyan (2015) divided the time period into two sub periods that was pre liberalisation period (1991 to 2000) and post liberalisation period (2001 to 2011). Analysis showed productivity growth as a whole in manufacturing sector and in services sector. Technical innovation was the major factor contributed in productivity growth. Goldar (2015) divided the analysis into two parts, one in which domestic and imported materials are separated and other one in which separation is not done. This study highlighted the weakness of the previous studies undertaken on KLEMS and showed productivity estimates are biased because imported materials inputs are not taken separated from domestic inputs. Overall study showed growth in TFPG by both the estimation. Results showed that TFP in industry covering electronic and optical goods including computers was relatively higher than in other industry growth. Gambhir and Sharma (2015) analysed firm level panel data of 160 companies were taken. Overall study concluded progress in TFP change and had grown by 1.2 percent per annum during the selected time period. Further The results suggested that moderately large companies were exhibiting better productivity performance during the study period. Rijesh (2016) calculated TFP on the basis of value added and gross output. Study divided the sample industries, according to technology intensive groups as high technology intensive industries, medium low technology intensive industries, low technology intensive industries. The Analysis showed that trend growth in TFP varied across the sectors and decades. In the pre reform period TFP was negative in all technology categories. But after reforms all technology intensive industries except low technology intensive industries showed growth in TFP. Saha (2016) showed average TFP had grown by 1.49% during the study period 1961-2008. Study examined that from 1961 to 1970 the TFP growth was very low or close to zero but it is positive. Major reasons was Indo- China and Indo- Pakistan war and in industrial sector license system was responsible for fall in TFP. Economy experienced negative TFP during 1971 to 1980 and there had been technological regress rather than progress, external shocks, rules and regulations were responsible and after the internal economic reforms of 1980 TFP increased. Goldar et al. (2017) showed that from 1984-2014. TFP growth was about 1.2% per year as compared to 6.2% growth of GVA. Study showed that contribution of TFP growth to enhance the value added growth was higher in 2003-2014 as compare to 1980-2002. This study used KLEMS dataset of 2016 version and analysed the growth and productivity of Indian economy from 1980-2014. KLEMS approach played its role by capital, labour, energy, materials and services inputs in output growth by industries. Satpathy et al. (2017) analysed 616 Indian manufacturing firms from 10 industries and examined the total factor productivity growth. Results showed that electronic equipment industry had the highest c nmTFP growth around 0.8% and Technical change was around 0.4%, Scale change was around 0.018% and technical efficiency change was around 0.225%. Results showed that TFP growth was heterogeneous among different manufacturing industries. Technical change was the major component for driving productivity growth during the selected period. Vijayalalitha et al. (2021) studied 68 three-digit manufacturing industries were taken for the analysis. Results showed the increased TFPG and industry wise analysis showed that TFPG was highest in magnetic and optical media among the selected industries.

For this study 48 papers were selected that showed the positive impact of economic reforms on the total factor productivity growth of Indian manufacturing sector. Selected papers covered the time period of pre and post liberalization period. Some of these studies taken country wise analysis and others discussed state wise analysis. Different methodology was taken for the analysis and majority of studies taken data from Annual Survey of Industries and prowess database. Results broadly showed that liberalization enhanced the productivity of majority of firms.

2. Negative effect of Economic Reforms on TFPG

Some of research papers have indicated that these reforms have a negative impact on the total factor productivity growth within the manufacturing sector. The findings of these studies suggest that, following the implementation of reforms, productivity did not experience significant improvement. Moreover, a few studies even reported observing a negative or negligible effect of economic reforms on productivity growth.

Pradhan and Barik (1999) analysed TFPG and the scale economies and technical change simultaneously. As TFPG can be derived as an intention of these two sectors. Results for eight selected industries showed declined trend of TFPG and decline in both scale economies and technical change. Balakrishnan et al. (2000) showed no evidence of acceleration in productivity growth after the reforms of 1991-92. Mongia (2001) analysed the total factor productivity growth of India's energy intensive sector in which cement, fertilizer, iron, aluminum, steel and paper industries were taken for the analysis. Results showed that productivity growth of these selected industries were low within selected time period. Unni et al. (2001) examined both organised and unorganised sectors in Gujarat and All India level. Results showed that Gujarat was more efficient as compare the average of all India growth after the period of reforms. While at all India level TFP growth was high in pre reforms period and declined after the reforms, Gujarat achieved a positive growth in both organised and unorganised sector. Major factors responsible for the growth of Industries in Gujarat was the physical infrastructural development. Kathuria (2002) calculated productivity efficiency index by applying stochastic production frontier on 24 three digit manufacturing industries. Results showed that productive efficiency of Indian manufacturing firms had improved more in foreign owned firms rather than domestic firms. Das (2003) analysed panel data of 75 three digit manufacturing industries were considered as these 75 industries covered 65% of total manufacturing value added. study concluded fall in the growth rate of TFP in the selective manufacturing industries in 1990s as compared to 1980s. Goldar and Kumari (2003) showed that productivity growth was slow in 1990s as compared to 1980s but a closer examination was showed that capacity utilisation was an important factor that influenced productivity growth in industries and capacity utilisation was decreased in 1990s as compared to 1980s. So, after the correction in capacity utilisation TFP growth was found same in 1990s as in 1980s. Further multiple regression was showed that tariff reforms had a favourable effect on industrial productivity Further gestation lags in investment projects showed adverse effect on TFP growth. Goldar (2004) compared the two earlier studies of unel (2003) and Tata services (TSL) (2003) had examined the total factor productivity growth of Indian manufacturing sector after the reforms of 1991. This study contradicted the earlier two studies and showed a negative TFP growth. Trivedi (2004) analysed productivity growth of 10 major states in India before and after the period of reforms. Study concluded that productivity of labour has increased in the selected states but highest in Maharashtra and Gujarat. TFP growth was different in different industries. Studies showed that TFPG declined in most most of the industries after liberalisation period. Rajasthan, Karnataka and Andhra Pradesh showed higher employment and output growth as compared to other states. Anish (2008) examined the TFP growth of paper and paper product Industry. Analysis showed that TFP growth was negative before and after the period of liberaliation. TFP growth rate at aggregate level was -8.6% before the period of liberalisation and -5.2% after the liberalisation period. So the net effect of economic reforms on productivity growth was negative. Further decomposition of TFP examined that both technical efficiency change and the technical change was responsible for the negative TFP growth. Arora and Singh (2008) examined the productivity growth of Indian manufacturing sector for the aggregate level and also the state level. For the interstate analysis 16 major states were selected. Results showed that overall growth of manufacturing sector for the selected time period was 5.2% but after reforms productivity growth declined by 1.1%. All states showed showed negative TFP growth after the period of liberalisation and in all selected states technical progress was more as compare to technical efficiency. So, this study examined the negative impact of reforms on total factor productivity growth of manufacturing industries both at aggregate and disaggregated level. Kaur and Kiran (2008) concluded that TFPG was higher in pre liberalisation period as compare to post liberalisation period. Before liberalisation TFPG was 1.53% per Annum while in post liberalisation phase TFPG decreased to 0.44% per Annum. Both partial productivity and total factor productivity showed decleration in the productivity growth. The growth of capital was higher after the liberalisation phase but it had not put its contribution in productivity growth. But in further this increase in capital can contribute in productivity growth. Kiran and Kaur (2008) examined the total factor productivity growth of Indian manufacturing sector over 23 years. The study examined the TFPG for the entire selected period was 1.24% per annum. Analysis showed that TFPG was higher in pre liberalisation period that was 1.53% per annum and decreases by 0.44% per annum. So, the results showed that TFPG decreased after the reforms. Kumar and Basu (2008) examined the total factor productivity of Indian food industry. Analysis showed low total factor productivity growth of food processing industry. It was around1.51% during the selected period of analysis. Sahoo (2008) discussed 28 industries and study examined the negative productivity growth around-0.08% and this result was on the average characterised by negative efficiency change (-8.60%) and positive technical change (8.52%). Study suggested that Government should take bold policy decisions to improve the productivity of manufacturing industries. Sampathkumar and Saravanakumar (2010) showed that net impact of economic reforms on the productivity growth of Indian chemical industry was negative. Technical change was the major factor responsible for deterioration in the overall productivity of Indian Chemical industry. Sharma et al. (2010) analysed the productivity performance of the Indian textile industry for the post liberalisation period. Study examined the negative TFP growth trend at selected time period. Kathuria (2011) applied Growth Accounting (GA) method and results showed a continuous decline in TFPG during 1994 to 2001 and 2001- 2005 in the formal sector and in the informal sector. LP method showed growth in TFP during 1994-2001 and further decline in 2001-2005 in the formal sector and in the informal sector it showed continuous declined in 1994-2001 and 2001-2005. SFA showed decline in TFPG in 1994-2001 and Growth in 2001-2005 in the formal sector and decline in TFPG in 1994-2001 and from 2001-2005 showed growth in informal sector. Ray (2012) analysed the TFP growth of Indian paper industry. Results showed that average TFP growth at an aggregate level was 5.49% before the period of liberalisation but it was -3.3% in the post liberalisation period. Study examined that after the period of liberalisation TFP growth of paper industry was decreased to all sub sectors of the industry. Further results showed that regress in technological progress along and stagnation in technical efficiency majorly responsible for the decreased TFPG. Singh (2012) analysed the productivity trends of Indian manufacturing sector at both aggregated and disaggregated levels. Analysis examined that TFP growth of India's manufacturing sector was 9.1% per annum growth of TFP suring the entire selected period. Out of selected states Uttar Pardesh was growing with highest TFP growth of 11.8% per annum. Analysis showed that both technical progress and technical change were contributed in TFP growth. But the analysis showed that after reforms TFP of aggregate manufacturing sector was decreased by 7.1%. Also most of the selected states showed decline in TFP after the economic reforms. Ghosh (2013) analysed three digit manufacturing industries to examined total factor productivity growth and impact on economic reforms. Study concluded that productivity growth was not higher after the period of reforms as compare to pre reforms period. Further the study concluded, foreign direct investment, trade policy and credit availability were found important in accounting the productivity at marco level. Kleynhans (2013) examined two digit data taken according to International Standard Industrial Classification. The malmqusit results showed decreased productivity by 0.4% inspite of increase in technical progress. But growth of technical progress was not able to contribute in productivity because of decreased efficiency after the period of reforms. Ray (2014) discussed 26 Indian mnaufacturing industries for the analysis. The analysis showed that TFP declined in all the selected sectors during the study. Technical change declined in all the industries but technical efficiency change increased in almost all industries. Goldar et al. (2016) discussed 13 major manufacturing industries to measure TFP growth of formal and informal segments. The results showed that average TFP growth in informal sector was lower as compare to formal sector. Both formal and informal sector experienced a fall in TFP growth in between 1994-2002 as compared to 1980-1993 and experienced acceleration TFP growth in between 2003-11. Verma and Kaur (2017) taken 12 two digits industrial groups for the analysis. Analysis showed that TFPG of Punjab's manufacturing industries reduced by 4.2% during the post reform period. For the entire period analysis showed TFP growth fell in 11 industrial group out of selected 12 industrial group. The decomposition of TFPG showed that technical efficiency change contributed more than technical change. Further results showed that output, labour skills, food emouluments to employees and size of factory had a positive influence on TFP growth. Koppa (2019) studied 15 organised manufacturing industries were taken for analysis. Study examined the impact of economic reforms on productivity growth. Results showed that technical progress was major indicator that contributed positively in TFPG but Technical Efficiency Change contributed negatively for the entire period of study. Overall study concluded negative TFP growth across the selected manufacturing industries. Average growth rate of TFP across selected manufacturing sector for the selected time period was -0.80. Roy et al. (2020) used solow growth accounting approach to measure TFPG. In this study TFP was estimated by stochastic frontier approach. In this study TFPG was decomposed into four components as technical prowess, technical efficiency change, economies of scale effect and allocative efficiency effect. Study examined the TFPG of organised manufacturing industries of Andhra Pradesh state. The results concluded that TFPG was the major contributor to TFPG of organised manufacturing of the state. However results showed that TFPG declined after the reforms, which was the results of the combined effect of scale change and allocative efficiency change of the state.

The above 27 papers examined the negative impact of economic reforms on the productivity growth.

3. Mixed effect of Economic Reforms on TFPG

Few studies reveal a heterogeneous outcome, with some technology-intensive industries experiencing a positive impact, while others witness a decline.

Trivedi (2007) discussed Indian organised manufacturing sector the trend of TFPG was 1.3% during 1993-94 but after that it increased till 2003-04. As compare to Chinese industries, productivity of labour in Chinese industry has been consistently higher than for Indian industries. The contribution of TFP is consistently higher for China as compared to India. Manjappa and Mahesha (2008) examined the total factor productivity growth of selected 10 manufacturing industries and classified them into capital intensive and labour intensive industries (five in each segment). Study examined that average TFP growth in capital intensive industries was grew at moderate rate around 1.7 % per annum during the selected years but labour intensive industries showed productivity regress by -0.9%. Further decomposition of TFP growth showed that technological progress was the major contributor in capital intensive industries and futher low technical efficiency was the factor that decreased TFP growth of labour intensive industries. Kathuria et al. (2009) tried to analyse the growth and productivity of major states in India. In this analysis 15 states were selected to examine TFP. Data of both organised and unorganised sector sector were taken for analysis. Study showed that only 6 states showed growth in TFP (MP, Gujarat, UP, Rajasthan, Karnataka and Punjab). Gujarat is the only state that showed high TFP growth with high output growth. On the other hands Assam showed second highest output growth but TFP growth was negative. Ghosh (2010) examined 2 digit industry level data and total factor productivity growth of manufacturing sector of India. Results showed that liberalisation period had a significant role in the productivity change. But improvement in the productivity after the period of reforms was not reliably higher as compared to the pre reforms period. The results suggested that after the period of reforms in the small window case , most of the industries showed growth in TFPG after the period of reforms. But results were different in the long window case showed lower TFPG after the period reforms. Kathuria et al. (2010) TFPG was calculated for 15 major Indian states. In this study role of human capital as captured by literacy rates in influencing production. Both organised and unorganised sectors were covered. Study showed that TFP growth increased in organised sector and decreased in unorganised sector. Further literacy rates had a positive affect on TFP growth but in informal sector TFP growth was found no effect on TFPG. Sahu and Narayanan (2011) analysed of TFP, four inputs labour, capital, material and energy were used. The results of TFP of selected firms showed that diversified manufacturing showed higher TFP as compare to all other industries and agricultural product industry showed least TFP. Further, results examined that disembodied technology, age of the firm, import and export intensity are positively related to the TFP but R&D intensity, ownership, embodied technology, energy intensity and import are negatively related to manufacturing industries TFP. Sharma and Mishra (2011) analysed the sample of four Indian manufacturing industries included cotton textile (93 firms), electrical (83 firms), pharamaceutical(87 firms) and transport equipment (automobile and auto ancillary) (94 firms). Out of these four industries only cotton industry showed the positive and significant impact on the productivity performance of firms. Overall results that by entering in export market does not improved the productivity but by exit from export output market does had adverse effect on productivity. Kim and Saravanakumar, (2012) discussed firm level panel data of seven manufacturing industries. Stochastic frontier analysis was used to breakdown productivity into four components: technical progress (TP), Technical efficiency change (TEC), Allocative Efficiency Change (AEC) and Scale Efficiency Change (SEC). Results showed that technical progress was the major component in determining TFPG (Total Factor Productivity Growth but all the other components also contributed significantly to determine TFPG. Average TFPG increased in the sample industries except non metal industry. Saravanakumar and kim (2012) included time period of 24 years to analyse the impact of economic reforms on total factor productivity growth and its major two components i.e. efficiency improvement and technological progress in Indian manufacturing industries. The study covered only organised manufacturing segment of manufacturing industries and for this study value added was considered as output measure , labour and capital were considered as inputs. Results were differ in different sectors such as after reforms productivity of heavy industries were increased but the productivity of light industries were decreased. Babu et al. (2013) analysed state wise TFPG and results showed that TFPG improved in all states except Tamil Naidu and West Bengal and technical progress was the major driver of growth in all states of organised manufacturing structure. 15 major states were selected for the analysis. Data Envelopment Analysis was calculated to compute Malmquist Total Factor Productivity Growth. Labour Productivity and TFPG was calculated. Study showed significant growth in labour productivity across states its around 4 to 10%. LP registered faster growth in 1980/81 to 1990/91 and slower growth in 1991/92 to 2000/01. Study also suggested that where capital stock was faster registered higher labour productivity and state and slower growth in employment. Goldar et al. (2016) discussed13 major manufacturing industries were considered to measure TFP growth of formal and informal segments. The results showed that average TFP growth in informal sector was lower as compare to formal sector. Both formal and informal sector experienced a fall in TFP growth in between 1994-2002 as compared to 1980- 1993 and experienced acceleration TFP growth in between 2003-11.

These above 11 studies showed mixed effect of economic reforms on the total factor productivity growth of Indian manufacturing sector. It is evident that certain sectors necessitate additional research and favorable government policies to foster growth in the face of economic reforms.

SUMMARY

Several empirical studies have thoroughly investigated the impacts of reforms on the total factor productivity growth within the Indian manufacturing sector. Based on the available data, a summary of the 86 studies reveals that approximately 59% (48 studies) indicate a positive impact of economic reforms on Total Factor Productivity Growth within the manufacturing sector. On the other hand, around 32% (27 studies) report either negative outcomes or no significant impact from economic reforms. Additionally, about 13% (11 studies) highlight a mixed effect resulting from these reforms on sector's total factor productivity growth.

This thorough analysis provides opportunities for future studies to use these results and delve deeper into how economic changes affect how well the manufacturing sector performs in India. More research in this direction can help us understand the topic better and provide useful insights for making policies and decisions.

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The Paradox of Data & Privacy: The Dilemma of Data Sharing

Himadri Shikhar Prajapati[1]
[1]Independent Researcher for Mach.ONE

Abstract
The digital era has become the most valuable commodity, often surpassing traditional assets in worth. The notion that privacy is an inherent right has now been challenged by widespread data collection, algorithmic profiling, and real time behavioural tracking by corporations, governments and data brokers. Privacy once regarded as an inviolable human right, has now became a transactional asset. This century has witnessed the rise from capitalism to data capitalism, wherein the individual behaviours, preferences, & interactions are harvested and monetised at an unprecedented scale. Digital surveillance mechanisms, often masked as convenience tools, erode the boundaries of personal privacy. The surveillance economy is not an anomaly but a design crafted to harvest human attention and behavioural predictability for profit.

While the 'Privacy Paradox' represents the growing contradiction between individuals' expressed concerns about data privacy and their actual online behaviours, which often involve voluntary disclosure of personal information. As individuals assert a desire to protect their personal data, yet willingly exchange it for their own convenience, personalisation & connectivity, and this contradiction lies at the heart of this paradox. The privacy paradox runs mainly unconsciously, making it even more prone to lead to risks. These are multifaceted and far-reaching, from privacy violations and data breaches to the manipulation and exploitation of user data by companies. The paradox persists in the first place not because people do not care about their privacy, but a manipulated digital system subtly coerces them into trade-offs that prioritise participation over the protection of personal data.

**Email: hsprajapati1407@gmail.com*

Keywords: data capitalism, digital surveillance, data monetisation, digital privacy, data exploitation, right to privacy, privacy trade-offs, behavioural tracking, attention economy.

INTRODUCTION

Data Privacy

Data Privacy is fundamentally about maintaining an individual's control over their personal information how it is collected, processed, and used by others. It lies at the intersection of ethics, technology, and human rights, emphasizing autonomy, dignity, and the right to be forgotten in the digital space.

In the modern digital ecosystem, data privacy goes beyond protecting mere "personal details." It encompasses everything that can reveal a person's identity, preferences, beliefs, and behavioural patterns often derived through invisible layers of algorithmic analysis and data inference. Every click, search, and interaction generates data that contributes to a user's digital footprint, which can be aggregated to predict or manipulate future choices.

The paradox of privacy lies in its invisibility, while individuals express deep concern about their data being misused, they often remain unaware of the extent of surveillance and profiling occurring in the background. Modern technology systems are designed to collect data seamlessly, disguising surveillance as personalization. For instance, recommendation engines, location-based services, and smart assistants continuously gather contextual data under the guise of convenience.

Thus, data privacy is not merely about protecting information; it is about preserving agency in the digital environment. It questions whether individuals truly have the freedom to make informed decisions when the system itself is structured to trade personal autonomy for participation.

Data Sharing

Data Sharing represents the movement of data across individuals, organizations, or platforms for various purposes ranging from analytics and innovation to personalization and marketing. While it serves as the foundation of the digital economy, it also introduces complex layers of dependency, control, and ethical conflict.

At its core, data sharing is a transaction of trust. When users share their information, they implicitly assume that it will be handled responsibly and securely. However, this trust is often misplaced due to asymmetric power dynamics between data collectors (corporations, platforms) and data providers (users). What begins as voluntary disclosure often transforms into involuntary surveillance, as shared data is repurposed, aggregated, and sold to third parties.

Data sharing also embodies the duality of digital progress it is both enabling and exploitative. On one hand, it fuels innovation, artificial intelligence, and efficiency. On the other, it commodifies human experiences by turning personal information into a market asset, stripping it of context and consent. The modern internet economy thrives on this cycle, where users continuously feed data streams that reinforce predictive algorithms, advertisements, and corporate profits.

Interrelationship Between Data Privacy and Data Sharing

The relationship between data privacy and data sharing is inherently paradoxical that they coexist in tension, yet depend on each other. Without data sharing, the digital world loses its connective and innovative potential; without data privacy, it risks becoming a space of total surveillance and manipulation.

This interplay forms the foundation of what research scholars term the “data dilemma”, individuals and organizations must decide how much privacy they are willing to sacrifice for access, convenience, or participation. The more data is shared, the more predictive and personalized digital systems become yet the less control individuals retain over their digital identities.

In practical terms, every interaction online involves a privacy trade-off: logging into a service, accepting cookies, or using personalized recommendations implies consenting to data collection. Over time, this dynamic normalizes surveillance, making privacy seem like a negotiable comfort rather than a non-negotiable right.

Moreover, the psychological dimension of this relationship is equally critical. The convenience of modern technology often triggers cognitive dissonance; individuals know the risks of data exposure but rationalize their participation as necessary. This behaviour sustains the privacy paradox, where awareness does not translate into action.

Ultimately, data privacy and data sharing reflect the moral architecture of the digital age. The balance between them determines whether technology empowers individuals through knowledge and connection or reduces them to data points in a profit-driven system. The challenge ahead lies not merely in protecting data, but in redefining what it means to be private and free in an interconnected, data-centric world.

PROBLEM

The tension between data privacy and data sharing creates profound challenges that ripple through both individual lives and entire societies. While the exchange of data drives connectivity, personalization, and innovation, it simultaneously exposes individuals to manipulation and societies to structural vulnerabilities.

The problem, therefore, is not just about who owns the data, but about who controls the narrative and the power it generates.

1. The Individual User Problem

At the individual level, the erosion of privacy begins subtly, often disguised as convenience. The problem is psychological, behavioural, and moral in nature.

a. Loss of Autonomy and Informed Consent

Most users lack awareness of how much data they generate or how it is used. Consent is often obtained through long, opaque privacy policies that are neither read nor understood. This illusion of consent means individuals lose meaningful control over their own digital identities.

Even when users “agree” to share their data, it’s rarely an informed decision, it’s coerced participation. The digital ecosystem is designed to make opting out inconvenient, effectively forcing users to trade privacy for participation.

b. Behavioral Manipulation and Surveillance
Collected data is not just stored; it is analysed to predict, influence, and shape behaviors. Algorithms learn what users like, fear, or desire and use this knowledge to nudge decisions in specific directions, from consumer purchases to political opinions.
In this way, privacy loss becomes a psychological control mechanism, reducing individual agency and promoting predictable, programmable behaviors.

c. Identity Theft and Data Exploitation

The more data an individual shares, the greater their exposure to cybercrimes, identity theft, and fraud. Personal data such as biometrics, financial records, or browsing histories can be stolen, sold, or misused for impersonation and financial exploitation.

d. Emotional and Cognitive Fatigue
Constant surveillance creates a sense of digital vulnerability. The awareness that one’s actions, preferences, and communications are being tracked leads to self-censorship and a decline in authentic expression. Over time, this causes psychological fatigue, trust erosion, and anxiety about digital participation.

2. The Societal and Systemic Problem
At the societal level, data privacy violations and unchecked data sharing are not isolated issues they shape power structures, market behaviors, and even democratic processes.

a. Concentration of Power and Digital Inequality
Data has become the new capital, and those who control IT tech corporations, data brokers, and governments who hold disproportionate powers. This leads to a digital oligarchy, where a few entities dominate public discourse, consumer choices, and access to information.
Smaller organizations or developing nations without large-scale data access face structural disadvantages, deepening economic inequality.

b. Erosion of Trust and Transparency
When users realize their data is constantly monitored or exploited, it diminishes trust in institutions at both corporate and government level. A trust deficit emerges, where citizens doubt the intentions behind digital initiatives or online platforms. This distrust hinders innovation and slows digital adoption in the long run.

c. Mass Surveillance and Social Control
At the macro level, mass data collection enables systemic surveillance, allowing states or corporations to monitor populations in real time. This surveillance can be weaponized for political control, discrimination, or censorship, undermining democratic freedoms and civil rights.

d. Algorithmic Bias and Discrimination
When shared data is used to train AI systems, it often reflects and amplifies existing social biases. This leads to discriminatory outcomes in hiring, policing, credit scoring, or healthcare access. Thus, the misuse of shared data extends beyond privacy as it reshapes fairness and justice at systemic levels.

e. Commodification of Human Experience

Perhaps the most profound macro consequence is the commodification of human life itself. In a data-driven economy, every action from sleeping patterns to emotional expressions could become a potential revenue source. This redefines human beings not as citizens or consumers, but as data-generating resources, reducing individuality to market value.

PRIVACY PARADOX

The Data Privacy Paradox refers to the inconsistency between individuals expressed concern for data privacy and their actual online behaviors'. In theory, users value their privacy and claim to be cautious about sharing personal information. In practice, however, they frequently disclose sensitive data to digital platforms, apps, and services often willingly and without scrutiny.

This paradox lies at the core of modern digital behaviors: people care about privacy yet act as if they don't. It exposes the psychological and systemic manipulation that defines the contemporary digital ecosystem, where convenience, social connection, and personalization override rational privacy concerns.

Why the Data Privacy Paradox Exists?

The paradox exists not because individuals are careless, but because the digital environment is engineered to encourage data disclosure through psychological, behavioral, and structural mechanisms.

1. **Asymmetric Power and Information Gaps**

Digital systems are designed by corporations that understand user behaviors far better than the users understand the systems themselves. This information asymmetry gives platforms complete control over how choices are framed, permissions are requested, and defaults are set.

2. **Behavioural Conditioning through Convenience**

Human decision-making is largely driven by convenience and reward. The instant gratification of digital platforms for faster checkout, personalized recommendations, or free services which makes data sharing seem like a fair exchange. This habitual trade-off reinforces a feedback loop where users prioritize ease over privacy.

3. **The Illusion of Control**

Most digital systems provide users with privacy settings or consent options that create a sense of control. In reality, these settings are often complex, misleading, or ineffective. The illusion of control pacifies privacy anxiety, leading users to believe they have safeguarded their data when they have not.

4. **Social Pressure and Digital Normalization**

Social media platforms thrive on visibility and participation. The need to belong, share, and express oneself online encourages users to overshare personal information. Over time, privacy loss becomes normalized, and surveillance is accepted as the "cost of being social."

5. **Manipulated Design Systems**

Digital systems are deliberately structured to make privacy protection inconvenient. Algorithms track every digital footprint to predict behaviour, while design nudges like default data sharing, continuous prompts, and personalized incentives to coerce users into voluntary exposure.

Behavioural Patterns in a Manipulated Digital Ecosystem

Behavioural Pattern	Explanation	Example
Cognitive Dissonance	Users express concern for privacy but justify sharing data as "necessary."	Downloading a free app despite knowing it collects contacts and location.
Optimism Bias	Belief that privacy violations happen to others, not to oneself.	"I'm not important enough for my data to matter."
Instant Gratification	Prioritizing immediate convenience over long-term data safety.	Accepting cookies to quickly access a website.
Trust in Platform Authority	Assuming reputed brands automatically protect privacy.	Believing a global social media platform won't misuse information.
Privacy Fatigue	Overwhelmed by privacy choices, users surrender to defaults.	Ignoring permission requests and clicking "Allow All."

Fig.1: Consumer behaviour within manipulated digital systems reflects several recurring psychological patterns

CASE STUDY: THE CAMBRIDGE ANALYTICA- FACEBOOK SCANDAL

Background

The Cambridge Analytica scandal (2018) is one of the most significant real-world examples illustrating the data privacy paradox and its systemic implications. Cambridge Analytica, a political consulting firm, harvested personal data from over 87 million Facebook users without their explicit consent and used it to influence voter behaviour in political campaigns, including the 2016 U.S. Presidential Election and the Brexit referendum.

How It Happened?

1. **Data Collection through Deception-** A seemingly harmless Facebook quiz app, "This Is Your Digital Life," developed by researcher Aleksandr Kogan, collected not only the quiz participants' data but also data from their entire friend network exploiting Facebook's API loophole.
2. **Profiling and Psychographic Analysis-** Using the harvested data, Cambridge Analytica built detailed psychological profiles of millions of individuals, identifying their personality traits, fears, and motivations.
3. **Targeted Political Advertising-** These insights were then used to micro-target individuals with personalized political ads, propaganda, and misinformation shaping opinions, reinforcing biases, and influencing voting decisions.

The Privacy Paradox in Action

Despite years of public awareness about Facebook's data collection, users willingly shared personal information and participated in quizzes or apps for entertainment. The perceived harmlessness of interaction blinded users to the massive extraction of personal data occurring in the background.

Even after the scandal surfaced, billions continued to use Facebook and Instagram, demonstrating how behavioural dependency and convenience overpower privacy concerns.

Consequences

- Facebook faced a $5 billion fine by the U.S. Federal Trade Commission (FTC) one of the largest in history.
- The incident sparked global discussions on data ethics, user consent, and algorithmic accountability.
- It revealed the vulnerability of democracies to data-driven manipulation and the political power of digital surveillance.

Key Takeaways from the Case Study

1. **Privacy Breach Is Not Always Visible-** Users often cannot detect when their data is misused. The invisible nature of data harvesting makes surveillance more dangerous than theft.
2. **Consent Does Not Equal Control-** Users technically gave permission to Facebook's ecosystem but lacked meaningful understanding of its implications. This exposes the illusion of informed consent in digital systems.
3. **Data Is Political Power-** Personal information, when aggregated, can manipulate public opinion and influence democratic outcomes showing that privacy loss extends beyond individuals to societal integrity.
4. **Platforms Profit from Engagement, Not Protection-** Facebook's algorithms prioritized user engagement (likes, shares, clicks) over ethical safeguards, proving that corporate incentives often conflict with privacy protection.
5. **The Paradox still Persists-** Despite global outrage, Facebook's user base grew after the scandal. This reflects the deep-rooted psychological dependency of users on digital platforms, reinforcing the privacy paradox.

What does the Situation in India looks like?

In recent years, data privacy concerns in India have intensified amid an alarming rise in cyber threats, large-scale data breaches, and growing debate over the implications of the Digital Personal Data Protection (DPDP) Act, 2023. While the Act represents a major step toward safeguarding individual privacy, it has also sparked apprehension about state surveillance, implementation gaps, and potential misuse of exemptions granted to government agencies.

Rising Tide of Data Breaches and Cyber Threats

India has witnessed a **sharp escalation in data breaches** across both corporate and public sectors, leading to the exposure of sensitive personal information belonging to millions of citizens. The scale and sophistication of these cyber incidents underscore the nation's growing digital vulnerability.

- **Surge in Cyberattacks:** The number of cybersecurity incidents reported in India more than doubled, from 1.03 million in 2022 to 2.27 million in 2024. In the same year alone, the country faced an estimated 370 million malware attacks, marking one of the highest global figures.

- **Major Data Breaches:**

➢ **Indian Council of Medical Research (ICMR):** In late 2023, the personal data of over 815 million Indians including Aadhaar and passport details was leaked on the dark web, prompting an ongoing investigation by the Central Bureau of Investigation (CBI).

➢ **boAt (April 2024):** The electronics brand suffered a breach that compromised data from 7.5 million customers, with personal information surfacing on the dark web.

➢ **Angel One (July 2024)**: The stockbroking firm reported a leak affecting 8 million clients, exposing bank account numbers and financial credentials.

➢ **Star Health Insurance (September 2024):** A data breach revealed 31 million records, including medical histories, PAN numbers, and policy details.

Sectoral Vulnerabilities

According to 2024 reports, the education, government, financial services, and technology sectors remain prime targets for cybercriminals due to their extensive handling of personal and financial data. These incidents highlight not only systemic lapses in cybersecurity but also the urgent need for stronger data governance frameworks, user awareness, and accountability among organizations handling sensitive information.

Why These Breaches Pose Serious Risks

The escalating frequency of data breaches and cyber incidents in India poses significant risks at both individual and national levels, making data privacy not just a personal concern but a matter of digital sovereignty and economic stability.

At the individual level, compromised data such as Aadhaar numbers, financial credentials, and medical records can lead to identity theft, financial fraud, phishing attacks, and unauthorized surveillance. Personal data in the wrong hands can be exploited for blackmail, targeted misinformation, or even psychological profiling, undermining citizens' trust in digital platforms and institutions.

At the macro level, repeated breaches erode public confidence in digital governance, discourage innovation, and threaten the foundations of India's growing digital economy. Sensitive leaks from government or healthcare databases expose vulnerabilities in national infrastructure, which can be exploited by hostile actors for espionage, manipulation, or cyber warfare. Moreover, inadequate enforcement and accountability in data handling create a culture of impunity and weak corporate responsibility, further amplifying systemic risks.

Digital Personal Data Protection Act, 2023

The Digital Personal Data Protection Act (DPDP Act), 2023 is India's landmark legislation aimed at protecting personal data in the digital space. It replaces earlier, fragmented rules under the IT Act, 2000 and its amendments, establishing a comprehensive framework for processing and safeguarding digital personal data. The Act reflects India's efforts to balance individual privacy rights with the needs of a growing digital economy.

Significance

The DPDP Act represents India's effort to codify digital privacy as a fundamental aspect of modern life. It aims to create a trust-based digital ecosystem where individuals can participate in online services without sacrificing control over their personal data. At the same time, the Act has sparked debates about state surveillance, implementation challenges, and potential misuse of exemptions, highlighting the delicate balance between privacy, security, and governance in a digital society.

Key Objectives

1. **Safeguard Individual Privacy:** Ensure that individuals (data principals) have control over how their personal data is collected, used, and shared.
2. **Regulate Data Processing:** Establish clear rules for organizations (data fiduciaries) that handle personal data, making them accountable for responsible data usage.
3. **Promote Transparency and Accountability:** Require organizations to disclose the purpose, storage, and sharing practices of personal data.
4. **Enable Digital Innovation:** Provide a regulatory environment that allows businesses to innovate while respecting user privacy.

Key Features

- **Consent-Based Processing:** Personal data can only be collected, processed, or shared with the explicit, informed consent of the individual.
- **Purpose Limitation:** Data collected must only be used for the specific purpose declared at the time of collection.

- **Rights of Individuals:** Users have rights including access, correction, erasure, and grievance redressal regarding their personal data.

- **Data Fiduciary Obligations:** Organizations are responsible for ensuring accuracy, integrity, and security of the data they handle.

- **Exemptions for Government Agencies:** Certain government data processing activities are exempted, which has raised concerns about potential overreach.

- **Cross-Border Data Transfer:** Personal data can be transferred abroad only under conditions specified by the government.

- **Penalties for Non-Compliance:** The Act prescribes financial penalties and other enforcement measures for violations.

Evolving Privacy Risks in India

Beyond traditional data breaches and gaps in legislation, emerging technologies and modern market practices are creating new and complex privacy challenges for Indian users. These risks are dynamic, multifaceted, and often invisible, making them difficult to mitigate.

1. Mobile App Data Harvesting

A 2024 report highlighted that many mobile applications collect excessive user data, often without clear disclosure or consent. These apps track location, contacts, messages, and usage patterns, frequently for targeted advertising or behavioural profiling. The data is often shared with third-party advertisers or analytics companies, exposing users to potential misuse without their knowledge. This practice exploits users' limited understanding of digital consent and perpetuates the privacy paradox- users trade personal information for convenience or free services.

2. Big Tech Data Practices

Global technology giants, including Google, Meta (Facebook), and Amazon, maintain extensive data collection systems to track user behaviour across platforms. Data points such as browsing history, geolocation, and device usage patterns are aggregated to build highly detailed user profiles, which are monetized through advertising and commercial insights. Many users feel they have minimal control over how this data is collected, analysed, or shared, raising concerns about corporate accountability and digital autonomy.

3. AI-Driven Privacy Threats

The rapid rise of **Artificial Intelligence (AI)** has amplified privacy risks. AI systems can process vast datasets at unprecedented speeds, making them capable of:

- **Automated profiling and predictive analytics**, which can affect financial, healthcare, and employment decisions.
- **AI-driven scams**, such as phishing and social engineering attacks, which are increasingly sophisticated.
- **Deepfakes**, which can misuse personal images, voices, or videos for impersonation, fraud, or reputational harm.

4. Digital Infrastructure Vulnerabilities

Large-scale government digital initiatives have introduced both efficiency and privacy concerns.

Systems such as Aadhaar (biometric identification) and DigiYatra (biometric airport travel) collect highly sensitive personal and biometric data. Critics argue that these infrastructures:

- Lack adequate privacy safeguards to prevent misuse.
- Pose risks of mass surveillance if data is accessed without stringent controls.
- Amplify the consequences of potential data leaks or breaches, given the scale and sensitivity of the information collected.

These vulnerabilities illustrate that privacy risks are no longer limited to private corporations; they extend to national digital infrastructure, where breaches or misuse can have far-reaching societal consequences.

CONCLUSION

In the digital era, personal data has emerged as one of the most valuable commodities, reshaping both individual experiences and societal structures. While technological advancements have enhanced convenience, connectivity, and personalization, they have simultaneously exposed individuals and societies to unprecedented privacy risks. The Data Privacy Paradox exemplifies this tension: despite widespread awareness and concern over privacy, users frequently share personal information, often unconsciously, under the subtle influence of digital systems designed to prioritize participation over protection. Behavioural patterns such as cognitive dissonance, optimism bias, and privacy fatigue reinforce this paradox, creating a complex web where convenience and engagement come at the cost of autonomy and control. In essence, the evolving privacy landscape in India reflects a delicate balance between digital innovation and individual autonomy. Protecting personal data requires not only legal frameworks but also ethical corporate practices, user awareness, technological safeguards, and systemic accountability. The challenge ahead lies in redefining digital participation so that convenience, connectivity, and innovation coexist with privacy, trust, and agency, ensuring that the digital ecosystem empowers users rather than exploits them.

Ultimately, data privacy is no longer a peripheral concern; it is a cornerstone of ethical digital governance, social trust, and sustainable innovation. How India navigates this balance will determine not only the integrity of its digital economy but also the fundamental rights and freedoms of its citizens in the 21st century.

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Product-as-a-Service Business Models: Opportunities and Challenges in Industrial Circularity

Mr. Zafir Khan[1]
[1]Faculty, KK Modi University, Durg

Abstract

Product-as-a-Service (PaaS) represents a transformative shift from traditional linear ownership models to circular, service-based delivery systems within Industry 5.0 frameworks. This research examines PaaS as a catalyst for circular economy integration, analyzing financial viability, environmental sustainability, and operational complexities through empirical case studies and contemporary frameworks. Evidence from industry leaders—including Rolls-Royce's "Power by the Hour," Philips' "Lighting-as-a-Service," and Kaeser Kompressoren's compressed air utility—demonstrates that PaaS models generate substantial economic value while reducing resource extraction and waste. Key findings reveal 30-66% higher lifetime profitability compared to traditional sales, 20-40% product lifespan extensions, and 25-35% material consumption reductions. However, successful implementation requires fundamental organizational restructuring, significant digital infrastructure investment, and sophisticated financial assessment methodologies. This paper provides evidence-based insights for manufacturers and policymakers, identifying critical success factors and strategic pathways for scalable circular economy transitions.

*Email: zafir3007@gmail.com

Keywords: Product-as-a-Service, Circular Economy, Industry 5.0, Sustainable Manufacturing, Business Model Innovation

INTRODUCTION

1. Research Context and Motivation

The contemporary manufacturing sector confronts converging pressures that challenge traditional business model viability: accelerating resource scarcity, stringent environmental regulations, climate imperatives, and evolving customer expectations for sustainable alternatives. The linear "take-make-dispose" paradigm has become economically and environmentally untenable, necessitating fundamental transformation. Industry 5.0—characterized by human-centric manufacturing enhanced by advanced digital technologies—provides an enabling framework for this transition through integration of Internet of Things (IoT), artificial intelligence, and digital twins into production ecosystems.

Within this landscape, the circular economy has emerged as a strategic imperative rather than merely an environmental compliance concern. Modern circular business models demonstrate compelling economic benefits by maintaining products, components, and materials at their highest value through multiple lifecycle iterations, effectively "closing the loop" on resource flows.

Product-as-a-Service (PaaS) embodies a specific manifestation of circular principles by decoupling economic growth from resource consumption. Rather than transferring ownership of physical products to customers, manufacturers retain ownership while customers access product functionality through subscription, leasing, pay-per-use, or performance-based arrangements. This fundamental shift realigns manufacturer incentives toward product longevity, resource efficiency, and lifecycle optimization—direct contradictions to the planned obsolescence implicit in traditional sales models.

2. Research Gap and Objectives

Despite conceptual appeal and documented early successes, PaaS adoption remains limited across industrial sectors. Critical knowledge gaps persist regarding financial assessment frameworks that adequately capture multi-lifecycle revenue streams, implementation methodologies for product suitability evaluation, risk characterization for operational uncertainties, and policy coherence across fragmented regulatory jurisdictions.

This research addresses five fundamental questions: What financial conditions enable PaaS profitability compared to traditional models? How do organizational capabilities and digital infrastructure requirements differ? What environmental benefits materialize and how are they quantified? What policy mechanisms effectively accelerate adoption? What product and industry characteristics determine suitability?

Through synthesis of academic literature, industry case studies, and practitioner frameworks, this paper provides actionable guidance for manufacturers considering PaaS transitions within Industry 5.0 contexts.

CONCEPTUAL FRAMEWORK AND THEORETICAL FOUNDATIONS

1. PaaS Model Typology and Economic Mechanics

PaaS encompasses several operational models distinguished by revenue structures and risk allocation:

Leasing and Renting: Customers access products for defined periods while manufacturers maintain ownership and bear maintenance costs. Revenue derives from rental payments. Common in construction equipment, automobiles, and specialized machinery.

Pay-Per-Use Models: Revenue correlates directly with quantifiable product usage metrics (flight hours, copies produced, cubic meters delivered). This achieves strongest alignment between manufacturer incentives and sustainability objectives, as revenue maximization requires optimizing utilization efficiency and extending operational lifespan.

Performance-Based Contracts: Customers pay for guaranteed outcomes rather than products or usage—"illumination levels" rather than lighting fixtures, "temperature maintenance" rather than HVAC equipment. Result-oriented models exhibit highest circularity potential but demand sophisticated service delivery capabilities.

Product Subscriptions: Recurring fixed or variable fees bundle product access with maintenance, upgrades, and services, offering predictable revenue streams while managing customer acquisition costs through extended relationship lifecycles.

2. Asset Utilization Economics

Central to PaaS viability is asset utilization—the efficiency with which products generate revenue. Traditional ownership models fail to capture potential utilization because products remain underutilized by single customers. Construction equipment might operate 20% of available hours under customer ownership; under PaaS, the same equipment can service multiple customers across longer lifecycles, potentially achieving 60-80% utilization.

Higher asset utilization enables manufacturers to distribute fixed costs across more transaction cycles, generate greater lifetime revenue per unit, increase pricing flexibility, and create financial incentives for durability and reliability. This economic foundation underpins PaaS financial viability.

3. Circular Economy Integration Mechanisms

PaaS naturally embodies circular economy principles through multiple pathways:

Design Incentives: Retained ownership creates manufacturer incentives to design for durability, modularity, and end-of-life resource recovery—contrasting sharply with planned obsolescence in ownership-based models.

Closed-Loop Material Management: Manufacturers can recover materials at end-of-life, reintegrate them into manufacturing processes, or remanufacture products. The manufacturer assumes comprehensive lifecycle responsibility, not merely initial sale transaction.

Extended Product Lifecycles: Maintenance responsibility encourages specification of components with extended replacement intervals, upgrade pathways, and remanufacturability. Washing machines might transition from 12-year to 18+ year lifecycles under PaaS models.

Systemic Value Capture: Material residual value and remanufactured product revenue streams are retained by manufacturers, creating financial incentives previously absent in linear models.

FINANCIAL VIABILITY ASSESSMENT

1. Limitations of Traditional Financial Analysis
Traditional financial analysis treats product sales as terminal transactions, assuming single revenue events followed by customer responsibility for maintenance and disposal. This framework fundamentally misrepresents PaaS economics, which generate value across multiple lifecycles through leasing revenue, maintenance services, remanufacturing, material recovery, and residual asset value. Executives applying linear frameworks to circular models consistently underestimate profitability, creating systematic bias against PaaS adoption.

2. Lifecycle Costing and Net Present Value Framework
Rigorous PaaS financial assessment employs lifecycle costing methods comparing Net Present Value (NPV) and Total Cost of Ownership (TCO) from both provider and user perspectives across 15-25 year time horizons spanning multiple product lifecycles.

Provider Perspective:

- Revenues: Lease payments, maintenance fees, remanufactured product sales, material recovery value (typically 5-15% of manufacturing cost)
- Costs: Manufacturing, maintenance, component replacement, remanufacturing, recycling
- Cash flow consideration: Upfront manufacturing costs versus distributed revenue streams requiring appropriate discount rates

User Perspective:

- Costs: Service payments, transaction costs, opportunity costs of non-ownership
- Benefits: Eliminated capital investment, predictable expenses, guaranteed performance

3. Critical Profitability Drivers and Empirical Evidence
Research identifies seven variables determining PaaS financial viability: product initial cost (higher strengthens case), depreciation rate (slower favors PaaS), maintenance costs (predictable enables accurate projections), material residual value, service pricing, utilization frequency, and asset utilization rate—the critical variable that must increase sufficiently to justify operational complexity.

Construction Equipment Case Study:
Financial modeling over 15-year evaluation period revealed:

- Traditional sales model: €2,000 unit sale, 30% lifetime margin
- PaaS subscription model: €150 monthly subscription, 8-year average customer relationship
- Total revenue per unit: €14,400 (96 months)
- Total costs: €8,500 (manufacturing, maintenance, remanufacturing, recycling)
- Lifetime margin: €5,900 (41% margin)
- **Result: 66% higher profitability versus sales model**

Sensitivity analysis revealed breakeven at 42-month customer retention and 500+ active subscriptions for infrastructure cost amortization, demonstrating viable pathways to profitability under realistic operational assumptions.

ENVIRONMENTAL BENEFITS AND IMPACT QUANTIFICATION

1. Environmental Benefit Mechanisms

PaaS delivers quantifiable environmental benefits through four primary mechanisms:

Manufacturing Impact Reduction: Product longevity extension reduces manufacturing demand. Extending washing machine lifespan from 12 to 18 years eliminates 33% of replacement manufacturing per customer. Manufacturing typically accounts for 60-80% of lifecycle carbon emissions, making lifespan extension highly impactful.

Resource Conservation: Design for durability and recovery reduces material intensity. PaaS washing machines incorporate reinforced components, higher-quality bearings, and modular architecture enabling selective replacement. Analysis demonstrates 25-35% material consumption reductions compared to ownership models, translating to 180 kg steel savings per unit over 20 years.

Energy Efficiency Optimization: Retained manufacturer responsibility incentivizes energy-efficient design and maintenance optimization. Philips' Lighting-as-a-Service achieved 40-50% energy consumption reduction through LED technology and system optimization. Preventive maintenance sustains efficiency performance, delivering 10-15% energy savings compared to owner-maintained equipment.

Lifecycle Emissions Reduction: Extended lifespan distributes manufacturing emissions across more years while optimized maintenance reduces operational emissions. PaaS models demonstrate 15-40% lifecycle carbon footprint reductions, with washing machine case studies documenting 2.5 metric tons CO_2e savings over 20 years.

2. Quantification Framework and Performance Metrics

Recommended measurement framework includes five key metrics:

- **Product Lifespan Extension:** Years added versus traditional model (target: +25%)
- **Material Recapture Rate:** Percentage of end-of-life materials recovered (target: >85%)
- **Carbon Footprint Reduction:** Lifecycle emissions reduction percentage (target: >20%)
- **Energy Intensity Reduction:** Annual energy per unit service delivery (target: >15%)
- **Resource Efficiency Improvement:** Virgin material demand reduction (target: >30%)

3. Social Co-Benefits

Beyond environmental impacts, PaaS generates underappreciated social benefits. Employment creation in maintenance, repair, refurbishment, and remanufacturing provides opportunities in lower-income communities. Lower effective costs for durable product access benefit populations traditionally purchasing low-quality, high-impact replacement products. Retained manufacturer responsibility ensures evolving safety standard compliance, eliminating customer neglect risks in maintenance-critical systems.

REAL-WORLD IMPLEMENTATION: CASE STUDY EVIDENCE

1. Rolls-Royce "Power by the Hour" (Aerospace)

Rolls-Royce's pioneering model transformed aircraft engines into services where airlines pay per flight hour for engine provision, maintenance, and performance guarantees rather than purchasing engines. Serving 200+ operators globally, the model delivers higher lifetime margins despite lower unit prices through predictive maintenance enabled by performance data, reducing unscheduled downtime 40-50%. Environmental benefits include 15-25% lifespan extension and significant material recovery through remanufacturing. Success factors include high engine capital costs creating customer payment friction, significant maintenance costs justifying manufacturer optimization, safety-critical applications enabling premium pricing, and competitive differentiation through service quality.

2. Kaeser Kompressoren "Sigma Air Utility" (Industrial Equipment)

German manufacturer Kaeser transformed from equipment sales to compressed air utility, with customers paying per cubic meter delivered. Operating 15+ years with 500+ installations across manufacturing, automotive, and pharmaceutical facilities, customers achieve 20-40% TCO reduction while Kaeser delivers 10-15% energy efficiency improvements through advanced scheduling and system optimization. Energy costs representing 75-80% of compressed air TCO create perfect incentive alignment. Success demonstrates utility-like service models excel where operations are highly variable and manufacturer expertise provides differentiated optimization value.

3. Philips Lighting-as-a-Service (Commercial Lighting)
Philips pioneered outcome-based lighting contracts wherein customers pay for illumination levels rather than fixtures. Amsterdam Schiphol Airport deployment achieved 40-50% energy reduction through LED technology and optimization, extended fixture lifespan from 10-12 to 15-18 years through durability design, and commanded 15-25% pricing premiums over product sales. Commoditized market conditions threatened traditional margins, making service differentiation strategically essential. Environmental performance metrics resonated with institutional purchasers, creating competitive advantage.

4. Hilti Tool-as-a-Service (Construction Equipment)
Construction tool manufacturer Hilti introduced subscription models bundling tool access, maintenance, repairs, and replacements through fixed monthly fees. Operational since 2019 with expanding adoption, the model addresses construction industry capital constraints while eliminating maintenance cost unpredictability. Modular tool design enables efficient component replacement, and geographic service networks enable scalable delivery. Results demonstrate capital-constrained segments and unpredictable maintenance costs create strong PaaS adoption potential.

IMPLEMENTATION CHALLENGES AND BARRIERS

1. Organizational Transformation Requirements
Transitioning from transaction-based sales to relationship-based service revenue demands fundamental organizational restructuring. Revenue recognition accounting changes, sales team skill development (consultative versus transactional), service delivery infrastructure development, performance measurement redesign, and supply chain reconfiguration for reverse logistics present substantial challenges. Mitigation requires pilot programs limiting financial exposure, cross-functional transformation teams, and gradual migration through hybrid offerings.

2. Digital Infrastructure and Operational Complexity
PaaS optimization requires real-time product performance data, necessitating sensor deployment (€500-2,000 per unit), data transmission infrastructure, cloud analytics platforms, cybersecurity compliance, and legacy system integration. Digital infrastructure investment typically represents 8-15% of project capital expenditure. Service delivery costs (15-25% of revenue) must be carefully managed through digital technology leverage (IoT, predictive maintenance, remote diagnostics), strategic partnerships, and modular delivery enabling scalability.

3. Financial and Market Uncertainties
Traditional financing favors immediate product sales over distributed PaaS revenue streams. Balance sheet impacts (deferred revenue recognition), cash flow timing misalignment, and working capital requirements create capital structure challenges. Solutions include asset-backed financing, revenue securitization, and strategic partnerships with experienced circular economy financiers. Market uncertainty regarding customer adoption, pricing power, and competitive dynamics necessitates pilot programs, market research integration, and competitive monitoring.

4. Product Design and Suitability

Not all products suit PaaS models. Favorable characteristics include extended durability potential (10+ years), predictable maintenance requirements, significant material residual value, consistent utilization patterns, modular serviceability, and strong sustainability preferences. Unfavorable characteristics include consumable nature, rapid obsolescence, catastrophic failure modes, low material value, maintenance difficulty, and price-driven markets. Design-for-circularity modifications (modularity, component durability, recyclable materials, disassembly optimization, sensor integration) typically require 2-4 years and 5-15% of development budgets.

CIRCULAR ECONOMY INTEGRATION AND INDUSTRY 5.0 ENABLEMENT

1. Digital Technology Enablers

IoT and Sensor Integration: Real-time performance monitoring enables predictive maintenance, utilization optimization, and proactive problem resolution. Applications include engine parameter monitoring (Rolls-Royce), compressor performance tracking (Kaeser), and illumination system efficiency monitoring (Philips), informing design improvements and extending lifecycles through preventive maintenance.

Digital Twins and Simulation: Virtual product replicas enable testing design modifications, service scenarios, and end-of-life recovery processes without physical prototyping, accelerating design-for-circularity implementation while reducing development cycles and improving design quality.

Artificial Intelligence and Predictive Analytics: Machine learning algorithms identify performance patterns enabling predictive maintenance with 80-90% accuracy, demand forecasting for inventory optimization, and supply chain coordination for reverse logistics and remanufacturing, maximizing resource recovery efficiency.

2. Design-for-Circularity Principles

Modularity and Standardization: Standardized, interchangeable modules enable selective replacement, efficient disassembly, scalable remanufacturing, and cross-product commonality. Implementation requires 15-25% design effort increase but reduces lifecycle costs 20-30%.

Material Selection and Recyclability: Prioritizing high-value recyclable materials (aluminum, copper, rare earths), established recycling infrastructure, minimal hazardous content, and supply chain transparency. Redesign adds 2-5% manufacturing cost but enables 5-15% material cost recovery.

Disassembly Optimization: Standardized fastening, minimized adhesives, labeled materials, and optimized workflows. Implementation requires 40-60 hours engineering effort per product, reducing recovery labor 20-40%.

3. Policy Framework and Regulatory Support

Extended Producer Responsibility (EPR): Mandates financial and physical producer responsibility for entire product lifecycle including end-of-life collection and recycling. EU Textiles Regulation (2025) and Waste Framework Directive establish EPR principles, naturally aligning with PaaS models through retained manufacturer ownership.

Circular Product Policy: EU Ecodesign for Sustainable Products Regulation mandates design longevity, repairability, material transparency, planned obsolescence prohibition, and digital product passports for traceability, creating competitive advantage for sustainability-focused companies.

Green Finance Mechanisms: Green bonds, sustainability-linked loans, tax incentives for remanufactured products and recycled materials, R&D subsidies, and favorable public procurement policies. EU allocates €10+ billion to circular economy projects, and development banks integrate circular criteria into lending decisions.

STRATEGIC RECOMMENDATIONS AND CRITICAL SUCCESS FACTORS

1. For Manufacturing Organizations

Assessment and Planning: Identify product portfolios with PaaS potential using durability, maintenance intensity, and material value criteria. Establish dedicated transformation teams with executive sponsorship and cross-functional representation.

Pilot Implementation: Launch pilots with 3-5 early-adopter customers in specific geographies over 18-36 months, validating financial assumptions (customer acquisition cost, retention, service delivery costs), resolving operational challenges, developing service playbooks, building case studies, and training organizational capabilities.

Capability Development: Invest in digital infrastructure (sensors, cloud analytics, service management software, cybersecurity), service delivery operations (maintenance scheduling, spare parts logistics, technical workforce, geographic coverage), and organizational training. Consider strategic partnerships accelerating capability development.

Financial Restructuring: Implement lifecycle costing frameworks enabling rigorous PaaS assessment. Explore asset-backed financing, revenue securitization, customer financing partnerships, and private equity/venture capital partnerships for infrastructure investment. Transition performance metrics from sales volume to customer lifetime value.

2. For Policymakers

Regulatory Harmonization: Consolidate fragmented circular economy requirements across jurisdictions reducing compliance complexity for multinational manufacturers. Harmonize EPR requirements, establish circular product standards, implement green finance mechanisms, develop right-to-repair regulations, and create favorable public procurement policies.

Financial Support: Establish government-backed financing programs supporting circular transitions. Provide R&D subsidies for design-for-circularity innovation. Support pilot programs validating viability. Invest in digital infrastructure for IoT and analytics capabilities.

Stakeholder Engagement: Convene multi-stakeholder platforms with manufacturers, customers, policymakers, and financiers. Support standardization initiatives (ISO TC 323 on circular economy). Facilitate knowledge transfer and best practice documentation. Recognize successful implementations creating market awareness.

3. Customer Targeting and Market Entry

High-probability customer segments include sustainability-focused enterprises with explicit ESG commitments, capital-constrained organizations for whom OpEx models reduce cash requirements, variable-utilization customers with unpredictable consumption patterns, total-cost-conscious organizations making TCO-based decisions, and long-tenured customers providing incumbent advantage. Pursue geographic clusters enabling concentrated service delivery investment and regional operational scale.

FUTURE DIRECTIONS AND EMERGING OPPORTUNITIES

1. Advanced Technology Integration

Autonomous Maintenance Systems: AI-driven systems independently schedule maintenance, order components, and optimize delivery with minimal human intervention, dramatically reducing costs and enabling aggressive pricing benefiting adoption.

Blockchain and Transparency: Distributed ledger technologies enable transparent material provenance tracking and automated circular responsibility execution through smart contracts, enabling circular supply chain verification and certification.

Advanced Manufacturing: 3D printing and additive manufacturing enable distributed remanufacturing with minimal tooling and component customization for perfect-matching replacements from recovered materials, reducing transportation emissions and eliminating material waste.

2. Business Model Innovation

Platform Ecosystems: PaaS providers function as platforms enabling complementary service provider

ecosystems (predictive maintenance specialists, component suppliers, recyclers), reducing single-provider dependency, enabling specialized optimization, and creating customer optionality.
Outcome-Based Financing: Finance providers extend credit directly tied to product outcomes rather than ownership or usage, enabling customer access without capital requirements or subscription commitments, naturally aligning incentives with longevity and performance optimization.

3. Policy and Standards Evolution

International Standards: ISO TC 323 frameworks for circular business model assessment and certification reduce customer due diligence requirements and enable global scaling through international recognition.
Extended Responsibility Integration: Regulatory consolidation requiring comprehensive producer responsibility for environmental and social outcomes across lifecycles, naturally converging with PaaS incentive structures as frameworks become increasingly strict.

CONCLUSION

Product-as-a-Service represents a pragmatic, financially viable pathway toward industrial circularity and sustainable manufacturing aligned with Industry 5.0 objectives. Five key propositions emerge from this research:

First, rigorous financial assessment demonstrates higher lifetime profitability for PaaS under conditions of sufficient product durability, significant predictable maintenance costs, material residual value, and customer retention ≥3 years, requiring lifecycle costing methodologies capturing multi-cycle revenue streams unavailable in traditional frameworks.

Second, quantifiable environmental benefits materialize through extended product lifespans (25-40% emissions reduction), material conservation (20-35% resource reduction), energy efficiency optimization (10-15% operational reduction), and systemic resource circulation enabling near-zero-waste operations, requiring comprehensive lifecycle assessment frameworks.

Third, implementation complexity—including business model restructuring, digital infrastructure investment, service delivery capability development, and financial restructuring—is manageable through systematic phased implementation, pilot validation, strategic partnerships, and executive commitment.

Fourth, regulatory evolution including EPR mandates, circular economy design standards, and green finance mechanisms creates enabling tailwinds transforming circular business models from niche alternatives to competitive norms.

Fifth, Industry 5.0 digital technologies—IoT, artificial intelligence, digital twins—enable PaaS operational capabilities (predictive maintenance, remote optimization, supply chain coordination) previously infeasible, creating necessary conditions for widespread implementation.

Empirical evidence from early-adopter organizations demonstrates circular business models generate competitive advantage through simultaneous financial outperformance, environmental benefit, and customer satisfaction. The convergence of regulatory momentum, technological capabilities, financial instruments, and demonstrable viability creates compelling rationale for accelerated adoption.

However, substantial barriers remain regarding organizational capability development, capital structuring, and customer behavior change. Success requires sustained commitment to systematic transformation, acceptance of short-term profitability challenges during capability development, and strategic clarity regarding competitive positioning within evolving landscapes.

As regulatory frameworks increasingly mandate producer responsibility and environmental performance, the question is not whether circular business models will dominate, but which organizations will lead the transition and capture associated competitive advantage. Organizations proactively developing PaaS capabilities position themselves advantageously within this inevitable transformation.

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Millets, Manufacturing and the Circular Food Economy: Climate Resilience, Corporate Responses, and Pathways for Sustainable Food-Product Manufacture

Ms. Uzma Farheen[1]
[1]Faculty, KK Modi University, Durg

Abstract

This paper examines how sustainable manufacturing and circular-economy principles can mitigate climate change impacts within the food sector, with a focused case study on millets. It synthesises evidence that millets are climate-resilient, use less water, and require lower synthetic inputs compared with major cereals — making them well suited to low-input, climate-smart value chains. The paper reviews corporate responses (from supply-chain decarbonization to circular packaging and product-as-a-service), assesses manufacturing-stage interventions (energy optimisation, waste valorisation, lifecycle thinking), and proposes a roadmap for integrating millets into circular food manufacturing. Policy, technological, and corporate recommendations are proposed for manufacturers, agribusinesses, and policymakers.

Key findings: millets offer a lower water and input footprint and improved resilience under climate stress; circular strategies (closed-loop supply chains, by-product valorisation, sustainable packaging) can reduce GHGs and increase resilience in food manufacturing; corporate action must couple procurement, product design, and manufacturing innovations.

**Email: uzma010898@gmail.com*

Keywords- Sustainable manufacturing, circular economy, millets, climate resilience, food industry, greenhouse gas emissions, corporate sustainability

INTRODUCTION

Global food systems are both affected by and contributors to climate change. Industry-level transitions toward sustainable manufacturing and circular economy models can reduce greenhouse gas emissions (GHG), conserve water and materials, and increase resilience to climate extremes. For food-product manufacturers and food technologists, reorienting product design, ingredient sourcing, and factory processes is crucial for achieving climate goals while maintaining food safety and market viability. This paper explores those intersections, centring millets as an example of a climate-smart raw material and outlining corporate-level responses and manufacturing strategies.

RESEARCH QUESTIONS AND OBJECTIVES

Primary research questions:

1. How do millets perform relative to major staple cereals on water use, fertilizer input, and GHG emissions across production and manufacturing stages?
2. What manufacturing-stage interventions and circular-economy practices most effectively reduce environmental impacts in food product production?
3. How are corporations responding to climate risks in the food sector, and how can they incorporate millets into low-carbon, circular value chains?

Objectives:

- Synthesize evidence on millets' environmental performance.
- Map manufacturing interventions aligned with circular economy principles.
- Provide industry-focused recommendations and a roadmap for integrating millets into sustainable food manufacturing.

LITERATURE REVIEW

1. Climate-smart crops and millets
Millets are increasingly recognised as climate-resilient cereals: they tolerate heat and drought, grow on marginal soils, and often yield under conditions where other staples fail. International agencies and recent reviews highlight millets' potential role in resilient food systems and low-input agriculture.

2. Water footprint and input requirements
Comparative analyses show millets generally require substantially less irrigation water than rice and wheat, relying more on green water (rainfed). This lower water footprint reduces vulnerability to irrigation scarcity and energy use for pumping. Policy analyses for countries with water stress underline national-level water savings when shifting area from water-intensive cereals to millets.

3. Greenhouse gas emissions and energy intensity
Studies comparing energy use and lifecycle GHG emissions across cereals indicate rice production (especially paddy methane) is among the highest, while millets tend to have lower GHG intensity due to low methane emissions and reduced synthetic-input use. Lifecycle assessments and modelling point to meaningful emissions savings when crop mixes shift to millets at scale.

4. Circular economy in food systems
The circular economy framework — emphasizing waste reduction, material circulation, product longevity, and regenerative practices — is applicable to the food sector through strategies such as valorizing processing by-products, designing recyclable packaging, and creating closed-loop supply chains. Foundational work from the Ellen MacArthur Foundation quantifies the potential of circular strategies to reduce emissions across product systems, including food.

METHODOLOGY (CONCEPTUAL & EVIDENCE SYNTHESIS)

This paper employs a targeted literature synthesis and conceptual mapping approach: (1) authoritative agency reports and peer-reviewed studies on millets and crop GHG/water footprints were reviewed; (2) circular economy and sustainable manufacturing literature for food was examined to identify manufacturing-stage levers; (3) corporate sustainability practices were assessed from case studies and industry reports to identify actionable responses relevant to food manufacturers. The paper integrates quantitative evidence where available (water/GHG metrics) and qualitative systems analysis for manufacturing and corporate strategy.

MILLETS: FROM PRODUCTION TO MANUFACTURING - ENVIRONMENTAL AND PRACTICAL CONSIDERATIONS

1. Agronomic and environmental footprint

- **Water use:** Millets generally require far less irrigation than rice; many varieties thrive with rainfall only, making them well-suited for rainfed and arid agriculture. FAO and national assessments note millets' low water footprint and suitability for dryland farming.
- **Fertiliser and pesticide needs:** Millets typically require lower synthetic fertilizer and pesticide inputs compared to rice and wheat, lowering both direct input costs for farmers and indirect environmental impacts (manufacturing and transport of agrochemicals).

- **GHG emissions:** Because millets are non-paddy cereals, they avoid the methane emissions associated with flooded rice paddies. Lifecycle analyses suggest lower per-hectare GHG burdens for many millet systems versus rice.

2. Post-harvest and manufacturing considerations

- **Processing adaptions:** Millets require hulling, dehusking and sometimes stabilization steps (to prevent rancidity for oilier millet types). Manufacturing lines may need specific dehulling and milling equipment tuned to grain size and hardness — investments that are modest compared to switching whole value chains.
- **By-product streams and circularity:** Millet processing generates husk, bran, and other residues that can be valorized as animal feed, compost, bioenergy feedstock, or as ingredients in novel products (fiber-rich flours, extruded snacks). Integrating by-product valorisation into plant operations exemplifies circular manufacturing.
- **Shelf-life and formulation:** Some millet flours are more prone to lipid oxidation; food technologists must apply stabilization (heat treatment, antioxidants, modified atmosphere packaging) to maintain shelf stability in finished goods.

CORPORATE RESPONSES: FROM PROCUREMENT TO PRODUCT DESIGN

1. Sustainable procurement and supplier engagement
Corporations can reduce scope 3 emissions by sourcing climate-resilient crops (e.g., millets), supporting regenerative practices, and offering premiums or long-term contracts to farmers for sustainable production. Supply-chain programs that provide seed, technical assistance, and aggregation (FPOs) can support smallholders and reduce inputs. _

2. Manufacturing-stage decarbonization & circular manufacturing
Key interventions for manufacturers:

- **Energy transition:** Shift to renewable energy for thermal and electrical needs in plants; optimize process heating and cooling efficiency.
- **Material efficiency & waste valorization:** Minimize ingredient losses, route by-products to higher-value uses, and explore anaerobic digestion for wet waste to produce biogas for plant energy.
- **Eco-design for products and packaging:** Design products for minimal packaging, use recyclable or refillable containers, and prefer materials with lower embodied emissions. Ellen MacArthur Foundation modelling shows circular measures in food can yield significant emissions reductions.

3. Reporting, targets, and supply-chain transparency
Adopt science-based targets (SBTi) covering scope 1, 2, and where feasible, scope 3 emissions; disclose progress publicly; and use supplier-level traceability (digital IDs, traceability platforms) to validate claims and support circular flows.

CASE STUDIES & EXAMPLES (ILLUSTRATIVE)

1. Millet-focused value-chain in India (aggregated examples)
Recent programs in India have demonstrated how large-scale millet promotion can transform marginal lands, improve farmer incomes, and reduce input costs. Evidence shows that area shifts from water-intensive crops to millets lead to water and potential GHG savings at the regional scale. _

2. Corporate-level circular innovations (food sector)
Global food companies are piloting regenerative sourcing, closed-loop packaging pilots, and processing waste valorization — from nutrient-recovery to reuse of process heat — illustrating integrated manufacturing and circular solutions. Reports and industry examples show measurable reductions in scope 1/2 emissions and improvements in supply-chain resilience.

DISCUSSION: OPPORTUNITIES AND BARRIERS

1. Opportunities

- **Climate adaptation and mitigation co-benefits:** Millets reduce vulnerability to drought and reduce agricultural GHG intensity; circular manufacturing reduces waste-related emissions.
- **Economic resilience for smallholders:** Lower input costs and diversified markets for millet products can strengthen incomes and reduce climate risk exposure.
- **Product innovation:** Millets enable development of nutrient-dense, low-input food products that meet growing consumer demand for sustainable foods.

2. Barriers

- **Yield gap & scale:** Millet yields are often lower than high-input cereals, which can limit immediate substitution without improvements in agronomy and market incentives.
- **Processing and formulation requirements:** Manufacturers need R&D investment to reformulate products and stabilize millet-based flours.
- **Market and consumer preferences:** Consumer awareness and food habits may constrain rapid adoption; marketing and sensory product development are needed.
- **Policy and infrastructure:** Supportive procurement policies, price signals, and processing infrastructure are required to scale millet value chains.

RECOMMENDATIONS FOR FOOD TECHNOLOGISTS & MANUFACTURERS

1. Short-term (0–2 years)

- Pilot millet-based product lines (snacks, premixes, bakery blends), optimize formulations for shelf stability and sensory acceptance.
- Implement by-product valorization pilots (bran upcycling, composting, bioenergy digesters).
- Perform plant-level energy audits and adopt quick-win efficiency measures (heat recovery, variable-speed drives).

2. Medium-term (2–5 years)

- Partner with suppliers and FPOs to procure millets under sustainable contracts; fund agronomy training to close yield gaps without heavy synthetic inputs.
- Redesign packaging for recyclability/refill models and reduce packaging mass.
- Adopt digital traceability for raw materials to support circular flows and claims.

3. Long-term (5+ years)

- Incorporate millets as a strategic ingredient across product portfolio to reduce scope 3 exposure and increase resilience.

- Invest in process R&D for closed-loop manufacturing (material recovery, on-site renewable energy, circular water use).
- Commit to science-based emissions targets and routinely report progress.

Policy & Stakeholder Actions

- National policy should incentivize climate-smart crop diversification and support processing infrastructure for millets (mills, storage, aggregation).
- Public procurement (schools, hospitals) can create stable demand for climate-smart millet products.
- R&D funding for millet breeding, post-harvest stabilization, and product development will help overcome current technological barriers.

CONCLUSION

Millets represent a practical pathway to reduce the environmental footprint of food systems while enhancing climate resilience for farmers and supply chains. For food manufacturers and food technologists, integrating millets into product portfolios — together with circular manufacturing practices (waste valorization, energy transition, eco-design) — offers both mitigation and adaptation benefits. Corporate responses that couple procurement strategies, manufacturing innovation, and transparent reporting are essential to scale these advantages. With coordinated policy support, industry R&D, and buyer engagement, millet-centred circular value chains can materially contribute to sustainable food manufacturing and climate goals.

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Sustainable Pathways: Exploring the Intersection of Corporate Social Responsibility and Organizational Initiatives in Advancing Sustainable Goals

Vimla Sharma[1], Ankita Upadhyay[2]
[1]Research Scholar, Sanskriti University, 28 K. M. Stone, Mathura - Delhi Highway, Chhata, Mathura (U.P.)
[2]Research Scholar, Sanskriti University, 28 K. M. Stone, Mathura - Delhi Highway, Chhata, Mathura (U.P.)

Abstract

Sustainable development has remained a global priority since the Brundtland Commission emphasized meeting present needs without compromising future generations. This agenda has evolved through key international frameworks, including Agenda 21, the Millennium Development Goals, and the 2030 Agenda for Sustainable Development. Corporate Social Responsibility (CSR) has increasingly emerged as a strategic mechanism through which organizations contribute to sustainable development; however, its effectiveness depends largely on the robustness of Environmental, Social, and Governance (ESG) monitoring systems. This study adopts an analytical research design to examine the development and standard-setting processes of ESG monitoring tools and to assess whether ESG scores are accurately interpreted and aligned with sustainability objectives. Drawing on existing literature and secondary data, the study highlights challenges related to ESG measurement consistency, comparability, and interpretative clarity. A structured ESG scorecard framework is proposed and applied to the Tata Group as a case illustration. The findings indicate that well-monitored ESG scorecards enhance transparency, accountability, and strategic alignment of CSR initiatives, while inconsistent metrics may weaken their contribution to sustainable development outcomes. The study underscores the need for dynamic and standardized ESG measurement frameworks.

**Email: vimisha.bhardwaj@gmail.com, ankitaa.9999@gmail.com*

Keywords:- Corporate Social Responsibility (CSR); Environmental, Social and Governance (ESG); Sustainable Development Goals (SDGs); ESG Measurement; Sustainability Assessment; Agenda 2030

INTRODUCTION

It was in 1983 when the World Commission on Environment and Development (WCED) was held by the United Nations chaired by Gro Harlem Brundtland. This commission is commonly known as the Brundtland Commission. The main aim of this commission was to address the concern about what it called the rapid devastation of the environment for human beings and shrinkage of natural resources and the results of such devastation on social and economic development. The UN General Assembly addressed the environmental challenges as global concerns and pointed out the necessity of setting out policies for sustainable development. Before, such a concern for sustainability was only expressed by some NGOs.

In 1987, Oxford University Press published the Brundtland Commission report, Our Common Future. Sustainable Development is the development that meets the requirements of the present generations without compromising the ability of future generations to meet their own needs. This includes two key concepts:

• Needs, particularly the basic needs of the poor nations which need to be given priority; and
• Limits put through social and technological arrangements on the ability of environment to meet the requirements of present and future generations. (WCED, 1987: 16).

Five years afterwards, there was another conference held in 1992 in Rio de Janeiro.2 The conference, called the United Nations Conference on Environment and Development, later became famous as the

Earth Summit. In this conference delegates from 172 countries, 108 of which were the heads of governments or countries, participated. Moreover, more than two thousand people delegated NGOs and there were more than 15 thousand people with consultative status attending the parallel sessions. In this conference the following issues were addressed:

1. Analyzing the production patterns—in particular when hazardous and poisonous wastes or components were involved, e.g. petrol lead;
2. Replacement of fossil fuels with renewable energy sources. The relationship between fossil fuel and climate change was recognized then;
3. Improved use of public transport to lower problems related to health, traffic and emissions due to smog and air pollution;
4. Water shortage as a growing concern in the world.

This conference had an important outcome which was the agreement on the Climate Change Convention and it led to another achievement which was the Kyoto Protocol.

In order to meet the challenges of environment and development, States have decided to establish a new global partnership. This partnership commits all States to engage in a continuous and constructive form, inspired by the need to achieve a more efficient and equitable world economy, keeping in view the increasing interdependence of the community of nations and that sustainable development should become a priority item on the agenda of the international community.

Agenda 21 was another outcome in relation with sustainable development. The number 21 is used to declare our century and the aim was to imply its long term and futuristic expectations.

The drafting of this agenda began in 1989 through extensive consultations and negotiations and was formally adopted at the conference. The agenda comprises 40 chapters organized into four sections, covering a wide range of sustainability issues.

Section I: Socio-economic aspects focus on poverty eradication, sustainable consumption, population control, health and hygiene, human settlements, and environmentally informed decision-making.

Section II: Resource management and conservation address the protection of the atmosphere, deforestation control, biodiversity conservation, and pollution prevention.

Section III: Empowerment of major groups emphasizes the roles of women and children, non-governmental organizations, workers, businesses, and local authorities.

Section IV: Means of implementation include technology transfer, education and capacity building, and international cooperation through institutional and financial mechanisms.

Adopted in 2015 by all United Nations Member States, the 2030 Agenda for Sustainable Development provides a global framework for achieving peace, prosperity, and environmental protection through 17 Sustainable Development Goals (SDGs), calling for collective action by both developed and developing countries. The SDGs build on decades of international efforts, beginning with Agenda 21 adopted at the 1992 Earth Summit, followed by the Millennium Development Goals (MDGs) established in 2000, and reinforced through subsequent milestones such as the Johannesburg Summit (2002) and Rio+20 Conference (2012), which initiated the SDG formulation process. This process culminated in the adoption of the 2030 Agenda alongside other landmark agreements in 2015.Today, progress on the SDGs is reviewed through the High-level Political Forum on Sustainable Development, while the Division for Sustainable Development Goals (DSDG) under UNDESA supports implementation through policy guidance, capacity-building, monitoring, partnerships, and advocacy to ensure broad stakeholder engagement and effective realization of the global goals.

CSR initiatives significantly contribute to sustainable development by enhancing social well-being, protecting the environment, and supporting long-term economic growth. This study explores how corporate social responsibility (CSR) priorities and circular economy (CE) practices align with the Sustainable Development Goals (SDGs), drawing on organizational culture and dynamic capabilities as guiding theoretical frameworks. The findings reveal that organizations demonstrating sustained CSR efforts are better positioned to mitigate environmental impacts and strengthen their adherence to SDG targets, especially those concerning responsible consumption and production and climate action.

Sustainability Goals Should Be Measurable

Sustainable development should be measurable because measurement allows governments, organizations, and societies to **track progress, ensure accountability, and evaluate the real impact of policies and actions**. Without measurable indicators, sustainability remains a vague concept that cannot be effectively implemented or monitored.

In practice, measurability is achieved through **quantitative and qualitative indicators**, such as:

a. **Environmental indicators**: carbon emissions, renewable energy share, water use efficiency, biodiversity loss.
b. **Economic indicators**: inclusive growth, green investment, resource productivity.
c. **Social indicators**: poverty reduction, education access, gender equality, health outcomes.

The **UN Sustainable Development Goals (SDGs)** are a strong example of making sustainable development measurable, as each goal is linked with **specific targets and indicators**. These metrics enable comparisons across countries and over time, helping policymakers identify gaps and adjust strategies.

The problem of the study to measuring tools should be work and it should be dynamic. Through this paper examine the evolution and standard-setting processes underlying the development of ESG monitoring tools used for sustainability assessment. It also seeks to analyze whether ESG scores are being interpreted accurately and whether they are effectively aligned with their intended sustainability objectives.

REVIEW OF LITERATURE

***Giovannucci et al. (2014)* —** There isn't a widely available open-access PDF of the specific paper from Giovannucci in 2014 indexed in major academic databases online. From what's known, Daniele Giovannucci was heavily involved that year in work on **sustainability measurement frameworks** via the Committee on Sustainability Assessment (COSA), including publishing a **major comparative study of sustainability standards and indicators** (e.g., COSA's sustainability measurement work in agriculture). This work focused on developing **indicator frameworks and measurement tools** for sustainability in agricultural value chains, particularly coffee, and provided data on environmental, social, and economic outcomes often referenced in broader sustainability literature.The concept of sustainability has increasingly shaped corporate strategies, particularly through frameworks such as Corporate Social Responsibility (CSR), Environmental, Social and Governance (ESG) metrics, and the United Nations Sustainable Development Goals (SDGs). Prior literature highlights that CSR has evolved from a predominantly philanthropic and voluntary activity into a strategic and regulatory-driven mechanism aimed at integrating social, environmental, and economic responsibilities into core business operations.

According to Giovannucci et al. (2014). Martinuzz et al. (2017) in their research on CSR relationships as well as the Sustainable Development Goals emphasized much on putting into practice the guidelines on corporate social responsibility and promoting methodical management and measurement of the economic effect on the SDGs However, Bowen et al. (2017) assert that achieving the SDGs necessitates a trade-off among priorities in terms of location, investment, and circumstances.This evolution reflects a broader shift in corporate accountability, where firms are no longer evaluated solely on financial performance but also on their contribution to sustainable development outcomes .Several studies emphasize the strong alignment between CSR initiatives and the SDGs, arguing that CSR serves as an operational pathway through which corporations contribute to global sustainability goals. Moreover, a study by Arora and Walia (2019) looks into CSR initiatives in India's tourism sector and concludes that sustainability and corporate social responsibility are interlinked, thus increasing the sustainability rate. The literature clearly shows that CSR is necessary to achieve sustainable development goals while proving that there is enough evidence connecting it to sustainability challenges. CSR is emerging as an essential instrument in many countries at the global level to achieve sustainable business approaches (Kumar, 2014) . That is why it has been specifically linked with sustainable development when comes the question of Corporate accountability The main concern of this social contract is for the future and the use of the term “sustainability” is a manifestation of it (Seifi & Crowther, 2012). Despite extensive research on CSR–SDG alignment and sustainability reporting, a notable gap persists in evaluating the effectiveness and interpretative accuracy of ESG monitoring tools. While existing studies acknowledge the strategic value of ESG metrics, limited attention has been paid to whether these tools genuinely reflect sustainability performance or align with their intended objectives. This gap highlights the need for further research into the development, standard-setting processes, and interpretative reliability of ESG monitoring systems, particularly in the context of sustainable development assessment.

This paper aims to:

1. To examine the development and standard-setting processes involved in the design of ESG monitoring tools for sustainability assessment.
2. To analyze whether ESG scores are being interpreted accurately and aligned with their intended sustainability objectives.

RESEARCH METHODOLOGY

The present study adopts an **analytical research design**, as it seeks to critically examine the development and standard-setting processes of ESG monitoring tools and analyze the accuracy and alignment of ESG score interpretation with sustainability objectives through Corporate Social Responsibility. An analytical design is appropriate because the study relies on the systematic evaluation of existing frameworks, ESG ratings, and sustainability-related data rather than primary data collection.

Drawing from existing literature, the study develops hypotheses to examine the effectiveness and interpretative reliability of ESG monitoring tools in assessing sustainability performance. Prior research indicates that while CSR has evolved into a strategic mechanism aligned with the SDGs, challenges remain in the measurement, standardization, and interpretation of sustainability indicators. Studies by Giovannucci et al. (2014) and Martinuzzi et al. (2017) emphasize structured CSR implementation and measurement to enhance SDG outcomes, whereas Bowen et al. (2017) highlight trade-offs and contextual limitations in achieving sustainability goals. Furthermore, scholars such as Seifi and Crowther (2012) underscore sustainability as a long-term social contract, reinforcing the need for credible assessment tools.

DATA COLLECTION: ANALYTICAL RESEARCH STUDY

ESG Scorecard

Environmental (E)

Indicator	Description	Score (0–5)
Carbon Emissions	GHG emissions reduction initiatives	
Energy Management	Use of renewable energy and efficiency	
Water Management	Water conservation and recycling	
Waste Management	Waste reduction and disposal practices	
Environmental Compliance	Adherence to environmental laws	

Environmental Score (E) = Total / 25

Social (S)

Indicator	Description	Score (0–5)
Employee Welfare	Health, safety, and well-being	
Diversity & Inclusion	Gender and workforce diversity	
Human Rights	Fair labor practices	
Community Development	CSR & community engagement	
Customer Responsibility	Product safety and data privacy	

Social Score (S) = Total / 25

Governance (G)

Indicator	Description	Score (0–5)
Board Structure	Independence and diversity	
Ethical Practices	Anti-corruption policies	
Transparency	Disclosure quality	
Shareholder Rights	Protection of investor interests	
Risk Management	ESG risk oversight	

Governance Score (G) = Total / 25

Overall ESG Score Calculation

Component	Weight (%)	Score
Environmental	40%	
Social	30%	
Governance	30%	

Overall ESG Score = (E Score × 0.40) + (S Score × 0.30) + (G Score × 0.30)

ESG Performance Rating

ESG Score Range	Rating
80–100	Excellent
60–79	Good
40–59	Moderate
Below 40	Poor

Tata Steel : Environmental Social Governance (ESG)

Tata Steel Limited includes its steel plants (TS Jamshedpur, TS Kalinganagar, TS Meramandali and TS Gamharia), mining locations, upstream (DRI, Iron & Coke, Ferro Alloys, Tata Steel Growth Shop) and downstream units (rolling, tube making, tinplating, wire drawing, bearing production, etc.).

GHG emission from our steelmaking operations (Absolute emission in million (CO_2)

The Tata Group integrates ESG as a core strategic pillar, with major companies (Tata Steel, TCS, Tata Motors, etc.) committing to sustainability goals for FY30 and FY40, focusing on net-zero, circular economy, and social responsibility. Key achievements include improved Sustainalytics risk ratings, 'A' ratings from MSCI for some entities, and significant carbon footprint reduction initiatives.

ESG Focus Areas & Data Points:

Environmental (E):

a) Climate Change: Tata Group aims for net-zero emissions, with major companies covering 99.5% of Scope 1 & 2 emissions setting targets.

b) Energy: Accelerated adoption of renewable energy.

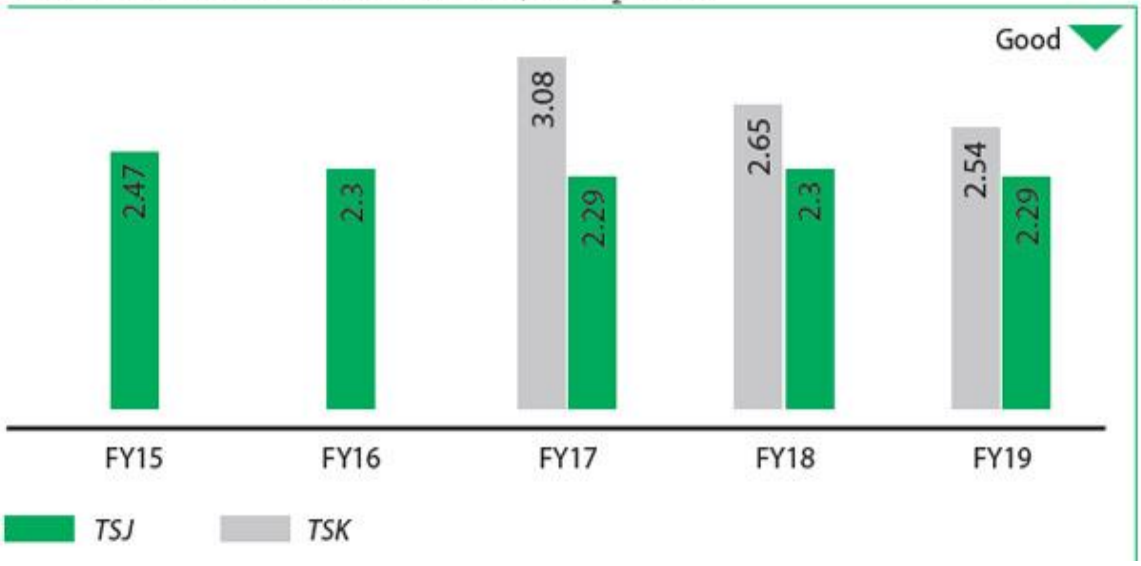
c) Resource Management: Tata Steel focuses on biodiversity and water management, including maintaining urban carbon sinks.

d) Waste:Emphasis on the circular economy.

Steelmaking Sites	Particulars	FY15	FY16	FY17	FY18	FY19
India (TSJ + TSK)	Scope 1	21.10	21.02	25.53	26.52	27.14
	Scope 1.1	2.27	2.31	3.69	3.96	4.53
	Scope 2	0.72	0.74	1.11	1.17	1.17
	Scope 3	-1.08	-1.19	-2.21	-1.99	-1.81
	Overall	23.02	22.89	28.11	29.66	31.03
Europe (incl. UK)	Overall	26.96	25.48	19.27	19.18	18.75
South East Asia (NatSteel + Tata Steel Thailand)	Overall	0.91	0.98	0.91	1.04	0.96

*** Based on revised methodology of World Steel Association - User Guidance 9, V22 since 2017-18**

TSJ & TSK - GHG emission intensity (tCO_2e/tcs)



Social (S):
a) Safety & Inclusion: Prioritizing workplace safety and fostering an inclusive culture.
b) Community: Substantial focus on community development,, with Tata Group recognized for global volunteering efforts.
c) Digital Inclusion: TCS drives digital empowerment.

Governance (G):
a) Ethical Standards: Adopts the Tata Code of Conduct (TCoC) for transparency and accountability.
b) Board Oversight: Strong, top-driven sustainability governance.
c) Risk Management: Active monitoring of environmental, social, and economic impacts.

Entity Performance (FY 2023-24):
Tata Consumer Products: Ranked India's Most Sustainable Consumer Goods Company by Business World, included in the S&P Global Sustainability Yearbook, and achieved a 15% improvement in ESG Risk Rating.
Tata Steel: Focuses on biodiversity, managing 37.75-acre green spaces.
Tata Communications: Focuses on People, Planet, and Community, with a robust ESG addendum.

ESG Analysis of Tata Group

The Tata Group demonstrates a comprehensive and mature integration of Environmental, Social, and Governance (ESG) principles as a core component of its corporate strategy. ESG considerations are embedded across major group entities such as Tata Steel, Tata Consultancy Services (TCS), Tata Motors, Tata Consumer Products, and Tata Communications, with clearly articulated sustainability goals extending to FY2030 and FY2040. This long-term orientation reflects a strategic commitment to net-zero emissions, circular economy practices, and inclusive social development, aligning strongly with global sustainability frameworks and the United Nations Sustainable Development Goals (SDGs).

Environmental Performance Analysis

From an environmental perspective, the Tata Group exhibits strong alignment with climate action and resource stewardship objectives. The group's commitment to net-zero emissions, with approximately 99.5% of Scope 1 and Scope 2 emissions covered by science-based targets, indicates a high level of environmental accountability. Accelerated adoption of renewable energy across operations further strengthens its climate mitigation strategy. Tata Steel's initiatives in biodiversity conservation, water stewardship, and the maintenance of urban carbon sinks demonstrate a holistic approach to environmental management that extends beyond compliance to ecological regeneration. The group's emphasis on circular economy principles and waste reduction reinforces its proactive stance on sustainable resource utilization. Collectively, these initiatives suggest a high level of environmental maturity and effective ESG standard implementation.

Social Performance Analysis

The social dimension of ESG within the Tata Group reflects a strong emphasis on employee welfare, inclusivity, and community engagement. Workplace safety and inclusive organizational culture are prioritized across group companies, indicating robust internal social governance. The group's extensive community development initiatives and global recognition for volunteering efforts highlight its commitment to social responsibility beyond corporate boundaries. Furthermore, TCS's focus on digital inclusion and empowerment contributes to broader societal transformation by addressing digital divides and enhancing skill development. These initiatives collectively position the Tata Group as a socially responsible organization with a positive and measurable impact on stakeholders.

Governance Performance Analysis

Governance remains a cornerstone of the Tata Group's ESG framework. The adoption of the Tata Code of Conduct (TCoC) ensures ethical behavior, transparency, and accountability across all group entities. Sustainability governance is strongly driven at the board and top management levels, reflecting effective oversight and strategic integration of ESG considerations. The group's active monitoring of environmental, social, and economic risks demonstrates a forward-looking approach to risk management, enhancing resilience and long-term value creation. This governance structure supports consistency in ESG implementation and strengthens stakeholder trust.

ESG Ratings and Performance Outcomes

The effectiveness of Tata Group's ESG initiatives is reflected in external ratings and recognitions. Improved Sustainalytics ESG risk ratings and 'A' ratings from MSCI for select entities indicate strong alignment between ESG practices and recognized assessment standards. Entity-specific achievements further reinforce this performance. Tata Consumer Products' inclusion in the S&P Global Sustainability Yearbook and its 15% improvement in ESG risk rating signal significant progress in sustainability performance. Tata Steel's biodiversity initiatives, including the management of 37.75 acres of green spaces, underscore its environmental commitment, while Tata Communications' structured focus on People, Planet, and Community demonstrates balanced ESG integration supported by transparent disclosures.

INTERPRETATION AND ALIGNMENT WITH RESEARCH OBJECTIVES

In relation to the study objectives, the Tata Group's ESG performance illustrates effective development and application of ESG monitoring tools, supported by standardized frameworks and transparent

governance mechanisms. The consistency between reported ESG initiatives, external ratings, and observed sustainability outcomes suggests that ESG scores for Tata Group entities are largely interpreted accurately and aligned with their intended sustainability objectives. However, variations across entities and rating agencies indicate the continued need for harmonized ESG standards and interpretative clarity.
Despite the growing reliance on ESG metrics by corporations and investors, the literature suggests inconsistencies in ESG methodologies and ambiguity in score interpretation, which may weaken their alignment with sustainability objectives.

CONCLUSION

Corporate Social Responsibility (CSR) can function effectively only when it is supported by a properly monitored ESG scorecard. ESG scorecards translate CSR commitments into **measurable, transparent, and comparable indicators** across environmental, social, and governance dimensions. When CSR initiatives are monitored through robust ESG metrics, organizations move beyond symbolic or philanthropic actions toward **accountable and performance-driven sustainability practices**.

Effective ESG monitoring helps ensure that CSR activities are:

- **Aligned with strategic objectives**, rather than ad hoc programs
- **Quantifiable and outcome-oriented**, reducing greenwashing risks
- **Comparable across firms and time**, enabling benchmarking and improvement
- **Credible to stakeholders**, including investors, regulators, and communities
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Without proper ESG monitoring, CSR often remains **voluntary, inconsistent, and difficult to evaluate**, limiting its real impact on sustainable development. Therefore, a well-designed and rigorously monitored ESG scorecard is essential for CSR to deliver measurable social, environmental, and governance outcomes.

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