Manuscript - The Relationship between Industry 4.0 & Circular Economy in the context of Sustainability

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ABSTRACT

- **Purpose:** The basic aim of this study is to identify the key enablers of Industry 4.0 in order to inter-link them with the concept of circular economy so that the goals related to sustainability can be achieved. These key enablers will help to understand better how Industry 4.0 can be used as a tool to achieve circular economy and eliminating sustainability issues in the process.
- **Design/Methodology/Approach:** An extensive review of the connected literature has been conducted and a framework has been established that connects Industry 4.0 and circular economy. The literature has been synthesized and a connection has been found that helps to lay a foundation of the framework.
- **Findings:** The results from the proposed study are as follows. The use of Industry 4.0 technologies might help organisations to achieve a sustainable competitive advantage at the firm level and on the broader scale it will help to achieve the ultimate goal of circular economy by closing the loop by digitizing all the stake holders present in the economy.
- **Practical implications:** Circular economy brings a radical disruption to the existing system of linear economy. At organizational level, digitization might be a good idea, it will help to low costs, zero waste and increase profits but in the larger picture; it is a radical change.
- **Social implications:** Circular economy combined with Industry 4.0 means less industrial waste, so it will bring positive impact on the environment and improve the quality of life. It will also force governments to revisit their industrial policies.

Keywords: Circular Economy, Industry 4.0, Sustainability and Cleaner Production

1. Introduction

The resource scarcity is one of the threats that have been faced by the world today. More importantly resources are depleting drastically than imagined by the experts. According to Acerbi et al. (2020) by the year of 2060 the usage of resources will reach 167 gigatonnes. Different measures have been introduced so far in order to counter the risk of resource depletion. Among all the introduced measures; the most prominent role was played by United Nations. They have introduced "Sustainable Development Goals (SDG)". There are 17 goals in total and most importantly the 12th goal is described as "responsible production and consumption". Manufactures has to adopt a new manufacturing way that is more economically, socially and environmentally sustainable.

Acerbi et al. (2020) argue that the most promising sustainable paradigm is circular economy (CE). CE has been defined as "an industrial economy that is restorative and regenerative by intention and design." The concept of CE was originated after the realization that present linear economy system is unable to cope with the production and consumption given the amount of limited resources. CE is based on the closed loop principle of the production system so that efficiency of resources could be increased. According to Dantas et al. (2021) the concept of CE explains a paradigm shift related to usage and disposal of resources. CE is based on primarily three principles. First is preservation and enhancement of natural resources, second is optimization of resources and the third is fostering effectiveness of systems. One of the basic purposes of CE is to slow down, narrow down and close the resource loops. CE can be viewed on three different levels. One is micro level; here CE deals at products and organizations level. Second is meso level; here CE operates at the level of network of companies, it can be an industrial cluster. Third is macro level; here CE deals at the level of cities, regions and nations. The adoption of CE will help manufacturers to reduce resource consumption and helps to minimize the toxicity of industrial waste.

According to Piscitelli et al. (2020) CE is a self-regenerative economic system which is designed to reuse resources in order to reduce industrial waste to the minimum. Adoption of CE will bring economic, social and societal benefits to the organizations. In other words this new economic system will help organizations to move towards sustainable development. Now policymakers are also shifting their attention towards the adoption of CE in the future. CE is a system that keeps production and consumption in a circulation order so that the value of the products and components can be created and recreated over a longer period of time. According to Jabbour et al. (2019) CE is restorative, regenerative and disruptive to present economic system and subsequently it introduces changes in the production and design structures. The CE helps to ensure multiple usages of products. CE contradicts the take, make and dispose phenomenon of the linear economy. Kumar et al. (2021) also argue that CE is regenerative system based on the zero waste philosophy. The waste produced by one organization has a potential of being used as a raw material in another organization. Kumar et al. (2021) define CE as "realization of closed loop material flow in the whole economic system." CE is restorative by design and its purpose is to keep products, components and other materials at higher utility rate and value at any given time.

Industry 4.0 presents a concept of smart manufacturing which means the use of digital technologies like cloud computing, additive manufacturing, augmented reality etc. in the manufacturing. These technologies might help to develop a production system with a closed loop. In literature smart manufacturing is also known as sustainable manufacturing. According to Spaltini et al. (2021) there

are 6Rs in sustainable manufacturing unlike traditional manufacturing. These 6Rs are Reduce, Reuse, Recycle, Recover, Redesign and Remanufacture. A sustainable changeover towards CE is necessary to reap all the benefits in terms of environment, social and economy. Adoption of CE means a huge paradigm shift in the industrial practices. It will bring change in the patterns of consumption and production. CE will also help to create new jobs that will help to boost economy.

Chauhan et al. (2021) argue that several studies have proven that the first 3Rs; Reduce, Reuse and Recycle are guiding principles for CE models. The reduction, which explains less usage of materials, electricity and industrial waste generation by the support of efficient consumption patterns. In reuse, a limited number of resources are being used in order to manufacture a new product. The resources can include material, labor etc. In recycling, there is an opportunity which allows using material form the products which are at the end of their product life cycle. It has positive impact on the environment. Recycling is also considered as parallel to CE as it has potential to bring industrial waste to zero level.

1.1 Research Questions

This paper is focused on the circular economy framework supported and backed by Industry 4.0 enabling technologies. It is not clear so far how I4.0 technologies help to achieve CE with respect to sustainable development goals. So the research questions are formulated as follows.

- RQ1: Develop a CE conceptual framework that is embedded with I4.0 technologies so that sustainable development goals could be achieved.
- RQ2: Development of a knowledge base to identify gaps and to identify a roadmap to implement CE framework embedded with I4.0 technologies into organizations.

1.2 Research Design

A thorough review of literature has been done in the first phase focused on the aspect of circular economy. For this purpose, published literature is being reviewed. Databases like Sciencedirect and Scopus has been consulted to gather related scientific literature. A study of existing circular economy frameworks has been done and literature only presents a relationship between circular economy and Industry 4.0 technologies has been studied for the purpose of this study.

2. Circular Economy and Industry 4.0

The technologies associated with I4.0 are required to collect and analyze data in order to improve efficiency and it will eventually lead to sustainable production and consumption which is the ultimate goal of the CE. Spaltini et al. (2021) argue that CE and I4.0 are the two sides of the same coin. CE is based on the regenerative aspect and on the other hand I4.0 is based on the interconnection of technologies and human interface to create a cyber-physical space. These two can help to close the loop with the use of technologies and data. These smart technologies can help to minimize costs and helps in predictive maintenance that will help to enhance product reliability and increase the product life cycle. Hamid et al. (2020) also argue that I4.0 technologies help to reduce manufacturing wastage and monitor manufacturing and operational processes. I4.0 technologies help to balance the social

impact by reducing environmental impacts and by increasing economic benefits. Moreover CE can help to increase the circularity of natural resources in the business operations so that the goal of preservation of natural resources could be achieved.

Shayganmehr et al. (2021) argue that cleaner production (CP) is considered as a prerequisite of the circular economy. The adoption of CE depends on the implementation of CP. For example, the prevention of industrial waste and pollution are the primary concern of CE and it cannot be achieved without CP implementation. Now with the emergence of I4.0 on the global scale, many organizations are transforming themselves in terms of managerial administration and operations. I4.0 technologies help organizations to implement flexible and efficient manufacturing processes so that costs could be minimized, product quality could be enhanced and a competitive advantage could be obtained. I4.0 technologies have a positive impact on the business operations. It optimizes remote connections with the help of robots and computers and minimizes the use of human interaction. I4.0 technologies are necessary to receive maximum output from the business operations. I4.0 technologies like Internet of Things (IoT), Cloud Computing (CC) and Artificial Intelligence (AI) help organizations to increase their product quality, efficiency and decrease their production costs.

According to Shayganmehr et al. (2021) several studies have proven that I4.0 technologies can work as enabling technologies in the implementation process of CE. Now businesses have to implement I4.0 technologies in order to reap benefits of modern technology. One of the primary contributions of I4.0 is that the enabling technologies help to digitize the CE processes. I4.0 enabling technologies offers plenty of opportunities to businesses to create CE system and ethical standards of social corporate responsibility. I4.0 technologies can also be used to monitor and improve the product life cycle of the products. One of the basic objectives of CP and CE collaboration is to achieve sustainable supply chain. If standard business procedure is not followed then I4.0 technologies cannot guarantees sustainable supply chain. So that's why standard procedures should be always followed.

Several studies have indicated that I4.0 technologies can play a vital role in the context of CP and CE. According to a research result mentioned by Shayganmehr et al. (2021) CP and CE develops a business synergy after the inclusion of I4.0 technologies. This business synergy results into sustainable development and production efficiency. Zhou et al. (2020) argue that CE is an economic system that seeks balance between economic growth and environmental protection. That's why it gained popularity in the context of sustainable development. It provides CP, resource efficiency and a sustainable economic structure. Moreover it also provides a product life cycle perspective; from production to consumption. I4.0 enabling technologies also ensure sustainability in terms of smart manufacturing, resource efficiency, new business frameworks and renewable industry structures. From a theoretical perspective, sustainability can be achieved by integrating CE into I4.0 technologies. Khan et al. (2021) argue that sustainability is based on three dimensions. These dimensions are economic, social and environmental, and the main objective of these dimensions to meet the resource gap so that present and future generations fulfill their needs without putting environmental dimension in harm's way. In 2008, China pioneered in devising policymaking related to CE. They have introduced "Made in China 2025" program to enhance the development and adoption of I4.0 technologies having CE as a central theme of the program. According to Zhou et al. (2020) it will help to achieve China's self-sustainability goal and also the enforcement of CE and I4.0 technologies to boost China's economy.

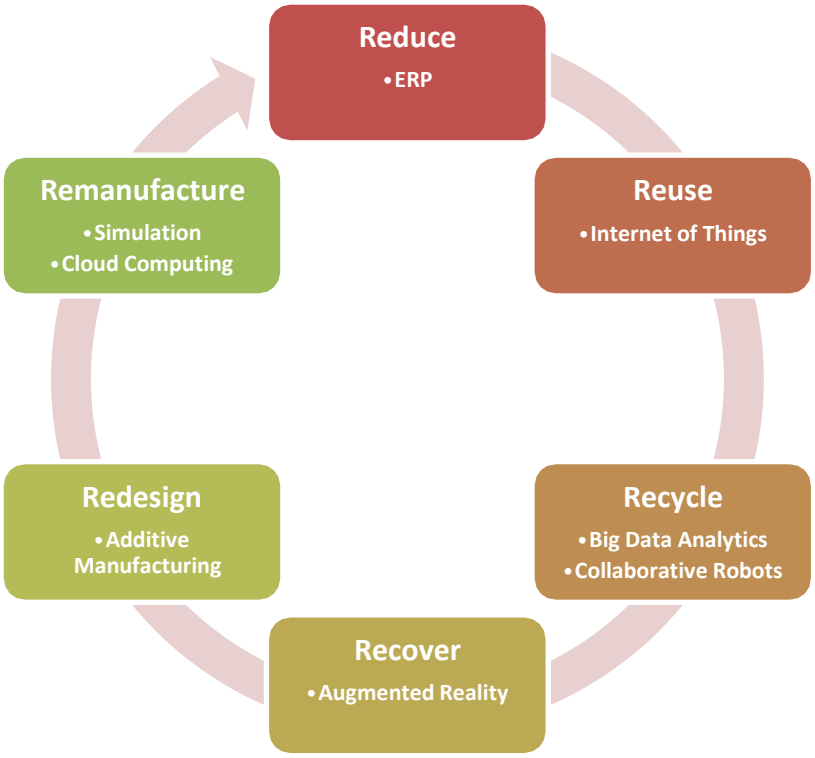

Figure 1: CE Conceptual Framework

As it can be seen that in figure 1 that a CE conceptual framework has been developed with the help of 6Rs which are instrumental for CE. It can also be seen that I4.0 enabling technologies are also used in this framework. These enabling technologies play an important role in the completion of each R. It is being illustrated that these technologies are instrumental in the formulation of CE framework. With the help of ERP software; organizations can reduce the usage of resources. ERP can also help to reduce the extra occupied space in the warehouse by ordering supplies which are required. It will also help to improve supply chain issues in an organization. Technologies like IoT are helping organizations to adopt reutilization of different products and services. With the help of IoT; smart use to products is possible which help organizations to save resources and as well as it also helps to increase product life cycle. Big data provides a platform to do data mining and machine learning. It happens only when large amount of data is being collected and being analyzed by the big data analytics. This technology will help to determine which products require recycling and collaborative robots will also help with the recycling process in order to produce recycled products. It is one small step towards sustainable manufacturing with the use of I4.0 enabling technologies. Augmented Reality is a technology that super imposes a virtual image on the real image. This tool can help to recover reusable materials from the products that are on the end of their product life cycle for the purpose of remanufacturing. Similarly additive manufacturing which is also known as 3d-printing can also help to design and produce new products from used materials in order to conserve natural resources. The last step in CE cycle is remanufacturing, it can be possible only when previous steps has been carried out. With the help of technologies like cloud computing and simulation; a completely new product can be produced and reproduced. These technologies can help to simulate the whole reproduction process on the computers

and help the organizations to understand how to conduct the remanufacturing process. These tools will also help to overcome the challenges that might come in the process of remanufacturing.

It is important to address and explore the complex nature of CE and I4.0 interaction. Numerous amount of work has been in the fields of CE, I4.0 and sustainability. Among them, some researchers focus their research on the implementation of CE in the context of I4.0. Some scholars focus their research on the barriers and driving forces in the adoption of CE in the context with I4.0. Similarly, some literature examines the relationship between I4.0 and sustainability and its connection with CE. In short, the main objective is the achievement of sustainability in the context of the relationship between CE and I4.0. It will bring technological progress, reconstruction of industrial structures, enhanced resource efficiency and suitable economic models. Khan et al. (2021) argue that sustainability is a major driving force behind I4.0 technologies. I4.0 technologies can be integrated with various business operations to obtain real time data of production and consumption patterns. These technologies help managers to monitor these patterns and allow them to make decisions based on the real-time information. These decisions will help to end the linear economy models and persuade organizations to move towards CE.

According to Kumar et al. (2021) I4.0 technologies are the major driving force behind sustainable business operations. I4.0 technologies help to foster sustainable decision making and assist in the smart manufacturing for CE. Kumar et al. (2021) argue that with the integration between I4.0 technologies and sustainable decision making; a sustainable smart manufacturing system can be established. It has been observed that with the help of I4.0 technologies, numerous challenges in CE can be resolved. It has been also noted that several organizations have not tapped the full scale benefits of I4.0 technologies and CE due to lack of awareness, knowledge and skillset.

2.1 CE & I4.0 in context with Sustainable Development Goals

Sustainability cannot be achieved without technology and innovation. Technological progress can play a vital role in the transformation of the industries and communities as a whole. Dantas et al. (2021) argue that I4.0 technologies can help to achieve SDGs, especially ones which are related to Industry. Moreover I4.0 technologies can help organizations to explore new dimensions in CE and other SDG targets in the process. I4.0 technologies are always considered as radical disruptive technologies because these technologies lead to autonomous and interconnected manufacturing which is also known as intelligent manufacturing. The basic aim to implement I4.0 technologies is to create smart interconnected factories which are economical and efficient. It is believed that I4.0 technologies will revamp the whole business operations and transform everything from product design to transportation.

I4.0 technologies are comprised on interconnected technologies for manufacturing enhancement. For example technologies like Cyber-Physical System (CPS), Internet of Things (IoT), Big Data Analytics (BDA) and Additive Manufacturing (AM) are used for production optimization. Some of the other I4.0 technologies include Cloud Computing (CC), Augmented Reality (AR), System Integration, Simulation, Cyber Security (CS) and Autonomous Robotics. These I4.0 technologies can be applied separately or simultaneously so that intelligent manufacturing could be achieved. These I4.0 technologies are not only supportive in the achievement of intelligent manufacturing but these are also helpful in the minimum waste generation. In this way, these I4.0 technologies will push towards less environmental hazardous production and push more towards cleaner production.

Sustainable development relies heavily on the technological development. In this context, I4.0 technologies can excel towards resource optimization, waste management and other sustainable practices. Dantas et al. (2021) argue that only investing in technologies is not enough in order to achieve SDGs. By limiting focus only on technology development might lead to increase in the greenhouse gas emissions which can eventually lead to depletion of natural resources. Bag et al. (2020) argue that resources such as infrastructure, skilled workforce, technical knowledge, domain knowledge, financial support and top management support are required by I4.0 to run sustainable operations smoothly.

3. Conclusion

The main objective of this study is to carry out a thorough review of the literature related to the present status of CE with the context of I4.0 technologies. The other goal includes the study the aspect of sustainability within the context of CE and I4.0 technologies. For this purpose, scientific literature has been collected from reputable sources and examined deeply. Scientific literature focused on CE framework and its relationship with I4.0 being core aspect of the review; it is being noted that there is a strong relationship exists between CE and I4.0 technologies. It is also observed that in recent time; publication of literature related CE has been increased drastically.

Most of the published literature is focused on the benefits of CE system over the linear economic system which includes remanufacturing, enhanced business operations and minimum waste generation. From the practical perspective, it has been analyzed that in order to implement CE framework; different set technologies can be used by different organizations. There is no one standard technology which can be used in order to obtain CE framework. Moreover it is also noted that investing only in technologies will not provide desired results unless organizations also invest in other resources like skilled labour force, domain knowledge and support from the management.

To conclude the discussion, it can be said that CE has a great potential in the future but it is still a less explored area of research. Now a lot of literature is being published regarding CE but more work in this research area is needed to be done. From scientific perspective; this study does not provide as such an original contribution topic but it provides a good review of the topic for a reader. This study also provides a CE conceptual framework embedded with I4.0 technologies which are inspired from the existing literature. This CE conceptual framework can be used as a sound base to extend the research on the same topic for the future researchers and academicians.

It is a definite fact that CE is not possible with I4.0 technologies and a socially and economically sustainable manufacturing system is not possible without advancing in CE system.

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