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3  
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## Contents – Part III

### Industry 4.0

Literature Review of Theory-Based Empirical Research Examining Consumers' Adoption of IoT . . . . .	3
<i>Salma S. Abed</i>	
A Conceptual Framework for Achieving Sustainability in Supply Chain Using Industry 4.0 Technologies in Emerging Economies . . . . .	15
<i>Vaibhav Sharma, Praveen Saraswat, and Rajeev Agrawal</i>	
Industry 4.0 Implementation: Evidence from Indian Industries . . . . .	23
<i>Abhijeet K. Digalwar, Sudhanshu Ranjan Singh, Rishi Pandey, and Ankur Sharma</i>	
Internet of Things and Sustainability: A Literature Review . . . . .	35
<i>Khusboo Gupta, Arpan Kumar Kar, and M. P. Gupta</i>	
Smart City as a Mix of Technology, Sustainability and Well-Being: A Myth or Reality? . . . . .	46
<i>Anton Manfreda and Tea Mijač</i>	
Managerial Competencies for Human Brains and Mechanical Muscles Interplay; A Study of Automotive Industries. . . . .	58
<i>Mugdha S. Kulkarni and Kanchan Patil</i>	
Advanced Manufacturing Technology Implementation in Indian Automotive Industry: An Interactive Qualitative Study. . . . .	69
<i>Amruta Patil and L. Prakash Sai</i>	
Role of Institutional Pressure and Organization Climate in Adoption of Process Innovation for Improving Environmental Performance – A Research on Indian Mining Industry . . . . .	82
<i>Lalit Mohan Soni and Nikunj Kumar Jain</i>	
Digital Twin for Industrial Applications – A Literature Review. . . . .	92
<i>Rashmi Pant Joshi, Surbhi Gulati, and Arpan Kumar Kar</i>	



# A Conceptual Framework for Achieving Sustainability in Supply Chain Using Industry 4.0 Technologies in Emerging Economies

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**Abstract.** Making the supply chain sustainable, practices aim to reduce the hazardous impacts of supply chain activities aimed at global pollution and global warming. However, the literature collected from Google Scholar has discussed how Industry 4.0 (I4.0) technologies can address the issue of sustainability in the supply chain by addressing resource efficiency, transparency, and energy consumption issues. The impact of each technology on sustainability is not discussed well, and how these technologies can be helpful to address sustainability issues in industries. Therefore, to fill this gap, the present paper aims to answer how these technologies can address sustainability issues. In the study, a novel framework is proposed that discusses how each technology of I4.0 can address the various sustainability issues in the supply chain. This study can help emerging economies and a novel contribution to the theory to understand the impact of I4.0 on the sustainable supply chain.

**Keywords:** Industry 4.0 · Sustainable Supply Chain · Emerging economies

## 1 Introduction

Sustainable supply chain management (SSCM) integrates the Triple Bottom Line (TBL) viewpoint to manage material, economic, and information flows to prevent negative impacts and create economic, ecological, and social capital [1]. The advent of Industry 4.0 by Germany [2] can create a smooth flow of information and material through the value chains. Different technologies of I4.0, such as the Internet of Things (IoT), Industrial Internet of Things (IIoT), Cyber-Physical Systems (CPS), Big Data Analytics/Artificial Intelligence (AI), Blockchain, Cloud Computing, Cognitive computing, Autonomous systems, Digital twin, Augmented Reality/Virtual Reality and Horizontal and Vertical integration make the machines capable of making autonomous decisions and enhancing the supply chain drivers (Facilities, Inventory, Transportation, Information, Sourcing, and Pricing) to increase the visibility and transparency on one hand and increasing the performance and deal with disruptions and mitigate the risks on the

other hand. The need for attaining sustainability is essential for the survival of mankind [3]. The three sustainability pillars (Economic, Social, and Environmental) are the key concepts to achieve sustainability [4]. The various functions involved in supplying raw materials sourcing and finished goods delivery to the customers positively impact society and people to achieve economic benefits [1]. Supply chain sustainability can be achieved by analyzing the social responsibility not only of the OEMs (Original Equipment Manufacturers) but also of suppliers by prioritizing the usage of renewable energy, recyclable materials, and circular products [5]. To achieve two major goals, visibility, and required ROI (Return on Investment), the importance of Sustainability with I4.0 is a well-established answer.

The study has five parts. Section 1 introduces. Section 2 reviews relevant literature. Section 3 discusses framework development based on review. Section 4 suggests ways organizations can overcome I4.0 technology implementation challenges. Section 5 concludes and suggests further research.

## 2 Literature Review

We reviewed the articles concerning industry 4.0 enhancing sustainability in supply chains of emerging economies by searching in Google Scholar. Sustainability is the need for manufacturing organizations to prevent themselves from huge financial losses, and various I4.0 technologies such as the Internet of Things, Big data analytics, Blockchain, Machine learning, etc. [6] can contribute to attaining sustainability in developing economies [7]. Various challenges, such as Organizational, Technological, Strategic, Legal, and ethical issues, must be addressed [8]. Including sustainability in supply chains requires organization-friendly Government policies, Collaboration, and transparency among the different supply chain stakeholders [9]. In emerging economies, SMEs (Small and Medium-sized Enterprises) are the most vulnerable sectors to adopt I4.0 technologies as they lack motivation from partners and customers [10]. Adopting I4.0 improves operational performance and competency of supply chains, although intrinsic and extrinsic factors negatively affect digitalization [11]. As discussed in [12], I4.0 technologies can help to play a significant role in reducing emissions and production for achieving sustainability in supply chains [8], whereas [13] presented in the context of MSMEs (Micro, Small and Medium Enterprises) the barriers to sustainability using I4.0, and supply chain and environmental related enablers were also presented.

### 2.1 Internet of Things (IoT)

The IoT in a different component of supply chains can be RFID (Radio Frequency Identification) based transportation that increases supply chain visibility and improves efficiency [14]. The benefits of the adoption of IoT in the supply chain can relate to finding enough data for real-time data management to proceed with Business Intelligence improvement, and the major challenge is a diminished understanding of the IoT benefits [15]. Other issues include framework preparedness, market and property motivations, technical capacity criteria, and policy resources [16].

## 2.2 Blockchain

Blockchain technology can act as a sustainability driver for the supply chain by reducing product recall, creating an accurate carbon footprint for a carbon tax, incentivizing recycling behavior, and reducing emission fraud [17]. Developed countries dominate the Blockchain-SCM understanding, so there is an immense opportunity for developing a maturity model for emerging economies [18]. But characteristics of Blockchain technologies: low-cost Blockchain deployment, low cost and rapid diffusion of IoT, and use of the mobile phone can act to enforce sustainability standards and remove institutional cost-benefit analysis power distribution challenges [19].

## 2.3 The Cloud

The cloud database can potentially increase the accuracy and real-time management of information, helping the stakeholders identify the problems that are creating environmental footprint performance across the supply chain [20]. Various green SCM practices, such as green purchasing, manufacturing, ecological design, and training, positively impact environmental performance; green manufacturing and green design positively impact economic performance [21]. On the other hand, green purchasing and training have a non-significant impact on economic performance, and the initial cost of implementing green supply SCM practices is high. However, digital technologies (IoT) are still being studied [21, 22].

## 2.4 AR/VR in SSCM

All the past research done on AR/VR (Augmented Reality/ Virtual Reality) in operations in Supply Chain Management (SCM) [23] is theoretical. The analysis of challenges and barriers for a deeper understanding of the implementation of AR/VR in Sustainable supply chains through data is still desired [23]. AR/VR technology can increase visibility in terms of the real-time look of manufacturing facilities, distribution centers, etc., improve customer order receiving, delivery of orders becoming efficient, and no late delivery, transparency by providing exact information on packaging and its content and security of the package to deliver after the customer recognition [24].

## 2.5 Big Data

For supply chains to become sustainable, Big data tools such as data processing, analytics, reporting, etc., can help organizations take corrective actions in the operations, transparency, and risk mitigation in the manufacturing supply chains [25]. Big data analytics can help emerging economies collect data and analyze data to disseminate the knowledge obtained to achieve sustainability in the supply chains [26].

## 2.6 AI

The AI technology can improve the supply chain resilience and supply chain performance [27]. Sharma et al. [28] suggested that AI has the potential to revolutionize different sectors of the economy, like healthcare, manufacturing, education, and agriculture. Increasing operational efficiency and reducing costs are important for enhancing decision-making. This can be achieved through inventory optimization, route optimization, demand forecasting, and quality control.

## 3 Emerging Economies and Challenges

Technologies pose challenges such as skill development of users and habituating the users to increase the efficiency of the supply chain by the mutual trust between the organization and employees. These are the challenges for various industries such as (Plastic, Paper, Cement, Automobile, Chemical, Electronics, Pharmaceutical) [12].

### 3.1 Sustainability of the Previous Steps

#### 3.1.1 Infrastructure Challenges

Firstly, emerging economies have a long way to go to implement the I4.0 technologies as it depends crucially on the Fiscal and Monetary policies to address the crisis they have encountered during COVID-19. For that, structural reforms are required to enhance the institutional capacity. Secondly, the policies that are adopted to date are required to prove their credibility so that the economies can be alleviated to become the developed ones under the umbrella of macroeconomic policies. However, infrastructure development in emerging economies can be challenging due to a lack of funding and resources and difficulties with regulatory hurdles [8, 11, 16]. Private-public partnerships, foreign investment, and international aid are some ways to finance infrastructure development in emerging economies.

#### 3.1.2 Macroeconomic Stability

Issues include commodity exports, money inflows and outflows, and institutional and regulatory capability. Macroeconomic stability boosts investment, poverty reduction, and living standards. Monetary and fiscal policies encouraging sustainable economic development, low inflation, and a stable exchange rate can enhance macroeconomic stability [10, 11]. They can also execute structural reforms to boost economic efficiency, decrease corruption, strengthen governance and regulation, and boost human capital investment. International organizations and wealthier nations can provide technical and financial aid to emerging economies.

#### 3.1.3 Population Size

Organizations and governments need to consider the potential impact of population growth on resource availability and environmental degradation to manage supply chains

sustainably in emerging economies. This may involve implementing sustainable sourcing practices, reducing waste and emissions in supply chain activities, and investing in renewable energy and resource-efficient technologies [12]. Additionally, the distribution of population within the emerging economy and how it affects the transportation and distribution of goods as the dispersed population can increase the complexity and cost of logistics. In contrast, a concentrated population can lead to increased urbanization, and associated environmental challenges, such as air and water pollution, are to be considered.

### **3.1.4 Ease of Doing Business**

A favorable business environment, with clear and streamlined regulations, efficient bureaucratic processes, and a stable political climate, can encourage investment, improve supply chain efficiency, and promote sustainable business practices [8, 29]. On the other hand, a challenging business environment, with complex regulations, corruption, and political instability, can lead to higher costs, supply chain disruptions, and a reduced focus on sustainability. In such cases, companies may be more likely to engage in unsustainable practices, such as environmental degradation and labor exploitation, to maintain profitability.

## **4 Framework for the Integration of I4.0 Technologies to Achieve Sustainability**

As shown in Fig. 1, emerging economies face policy-binding and financial adjustment issues hindering I4.0 technology implementation in SSCM. So, this study combines the different challenges from the literature review of emerging economies and their ability to implement I4.0 technologies. It also presents the advantages and drawbacks of I4.0 technologies, combining SSCM targets and sustainability pillars, as discussed in Sect. 2.

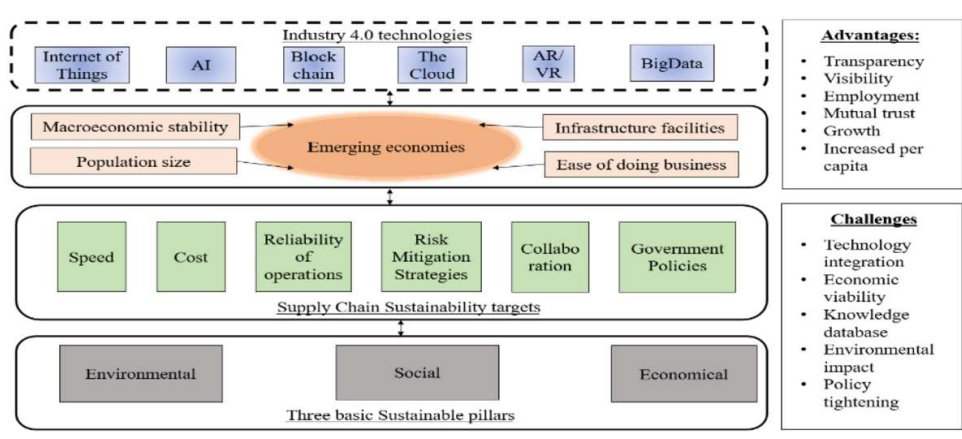
### **4.1 I4.0 Technologies for Achieving Sustainability in Supply Chains**

Technologies can help to reduce waste in supply chains, optimize supply chain operations, and increase efficiency and productivity, which can reduce costs and the carbon footprint. For example, the use of Big Data and AI can provide insight into the improvement in the reduction of supply chain emissions. Circular business models can be developed according to the conditions of a particular emerging economy. The other technology is Blockchain, which can increase transparency and traceability throughout the supply chain and manage disruptions and supply chain efficiency (Fig. 1). It can reduce intermediaries, increasing the speed of supply chains' activities. This can help companies to identify and address the sustainability challenges at the Triple Bottom Line (TBL).

### **4.2 Supply Chain Sustainability Targets**

IoT, AI, and robotics are some technologies that can play a crucial role in sustainability. IoT sensors and predictive maintenance can reduce carbon emissions. Blockchain can

help in the ethical sourcing of materials. AI algorithms can help in diversifying suppliers and increase resiliency in the supply chain, as well as manage production processes at the operational level. Technology access, skilled workforce, data privacy, and motivation of local suppliers to get integrated into mainstream technologies are challenges.



**Fig. 1.** Framework for achieving sustainability in the I4.0 era for emerging economies.

## 5 Practical Implication

The literature evaluation suggests training workers and managers and collaborating with research institutions to utilize I4.0 technologies in supply chain activities. Emerging economies aim for supply chain sustainability within their state's constraints and rules. I4.0 technologies will boost per capita income, operations transparency, supply chain visibility, mutual trust, country, organization, and stakeholder growth. Technology integration in their supply chain, the economic viability of investing in I4.0 technologies, a knowledge database to produce skilled workers, assessment of environmental impacts of supply chain activities, and strict policy adherence of their states are all necessary to achieve these advantages.

## 6 Conclusion and Future Implications

This study aims to help emerging economies adopt I4.0 technologies for supply chain sustainability. Population size, macroeconomic stability, infrastructure capabilities, and ease of doing business are the major factors to consider before implanting I4.0 technologies, as well as building on three major sustainability pillars to make the supply chains fast, responsive, reliable, resilient, and collaborative. This model can be extended to conduct a survey with the managers of emerging economies who want to achieve sustainability in their supply chains in a more detailed way, pointing out the main problems they encountered. Also, TOE (Technology Organizational Environment) can be used to further extend and verify the framework.



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