

The application of Industry 4.0 technologies and its effect on Circular Economy, in the context of R&D: A Literature Review

Abstract

As the manufacturing industry embrace the mega-trends, such as digitalisation through the application of Industry 4.0 and accelerating sustainability feature through the adoption of Circular Economy (CE). The fundamental principles of production and system dynamics are changing underlying research and development (R&D) and strategic reconfigurations. Therefore, this study will fill the gap in assessing the development of R&D strategy by identifying the drivers and understanding the challenges that are faced by firms moving towards a CE paradigm shift with the help of I4.0 technologies. This research will construct a theoretical construct by synthesising the connection between industry 4.0 (I4.0) technologies and the circular economy (CE) paradigm in the context of R&D using 28 research papers. This study is aimed to critically analysed the role of R&D in technological (circular) product innovation and process innovation. The findings revealed that the strategic executives need to understand the integration of I4.0 technologies to evaluate sustainable solutions through R&D that can be incorporated into a firm's strategy. As R&D strategy yields the development of differentiated offerings through improved production and delivery methods. Where I4.0 technologies aid in positioning CE principles within the business model through connected platforms. Instead of realising the essence of R&D as the driving essence of a firm's performance, it is left siloed from corporate priorities. It has been noted that the reliance on I4.0 technologies in different phases of operations has ascended the R&D-related costs (Gupta & Singh, 2021). However, the firms are expecting to receive enhanced financial benefits in the long term.

Keywords: Circular economy (CE), industry 4.0 (I4.0), research and development (R&D)

Introduction

Businesses are required to introduce innovative processes to reduce operating costs and enhance economic gains(Cano et al., 2022). Innovative processes/techniques could eliminate non-value-added activities from the supply chain network (Ali & Kannan, 2022). With the advancement in technology and growing awareness of environmental sustainability, social and ecological benefits such as reduced wastage and reduction in energy consumption (Boom-Cárcamo & Peñabaena-Niebles, 2022). Innovation through the application of Industry 4.0 and accelerating sustainability feature through the adoption of Circular Economy (CE) is gaining popularity (Suchek et al., 2022). This advancement is highly contributing to an organisation's performance, success, and survival. This need for innovation is determined by the external environment that pressurizes the businesses to adopt eco-friendly processes to minimise waste and maximise productivity (Gao et al., 2022). Therefore, I4.0 technologies provide a shared platform that aligns the R&D activities with the sustainable strategic priorities and establish a robust circular-product.

To date, there is scarcity of studies that analysed the affiliation among CE, I4.0 technologies and R&D. Therefore, this study aims to bridge the gap that interconnects the fundamental concept of growth when firm's implement R&D element within a firm's business model by

introducing innovation to enhance the firm’s productivity and minimising the production cost (Cano et al., 2022). The following study breaks up into three close related but disperse aspects. Firstly, an analysis of CE paradigm is conducted. Identifying the drivers that spurs the innovative plans for growth prospects. This study would try to recognise the inherent weaknesses in the circular market mechanism to identify the need for intervention to restrict over-exploitation of resources.

The next step will be drawn upon I4.0 technologies, that leverage this CE paradigm by developing productive capability through innovation. Lastly, identifying the drivers of R&D will be evaluated that tailor a firm’s strategy to support innovation driven long-term growth.

Methodology

Given the rapid evolution of industrial paradigm shift from linear to circular economy concept because of technological advances (through R&D measures), it is critical to assess the current state of related literature. Therefore, this study adopts the systematic literature review method to provide a more comprehensive overview to reveal research gaps and identify the future research agenda in a logical manner. The four logical steps that has been followed in current study are:

Step 1: Problem Formulation

The initial step involves development of research questions. This study intend to build a theoretical construct by combining industry 4.0 (I4.0) technology and the circular economy (CE) paradigm in the context of R&D. thus, 3 research questions were set:

- Research Question 1: What is the relationship and drivers among CE, I4.0 technologies and R&D that spurs the innovative plans for growth prospects
- Research Question 2: What are the main elements of I4.0 technologies that leverage the CE paradigm by developing productive capability through innovation (R&D)
- Research Question 3: What are the drivers of R&D will be evaluated that tailor a firm’s strategy to support innovation driven long-term growth

Step 2: Literature Search and Screening

The second phase entailed categorising the relevant keywords using a double quotation and Boolean logic (or/and) to combine the key variables (CE, I4.0 and R&D) in accordance with the study's objectives to properly place the research work in the relevant subject area. The primary database used in current study is “web of science” that is one of the most extensively used database in academia and research. Later three keywords (CE, I4.0 and R&D) were chosen after careful considerations that were far along refined using Boolean logic, such as “CE and/or I4.0”; “CE and/or R&D”; “I4.0 and/or R&D”.

Table 1: List of keywords and Boolean logic

Main categories and Boolean Logic	No. of articles in selected database
Circular economy (CE)	6099
Industry 4.0 (I4.0)	4339
Research and Development(R&D)	5119

CE and/or I4.0	216
CE and/or R&D	32
I4.0 and/or R&D	29
Finalised research papers	28

As shown in table 1, presents the refinement of number of research papers in the literature search and screening process according to the keyword search. The patterns, interventions, comparisons, and variances in articles relevant to the study's core variables were then extracted and analysed in a total of twenty-eight publications. (CE, I4.0 and R&D). Before finalising the research articles, the inclusion/exclusion search criteria were followed to validate the quality and reliability of the data in accordance with the research protocol. Table 2 presents the inclusion and exclusion criteria adopted in current study:

Table 2: The inclusion and exclusion criteria

Theme	Inclusion Criteria	Exclusion Criteria
Language	The papers that were written in the English language were selected	Papers written/translated in other languages (except English) were excluded
Type of papers	Only used peer-reviewed research journal articles.	Non-academic publications and non-peer-reviewed papers were not considered.
Time frame	The articles that were published between 2021 and 2022 were included.	Papers that did not fall within the pre-determined time frame (2021-2022) were disqualified.
Subject area	Only engineering and business-related journal articles were included.	The papers from other discipline were excluded.

Step 3: Bibliometric Analysis

A bibliometric analysis is a statistical examination of the available bibliometric data from numerous perspectives based on a quantitative appraisal of the collected research papers. Once the author had finalised the shortlisted papers, the author used VOS viewer to conduct bibliometric analysis and network analysis. The publications were analysed using keywords and authors wise.

Figure 1: Keyword-wise Analysis

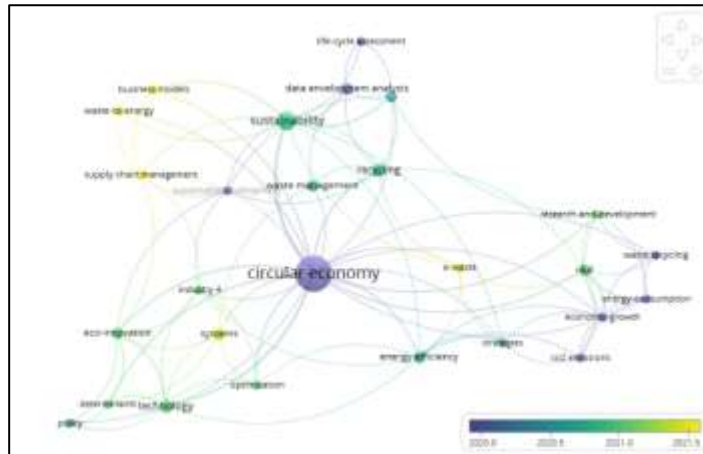


Figure 2: Base country-wise Analysis

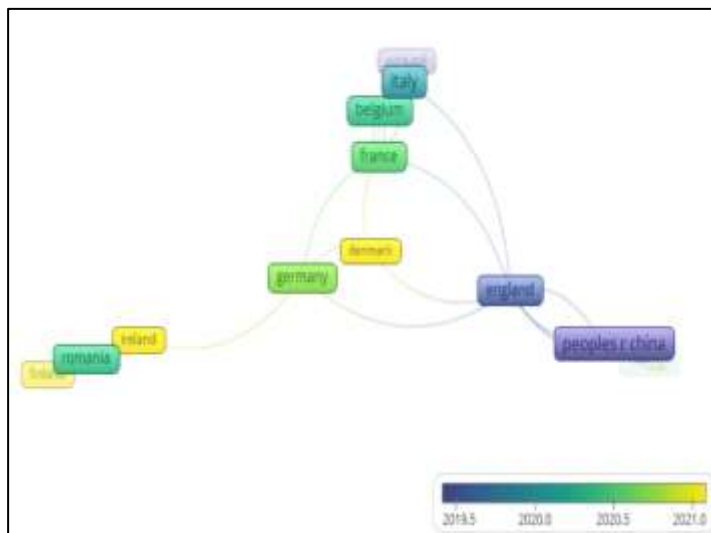


Figure 1 illustrates the keyword-wise analysis where there are 4 clusters, and the interaction and influence of these clusters are evident from the bibliometric analysis. The number of times each keyword is used, as well as the connection between pairs of keywords, are calculated in the co-occurrence analysis of keywords. This indicates that circular economy has been given extra attention in regard with sustainability, energy efficiency, strategies. Through the comparison of the co-citation analysis of selected articles, it has been discovered that the paradigm shift to CE has given prominent focus on R&D, technology, systems, and economic growth prospect, where e-waste, waste management and I4.0 appears to be playing an increasingly crucial role in this regard. Likewise, figure 2 presents base-country wise analysis with four clusters. Where China and England seem the most influential countries showing a connection with other European countries.

Step 4: Content Analysis:

Firms are pushed to rethink their strategy/business model to produce ecologically friendly products, yet there are certain drawbacks. The following research investigated a broader element of innovative R&D prospects and their potential for growth (Ali & Kannan, 2022). It has been highlighted that R&D is a well investigated field that incorporates a methodical procedure and is the most major driver of invention. Because a company's growth mechanism is directly or indirectly linked to its productivity. It is linked to increased innovation (spending in R&D, using I4.0 technologies, and implementing the CE paradigm), which will result in higher long-term productivity and growth for countries. A brief content analysis is as follows:

Circular Economy

When a firm adopts a circular economy paradigm into their business model, the management pledges to minimise wastage and reduction in environmental pollution (Badhotiya et al., 2022). Hence, the key to sustainable development is correlated with its innovation capabilities (Boom-Cárcamo & Peñabaena-Niebles, 2022). Though, innovation not always deliver the growth prospects directly, but it can be done through raising its productivity capabilities (Jabbour et al., 2019). There are two basic aims of this study. First, the CE paradigm has been increasingly getting traction among practitioners and researchers globally. This paradigm change aims to close the loop in the supply chain, resulting in the most efficient use of resources (Atif et al., 2021). Furthermore, the role of product design in a circular firm differs from that of enterprises that operate on a linear economy in some ways (based on throw-away products) (Suchek et al., 2022). Product design has a wide range of ramifications, according to the Ellen MacArthur Foundation, contributing to improved economic sustainability in production chains by improving product life cycles (Ching et al., 2022), making them more manageable, and providing innovation (J. X. Zhang et al., 2022). It is important to note that eco-design does not only apply to product development or even to product-oriented organisations. It is argued that thoughtful product design can provide organisations with competitive advantages, so one could see the value of investing in R&D activities as it affects economic performance (Kruger & Steyn, 2022).

Industry 4.0

The industrial paradigm comprising two major concepts: Inter of things (IoT) and cyber-physical systems (CPS) was grounded at Hannover fair in 2010 (Jafari et al., 2022). Later in 2015, it was coined as "Industry 4.0" as part of Germany's industrial strategy. It delivers an intrinsically accessible platform that assists management by adlibbing operational and digital transformation decision-making, optimising customer experience while increasing return on investment (C. Zhang et al., 2021). As a result, data has cemented itself as a critical component of company strategy. I4.0 plays a vital role to optimising the flow of material, resources, and information transfer within and outside a firm (Teisserenc & Sepasgozar, 2021). I4.0 has always had the potential to be a disruptor for economic growth. However, Covid-19 outbreak has provided a clear path to show its potential for greater economic impact beyond connectivity (Gupta & Singh, 2021). Therefore, most of the studies presented a positive impact of application of I4.0 technologies.

Research and development (R&D)

To compete in an increasingly globalised economy, R&D has been handled as a means of exploring competitive advantages and innovation (Baran & Polat, 2022). In this regard, R&D based on eco-design and life cycle assessments allows for the selection of alternative materials and the pursuit of improved economic and environmental performance throughout the life cycle of products (Ching et al., 2022). On these principles, a product's design stage can encourage a more circular performance (Muller et al., 2022). The consumption phase of those products is extended by designing long-life goods and extending the life of products (by, for example, giving services to extend product life, such as repairing and remanufacturing), thus reducing the flow of resources (Jabbour et al., 2019). Subsequently, Kate et al., (2022) asserted that R&D has played a vital role in development of innovative products within the pharmaceutical and agrochemical industries. Application of I4.0 technologies has leveraged this transition by converting random data that is generated at various phases of product development into meaningful information (Baran & Polat, 2022; Grimaldi et al., 2022).

Findings

The CE notion entails getting maximum economic and environmental benefits with fewer resources by synergistic or multiplier effects through improvising product and process-modification (Boom-Cárcamo & Peñabaena-Niebles, 2022). Traditionally, production cost doesn't include the environmental costs, but CE paradigm implies a new dynamic that is based on innovation (Cano et al., 2022). Jafari et al., (2022) suggested to incorporate the I4.0 with CE paradigm to resolve issues and disruptions related to the sustainable development. As businesses operates with the motive of reducing production costs with superior productivity. Therefore, I4.0 infused digital transformation will aid in development of a circular products with superior performance that justifies the price premium charged to customers (C. Zhang et al., 2021). From theoretical approaches, it is evident that there have been a variety of studies that suggest businesses to resolve environmental problems by extending a product's lifecycle by considering green procedures and through application of I4.0 technologies for energy-efficacy (Jafari et al., 2022).

Therefore, it is evident that businesses are investing in R&D for sustainable technical progression have accelerated over the period, and these may be the product, services, or infrastructure-related operations that have an imperative influence (Muller et al., 2022). Businesses need to enable and enhance technical development within the business model as well as commercialise it to gain a competitive market advantage (Alvarez-Aros & Bernal-Torres, 2021). The adoption of R&D practices moderates the productivity of any business that draws a positive impact on its performance. It is a combination of output produced and its interface with internal and external environments. Businesses are compelled to develop and design processes that increase the capacity to meet demand by using the post-manufacturing resources and minimise the number of wastes to create additional value (Malerba et al., 2022).

For which, the manufacturers are integrating economic goals with environmental welfare within their business model. Ecological upgrading shifts away from resources intensive productions towards value and knowledge-intensive businesses (Dabić et al., 2022). Therefore, businesses are required to invest in R&D so the advance technologies and

innovations will result in better environmental welfare and less waste while creating employments and gaining higher profit margins (Kruger & Steyn, 2022). R&D has helped them to detect the threats of environmental degradation, while identifying opportunities for a sustainable development (Suchek et al., 2021). The role of entrepreneurs towards innovation and diffusing of advanced technologies and techniques is vital to create cleaner production (Gao et al., 2022). So continuous reconfigurations in business strategy would steadily cut the waste emissions and minimising the production cost rather than limiting the reliance on environmental resources (Cano et al., 2022). Qu et al., (2021) undertook a study to examine the CE paradigm and concluded that R&D aids in the advancement of green technologies.

Suchek et al., (2021) and Badhotiya et al., (2022) suggested that there are certain complications compel with active scanning of environmental perspectives and exploiting new opportunities in the market that enhance a firm's performance. Further, Pereira et al., (2022) conducted a study and evaluated 5Rs of CE principles and concluded that SMEs are incorporating modern technologies to develop CE practices. Hence introducing innovative ideas by redesigning a firm's business model seems a reasonable amendment to gain competitive advantage, that helps in sustaining existing customers loyalty and attracts new segment of customers (J. X. Zhang et al., 2022). Rodrigues Dias et al., (2022) also conducted a study in the aerospace industry, the following information was confirmed, and it was found that financial rewards have prompted corporations to implement circular strategies. Therefore, infusing R&D is significant to be considered at the origin or commencement phase of any product's life cycle (Ching et al., 2022; Jabbour et al., 2019). The management level of a firm is responsible to set a strategy that helps them to sustain in the market while consolidating its growth and profitability. While operational level ensures development of a sustainable relationship with the supplier to ensure delivery of goods and/or services at a reasonable production cost in a timely manner (Sassanelli et al., 2021).

Conclusion and Future recommendations

In today's world, masses are well informed about environmental dilapidation. Therefore, the businesses are compelled to redesign their strategy/business model to deliver environmentally friendly products but there are some limitations associated with it. Following study has explored a wider aspect of innovative R&D prospects and its growth prospect. It has been noted that R&D is widely researched discipline as the most significant driver towards innovation and involves a systematic process (Feng et al., 2022). As the mechanism of growth of a firm is directly or indirectly related to its productivity. It is associated with higher innovation (investing in R&D, application of I4.0 technologies and implementing CE paradigm) that will generate higher productivity and growth in the long-term for economies.

I4.0 technologies helps in positioning CE principles within the business model through connected platforms. Instead of realising the essence of R&D as driving essence of a firm's performance, it is left as siloed from corporate priorities (Jabbour et al., 2019). Therefore, this study has assessed the development of R&D strategy. Therefore, it is recommended for future researchers to investigate the associated barriers to understand the challenges that are faced by firms moving towards CE paradigm-shift with the help of I4.0 technologies. Feng et al., (2022) also suggested to conduct further studies on how R&D strategy yield the development of differentiated offerings through improved production and delivery methods.

Most of the R&D related literature used in current study is from engineering related. It has been noted that there is scarcity of business management studies that has used R&D as a main/mediator variable for CE or I4.0. Hence, it is recommended for future researchers to analyse the role of R&D in innovation towards CE paradigm and application of I4.0 technologies.

It seems a reasonable assistance to governments and other regulatory bodies to impose financial penalties on enterprises to discourage them from polluting and promote waste-reduction measures (Teisserenc & Sepasgozar, 2021). still, current study shows that there is scarcity of empirical studies that investigates the policies, tax credits and other incentives offered by the governments (Boom-Cárcamo & Peñabaena-Niebles, 2022). As there is dynamic market rivalry and businesses do not operate in a static environment. Therefore, it will be interesting to see future researchers investigating the measure related to organisational strategy and their optimal decisions. To solve this environmental degradation predicament, businesses must invest in R&D to overcome organisational inertia by providing a connected platform to align individuals, groups, and corporate incentives while still gaining greater economic and environmental benefits.

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