**Redesigning Traditional Linear Supply Chains into Circular Supply Chains – A Study into its Challenges**

**Abstract**

Transitioning to a Circular Economy (CE) is considered the most promising way to achieve economic and environmental sustainability. However, companies and governments are faced with challenges in redesigning existing linear supply chains (SCs) into circular supply chains (CSCs). Although previous research has tried to identify challenges in the implementation of CE in their own specific contexts, the literature lacks a systematic identification and validation of challenges to transition to circular supply chain management (CSCM). This study identifies the key barriers to the redesign of SCs into CSCs in the global manufacturing sector and develops a broad classification to facilitate their mitigation. An extensive review of the state-of-the-art literature on CSCM identified a list of 20 barriers plaguing manufacturing firms and impeding the transition of their linear SCs into CSCs. The barriers were analysed through 200 responses received from experts in the fields of CE and supply chain management using a questionnaire-based survey. The findings of the study suggest significant restraints towards CSCs implementation owing to the lack of incentives and policies, and product complexity. Moreover, the study of the broadly classified barriers such as standardisation and legal barriers, and financial and economic barriers indicate substantial similarities between the results and findings of the extant literature thereby implying significant alignment between the industry and the academia regarding the subject. This work is useful in formulating strategies to redesign CSCs, and helps researchers and practitioners to understand the challenges in implementing CSCs.

***Keywords:*** Circular Economy, Circular Supply Chain, Closed-loop Supply Chain, Barriers, Challenges, Sustainable manufacturing.

**1. Introduction**

The industrial revolution brought forth manufacturing methods that enabled companies to produce consumer goods on a large scale (Xu et al., 2018). With rising economic and industrial development coupled with globalisation, the cost of manufacturing declined, and the purchasing power of consumers grew, resulting in a frequent purchase, use, and disposal of goods that followed a linear supply and consumption model (Baker et al., 2020). This not only led to increased demand and utilization of natural resources but also drove a significant rise in levels of waste generation and carbon emissions. The current environmental issues concerning climate change and global resource scarcity stem from the unregulated and unsustainable use of earth’s resources by governments and businesses in the past (Lieder and Rashid, 2016). Due to the growing population, the demand for resources has increased exponentially and it is hence necessary to measure resource consumption to meet the requirement. Since the availability of resources is limited, it is important to adopt reuse strategies to cope with resource depletion.

The concept of Circular Economy (CE) contributes to addressing the above issues in an industrial context and has gained widespread attention from academia, industries, and governments (Mangla *et al.*, 2018). Biodiversity losses are becoming a critical concern for the global economy. Many initiatives have been taken by different countries to reduce biodiversity loss and ensure sustainable development through the adoption of CE practices (Wallace, 2020). Whilst policies for the adoption of the CE approach have been issued by various governments including China, Japan, the US, and the European Union, companies are currently facing challenges in converting their traditional linear supply chains into circular supply chains whilst realising environmental, social, and economic benefits (Bressanelli *et al.,* 2019). To become an integral part of a circular supply chain (CSC), a manufacturing firm needs to first identify the challenges in redesigning its existing supply chain followed by formulating strategies and solutions to mitigate those challenges and facilitate a gradual and smooth transition to CSCs.

Traditional manufacturing focuses on a ‘take-make-dispose’ approach, which feasibility is now under question given resources price volatility, growing consumption levels, and rising regulatory and environmental pressures (De Angelis *et al.,* 2018). Flexibility in supply chains not only ensures quick deliveries but also helps in achieving sustainability (Dwivedi *et al.,* 2021). Shifting to a circular economy offers a potential solution for simultaneously achieving economic growth as well as environmental conservation. Such a shift is enabled by the redesign of existing supply chains into CSCs through a systemic and holistic approach that encompasses the re-design of products, business models, supply chain networks, material and information flows, and enablers (Bressanelli *et al.,* 2019). However, the redesigning approach poses several barriers and challenges that must be taken into consideration.

Several studies have pointed out these challenges in the implementation of closed-loop supply chains (Govindan and Hasanagic, 2018; Bouzon *et al.,* 2018; Bressanelli *et al.,* 2019), although in a rather general context which includes both the manufacturing and non-manufacturing sectors. Moreover, previous research on CE and CSC have only focused either on a specific industrial sector (Densley Tingley *et al.,* 2017; Khodier *et al.,* 2018; Rajput and Singh, 2019), a particular geography or region (Whalen *et al.,* 2018; Batista *et al.*, 2019; Kumar *et al.*, 2019), or an organisational group such as social enterprises and SMEs (Faccio et al., 2014; Zamfir *et al.,* 2017; Ormazabal *et al.,* 2018). Other studies (Lieder and Rashid, 2016; Lieder *et al.*, 2017; Nascimento *et al.*, 2019) that cover the global manufacturing sector have taken into account the overarching goal of CE implementation rather than focusing on the redesign of supply chains, which is a pre-requisite to the industrial adoption of CE. Industry 4.0 technologies have been identified as a potential solution to tackle circular economy challenges (Agrawal et al., 2021). Therefore, a holistic categorisation of the challenges, especially in a manufacturing supply chain context, does not exist in the extant literature on CE and CSCs. This paper addresses this gap in the academic literature by addressing the following research questions:

RQ1. What are the potential barriers to redesigning traditional supply chains into circular supply chains?

RQ2. How could these barriers be analysed for the effective adoption of circular practices in supply chains?

To summarise, whilst numerous benefits from converting a traditional supply chain into a CSC are often found in the scholarly literature (Bressanelli *et al.,* 2019; Govindan and Hasanagic, 2018; Mangla *et al.*, 2018), limited studies that identify and analyse the barriers for redesigning SCs in the context of the CE perspective have been conducted (Nandi *et al.,* 2021; Sawe *et al.,* 2021). This study makes a unique contribution to the existing literature when redesigning traditional linear SCs into CSCs by considering the opinion of experts from different regions and multi-industries to identify and analyse the challenges. Therefore, this paper identifies such challenges in terms of organisation, technology, materials, economy, society, and legal aspects which restrain, in this modern day and age, the development of CSCs.

The paper does not only address the aforementioned existing gap in the literature and provide a foundation for further research on the topic but also serve as a guiding platform for enabling manufacturing organisations to play a proactive role in mapping the challenges to their individual businesses and supply chain contexts and assess the feasibility of transitioning towards CSCs in the future to successfully implement the model of a CE thereby championing sustainability.

The rest of the paper addresses the following topics: Section 2 explores published and peer-reviewed literature on the topic of CE and CSCs to extract a list of commonly cited barriers. The research methodology followed within this paper is presented in Section 3; the analysis and validation of the barriers as well as the results are included in Section 4. Section 5 discusses the results in relation to relevant literature. Finally, Section 6 provides the conclusions.

**2. Research context**

This section includes a review of past and current research work on circular supply chain management and challenges in redesigning traditional SCs into CSCs.

**2.1 Circular Supply Chain Management (CSCM)**

This subsection presents a review of the adoption of circular practices in supply chains. Organisations around the world are seeking to improve their product offering with respect to their design, production methods, and delivery to provide maximum value to customers and at the same time make them sustainable in the market (Mangla *et al.*, 2018). Whilst the concepts of Sustainable Supply Chain Management (SSCM) and Green Supply Chain Management (GSCM) present the integration of sustainable thinking into supply chains, none of them conforms entirely to the CE philosophy (Farooque *et al.*, 2019). It has been argued that through the adoption of a circular model of the flow of materials, components, and products, organisations can reduce waste and the negative environmental impacts of their supply chain practices (Genovese *et al.,* 2017). Moreover, in order to improve the ecological, economic, and social performance of industrial supply chains, it has become necessary to integrate traditional Supply Chain Management (SCM) with CE (Mangla *et al.*, 2018). This has led to the incorporation of CE practices in SCM which is now commonly known as closed-loop or circular SCM (CSCM) (Lahane et al., 2020).

CSCM enables the main characteristic of CSCs by providing a circular flow of resources. Circular resource flows are symbolic of CE practices to circulate materials, goods, and energy back into the economy through reverse supply chains (Farooque *et al.,* 2019; Lahane *et al.,* 2020). Cycling materials and preserving their value require re-thinking of traditional reverse supply chains to incorporate CE practices such as reselling (reusing), repairing, remanufacturing, refurbishing, and recycling by involving one or more supply chain partners.

The development of a symbiotic relationship between partners would mean that the waste generated by one becomes a nutrient for another (Weetman, 2017). For instance, cooking oil produced and utilised in a food supply chain can be processed and refined to produce biodiesel, which can be used to run equipment or a vehicle (Genovese *et al.*, 2017). Such practice is already being implemented by the fast-food chain McDonald’s, which recycles cooking oil, which was previously being discarded as waste, to generate biodiesel to power its supply delivery trucks (Business Today, 2018). H&M, the world’s leading clothing manufacturer, is also moving towards a circular and renewable fashion industry by creating CSCs for textiles (where unwanted clothes are reused or recycled into new ones), collaborating with reverse logistics service providers, and innovating material selection at the design stage (H&M Group, 2020).

Whilst some global corporations are starting to adopt CE practices in their transition to CSC, research regarding CSCM is still at a nascent stage to conceptualize the advancement of SCM theories and practices to realise CE’s vision and potential (Farooque *et al.*, 2019). Moreover, implementing CSCM practices is a challenging task as it is hindered by numerous barriers (Mangla *et al.*, 2018) and transition towards CSCM requires a significant transformation in business models, configurations of SCs, and practices related to product design, production, consumption, waste management, and recovery (Mendoza *et al.*, 2017). The identification of these barriers would be the first step in transitioning towards a circular SC model. This is the objective of the following section.

**2.2** **Challenges in redesigning traditional SCs into CSCs**

The concept of CSCM has grown in prominence in the literature over recent years. However, manufacturers find themselves ill-positioned to exploit the opportunities offered by CSCM (Kumar *et al.*, 2019). Moreover, from a SC perspective, it is almost impossible for a single manufacturing organisation to redesign the entire value chain to implement CE practices since multiple actors are involved in the production, distribution and consumption processes (Bressanelli *et al.,* 2019). The identification of such challenges becomes critical to formulating strategies for their mitigation to eventually shift from traditional SCM to CSCM (Govindan and Hasanagic, 2018).

Evidence suggests that one of the key barriers in the implementation of CSC is the longer payback period offered by product service systems (PSS) (Homrich *et al.,* 2018; Werning and Spinler, 2020). PSS is an example of a circular business model (CBM) wherein products are not sold but offered as a service. The payment to the service provider takes place throughout the usage of the product or solution which has a negative impact on the cash flow of the firm, thus posing an economic and financial challenge towards the implementation of CSC. Furthermore, the financial and operational risks in PSS are borne by suppliers and service providers. For instance, early termination of a contract by customers might expose suppliers to financial risks. Moreover, responsibility for maintenance and repairs is borne by service providers, which pose an operational risk in the CSC (Flachenecker and Rentschler, 2019; González-Sánchez *et al.,* 2020).

In CE, products are designed to last longer than those in the linear economy. Shifting to CSCM would mean that circular products will cannibalise the sales of new products (Loon and Wassenhove, 2018; Kane *et al.,* 2018). Repair and maintenance activities further lengthen the life of the existing products, which limits the future revenue stream of companies (Pedersen *et al.,* 2019; Guldmann and Huulgaard, 2020). This poses a financial challenge to manufacturers and SC partners. Additionally, manufacturers and original equipment manufacturers (OEMs) are often cautious and limit sharing their know-how and intellectual property (IP) with their SC partners, which hamper the execution of CE practices such as repair and remanufacturing (Kane *et al.,* 2018). Suppliers may also prevent access to information, materials, components, and spare parts to their SC partners to maintain their sole proprietorship and gain a competitive advantage (Saidani *et al*., 2019; Guldmann and Huulgaard, 2020).

*Designed-to-last* or *built-to-last* products have a longer lifecycle and find lower adoption in fast fashion industries such as clothing and mobile electronics owing to consumers’ purchase behaviour. Preference for *use-and-throw* products that come with options for a variety selection serves as another reason for the unattractiveness of circular products (Kumar and Carolin, 2019; Bressanelli *et al.,* 2019; Shirvanimoghaddam *et al.,* 2020). Product complexity is another barrier for implementing CSCM as CE practices become difficult and costly to undertake as the complexity of the products increases in terms of their design and constituent materials (Halse and Jæger, 2019; Rosa *et al.,* 2019). Mass customisation of products further aggravates the challenges faced in the recovery phase as processing and re-circulation of diverse materials and components require separate methods, processes, and facilities, which increase the complexity and cost of implementing CSC (Khodier *et al.,* 2018; Pacheco *et al.*, 2019).

Although governments and research organisations are pushing for sustainable manufacturing, there is a lack of standardisation in the adoption of CE practices regarding processes, activities, and materials across industries and sectors. The absence of a holistic framework makes it difficult for manufacturing organisations to implement CSCs (Mangla *et al*., 2018; Ranta *et al*., 2018; Bouzon *et al.,* 2018). Moreover, the lack of financial incentives from the government regarding, for example, the use of renewable energy sources and waste reduction deter organisations from switching to CSCM. There is currently a lack of such taxation systems, regulations and policies spanning across the manufacturing sector, which can promote the adoption of CE practices and incentivise firms striving to implement CSCM (Whalen *et al.,* 2018; Saidani *et al.*, 2019; Kumar *et al.*, 2019). Furthermore, existing indicators such as GDP and industrial production focus on the level of production and consumption based on a linear economy. There is a lack of a commonly recognised system of metrics and indicators that can measure the level of value recovery in a circular economy and enable organisations to monitor and evaluate their CSC performance (Kravchenko *et al.,* 2019; Bressanelli *et al.,* 2019; Gong *et al.,* 2020).

Uncertainty regarding the return flow of the products in terms of their quantity, quality, mix, time, and place decreases the prospects of optimizing and achieving economies of scale in reverse supply chain activities. The increased recovery costs and efforts restrain companies from adopting a circular approach in their existing supply chain (Ranta *et al.*, 2018; Bouzon *et al.,* 2018). Moreover, recovery of used products implies that additional infrastructure and logistics are needed for their transportation, handling, processing, and storage, which would drive up the operational costs in implementing CSCM (Whalen *et al.,* 2018; Levering and Vos, 2019; González-Sánchez *et al.*, 2020). Furthermore, all supply chain partners must be aligned with the manufacturing organisation’s CE vision and should possess the skills, resources, and capabilities to realise various CE practices. Currently, companies face challenges in finding such suitable partners as complete vertical integration is seldom achieved in manufacturing SCs (Bouzon *et al.,* 2018; Tura *et al.*, 2019). Even if firms manage to find suitable SC partners, systems for information sharing might differ across the chain, which will make coordination difficult to achieve. Lack of standardized systems and IT integration thus becomes a challenge faced by manufacturers in shifting towards CSCM. Furthermore, competition amongst supply chain tiers is a major barrier against the formation of a transparent and streamlined supply chain (Mangla *et al*., 2018; Bressanelli *et al.,* 2019).

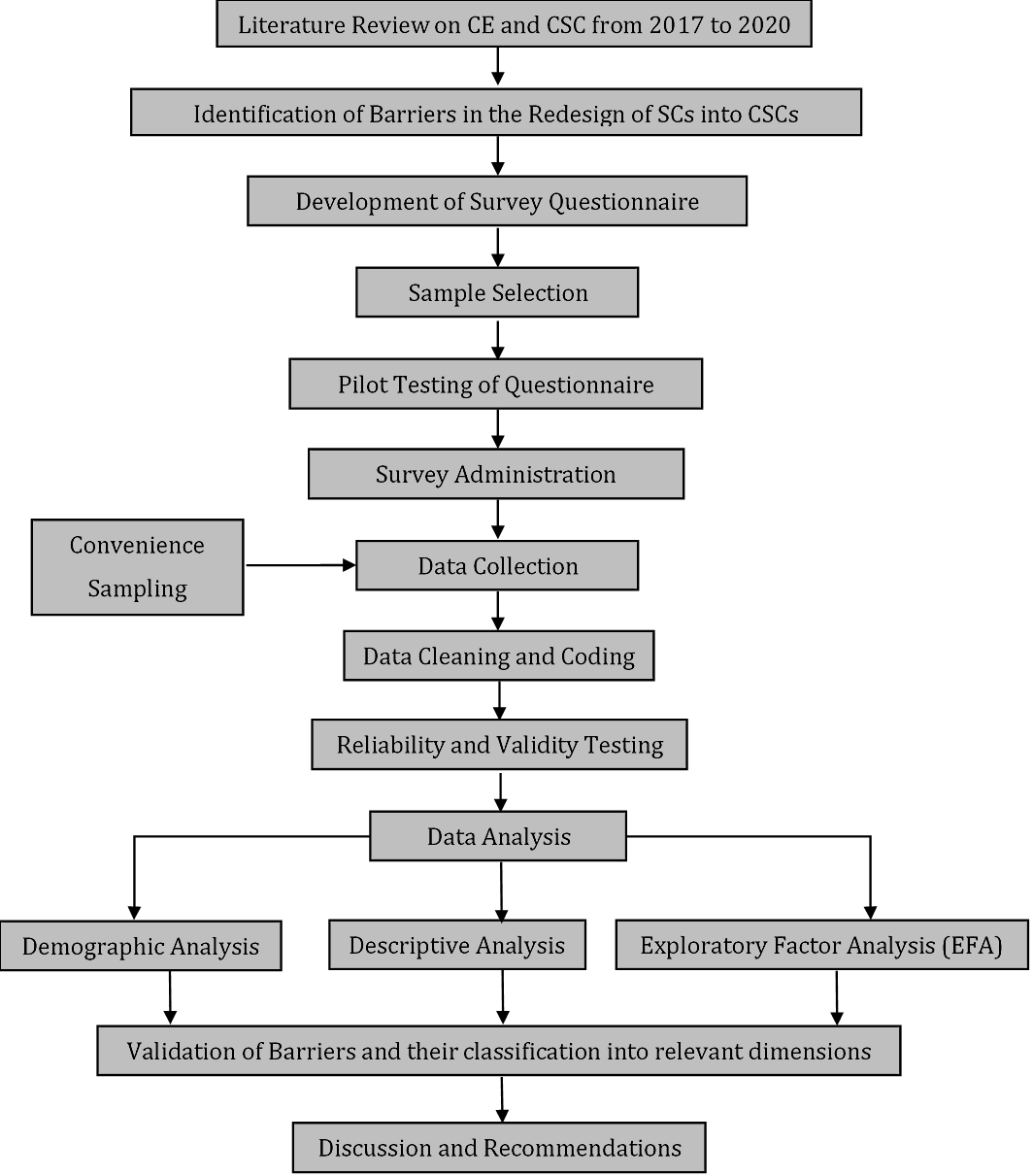
Another challenge faced by manufacturers is a failure in the recovery of end-of-life (EoL) products. Products are often lost, misplaced, or damaged during the collection and recovery phase due to improper handling and transportation (Saidani *et al.*, 2019). Processing of recovered products might further lead to contamination of inherent materials that would render them unsuitable for recycling or remanufacturing. Renovation processes are not only inefficient in terms of material recovery but also expensive compared to production from virgin materials in the linear economy (Bouzon *et al.,* 2018; Agyemang *et al.*, 2019). Moreover, limitations in existing track and trace mechanisms related to hardware (e.g. sensors, barcodes, and RFID) and software (e.g. traceability and tracking systems) makes it difficult for manufacturers and logistic partners to closely monitor products and material recovery in reverse SC activities (Bianchini *et al.,* 2019; Dieckmann *et al.*, 2020).

Shifting towards CSCM implies that technologies and processes have to be matched for every product being made circular. Innovations and improvements in product design, manufacturing processes, and employed technologies would require existing infrastructure to be upgraded and that will drive up the operational costs. Conversely, built-to-last circular products are not able to contribute towards product innovation, rendering them unattractive for firms focusing on innovative and bespoke products (Bressanelli *et al.,* 2019; Rajput and Singh, 2019).

Lower customer adoption of circular products is another major barrier as these products are often perceived to be possessing low value from a buyer’s standpoint. PSS takes the ownership of products away from customers, which makes them unattractive to certain customer segments. Customers fearing loss of sense of control, product availability, esteem and status are apprehensive and unenthusiastic to endorse circular products (Vermunt *et al.*, 2019; D’Agostin *et al.*, 2020). Moreover, customers devoid of product ownership portray careless behaviour and are not willing to fulfil their responsibility of maintaining and returning the products in a re-usable or recoverable state after end-of-use. This in turn leads to an increase in repair and maintenance costs and often incur disposal and wastage of EoL products (Agyemang *et al.*, 2019; Maheswari *et al.,* 2019). Moreover, price-conscious customers are not willing to pay a premium for switching to circular products as refurbished, recycled, or remanufactured products are perceived to have lower quality and face value as compared to *brand-new* products. Without integration, participation and commitment of customers, businesses find it immensely challenging in generating demand for circular products in their respective markets (Bouzon *et al.,* 2018; Mishra *et al.,* 2020). The previous discussion shows that numerous challenges exist concerning the successful transition from linearly traditional SCs into CSCM in the manufacturing sector.

**3. Research Methodology**

Figure 1 presents an overview of the stages that the present research went through. In the first stage, the barriers were identified from a thorough literature review collected from different databases as shown in Table1. Furthermore, after identifying a list of barriers, the authors conducted an empirical study to validate and group them into different categories by employing the Exploratory Factor Analysis (EFA) technique. The following sub-sections present and justify the data collection and analysis method employed as part of the research methodology followed by the present research.



**Figure 1.** Research stages

The concept of CSCs has gained momentum among researchers since 2017 as noticed in the SCOPUS database (Farooque *et al.,* 2019). Therefore, the research team decided to include articles from 2017 for reviewing the challenges to CSCs transformation. A review of the literature published between the years 2017 and 2020 was conducted to conceptually identify the barriers that manufacturing companies face when redesigning their SCs into CSCs. For the identification of these barriers, several keywords and their combinations were used in tandem, i.e., ‘*Challenges*’, ‘*Barriers*’, ‘*Circular Economy*’, ‘*Supply Chain*’, ‘*Circular Supply Chain*’, ‘*Closed-loop Supply Chain*’, ‘*Sustainability*’ and ‘*Manufacturing*’. To carry out the literature search, publishers' electronic databases that included Emerald, Springer, Taylor & Francis, Elsevier, Wiley, IEEE, Inderscience, Google Scholar, ISI Web of Science and EBSCO were explored. Whilst the articles and research papers were filtered based on the combination of these keywords and the year of their publication, the following criteria were also taken into account, namely: (1) the articles had to be published in English and in (2) a peer-reviewed journal. A total of 76 articles were identified, from which 40 articles were shortlisted to determine the barriers when redesigning SCs into CSCs. Following the completion of the literature review, a list of 20 barriers (Table 1) was finalised for further analysis and validation with the support of industry experts.

**3.1 Data collection and analysis**

Since this research focused on the current challenges in CSC implementation in the context of manufacturing industries globally, opinions from experts in this field were sought. This was possible by employing a survey questionnaire as a data collection strategy and *Qualtrics XM* as an electronic survey platform. Since the research project was time-constrained, a cross-sectional study design was followed (Saunders *et al.,* 2009). The survey questionnaire was self-administered and distributed by the researchers on professional network sites such as *LinkedIn*. Whilst approaching the academic scholars was simple and straightforward, accessing the network of industry professionals who were willing to participate in this research seemed relatively difficult. It was for this reason that *LinkedIn*, a social professional media platform, was chosen as the preferred tool to identify, make aware and collaborate with the industry professionals on this research to gain their active contribution. The selection of the respondents involved the fulfilment of one or more of the following criteria:

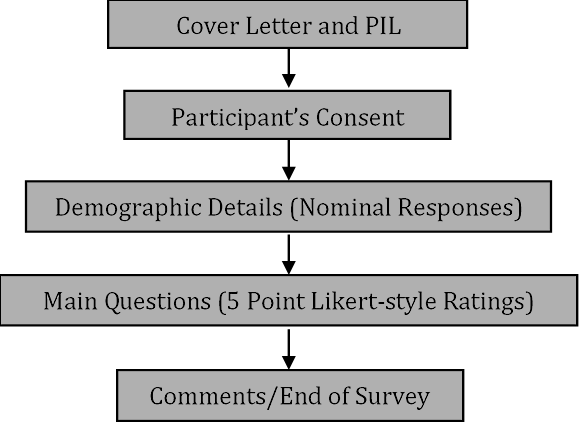
1. Research experience in CE/CSCM
2. Member of professional institution/organisation/university involved in studying/
   1. Researching/practising CE/CSCM
3. Employed in the industry with operations role with more than two years of experience in supply chain/manufacturing/industrial engineering/etc.

On LinkedIn, the link (URL) of the survey was distributed among closed groups via emails and *InMails* and the responses were collected back into the Qualtrics’ inbox. Since the population was non-exhaustive, the target was to obtain at least 150 responses using convenience sampling and reach a participant-to-variable ratio of 5:1 or higher (Reio Jr. and Shuck, 2015).

The raw response data was cleaned, tested for its reliability and validity, see Section 3.3, and subsequently processed using data analysis software such as *MS Excel* and *Statistical Package for the Social Sciences* (*SPSS) (Version 26)* to derive meaningful results.Data types and variables were defined, and the responses were coded in Excel to prepare the data for the next steps in the analysis phase. The cleaned and coded data were then processed to generate a demographic and descriptive analysis of the respondents. The SPSS software was employed to perform an Exploratory Factor Analysis (EFA) on the coded data to validate and group the barriers into broader dimensions.

**3.2 Survey questionnaire design**

A structured survey questionnaire was developed, taking into consideration the previous literature review conducted, with 26 closed-ended questions in order to collect, summarize, and analyse quantitative data (Ruane, 2005). Whilst demographic information was recorded using nominal variables, responses to core questions were recorded in the form of a 5-point Likert scale rating using ordinal variables (Moore and Lucas, 2021). The survey’s logic is illustrated in Figure 2.

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**Figure 2.** Questionnaire’s survey logic

The cover letter and participant information leaflet (PIL) were used to brief the potential participants regarding the purpose and details of the research. Consequently, their consent was sought to use their responses for recording/storage and further analysis. The demographic section of the questionnaire considered several factors related to the respondents for evaluating the differences in the key results of the survey. This section was followed by the core questions on which the respondents were advised to rate, on a Likert scale from 1 to 5, the significance (1- Not significant to 5- Extremely significant) of each of the 20 barriers, initially identified from the literature review, against their perceived impact on restraining the redesign of traditional SCs and into CSCs. The questionnaire questions and their justification are presented in Table 1 while the full questionnaire is included in Appendix 1. The questionnaire was divided into two sections, namely: (1) demographic questions to assess the variability in the demographics of the participants, and (2) the barriers to analysing their significance from the literature review to later validate and analyse them.

**Table 1.** Questions, categories and reasons for inclusion

|  |  |  |
| --- | --- | --- |
| **Question Category** | **Questions** | **Reason for Inclusion** |
| **Demographic** | * Which industry does your organisation belong to? * How will you classify your organisation? * Please indicate the size of your organisation * In which region is your organisation located? * How many years of experience do you have in circular economy (CE)? | These questions are included to assess the variability in the demographic information of the participants and evaluate the key differences in the results from the subsequent analysis of the responses since the sampling is non-targeted and the participation is voluntary. |
| **Significance (5 Point Likert-style) Rating of the Barriers** | * Kindly rate the significance of the impact of the following challenges in redesigning traditional supply chains into circular supply chains for the manufacturing sector: [list of 20 challenges along with their brief descriptions] | These questions are included to seek the opinion of the respondents on their perceived significance of the barriers identified from the LR to later validate and analyse them |

1. **Analysis and Results**

Following the completion of the literature review, a list of 20 barriers (Table 2) was finalised for further analysis and validation with the support of industry experts. The criteria used for selecting and categorizing these barriers were: (1) The barrier should be common to at least 3 highly cited research papers (which had at least 10 citations), and (2) The barrier should be contemporary and related to supply chains. A summary of the barriers identified from the literature is presented in Table 2.

**Table 2.** Barriers to the redesign of traditional linear supply chains into circular supply chains

|  |  |  |  |
| --- | --- | --- | --- |
| **S/N** | **Barrier** | **Description** | **Citations/Sources** |
| **1** | Longer payback period | In product-service systems, the cost of manufacturing is often paid back by the customer gradually over a longer period leading to a shortage of cash-in-hand for manufacturers | Homrich *et al.* (2018); Bressanelli *et al.* (2019); Werning and Spinler (2020) |
| **2** | Financial and operational risks | Risk and responsibility-sharing owing to, for example, product damages, repair, and maintenance stays with the manufacturer thus adding to their financial and operational costs | Sehnem *et al*. (2019); Flachenecker and Rentschler (2019); González-Sánchez *et al*. (2020) |
| **3** | Product cannibalisation | Products with a longer lifecycle restrain the sale of new products thus limiting a company’s revenue stream | Loon and Wassenhove (2018); Kane *et al.* (2018); Bouzon *et al.* (2018); Pedersen *et al.* (2019); Guldmann and Huulgaard (2020) |
| **4** | Patent and knowledge protection | Manufacturers are cautious and often limit sharing their IP and know-how with the suppliers and service providers | Whalen *et al.* (2018); Saidani *et al*. (2019); Kane *et al.* (2018); Guldmann and Huulgaard (2020) |
| **5** | Reduced agility of CSCs | Products having variety and regular design changes are preferred by customers over those designed- or built-to-last | Koszewska (2018); Kumar and Carolin (2019); Bressanelli *et al.* (2019); Shirvanimoghaddam *et al*. (2020) |
| **6** | Product complexity | An increase in material and product complexity leads to difficulties in managing the recovery and recycling process | Khodier *et al*. (2018); Halse and Jæger (2019); Rosa *et al*. (2019) |
| **7** | Mass customisation | Reuse and remanufacturing of mass customised products pose challenges to manufacturers | Kane *et al*. (2018); Khodier, Williams and Dallison (2018); Pacheco *et al*. (2019) |
| **8** | Lack of standards | There is a lack of comprehensive standards and frameworks regarding, for example, processes, materials, and activities that are aligned with CE principles | Mangla *et al*. (2018); Ranta *et al*. (2018); Bouzon *et al*. (2018); Shi *et al*. (2019); Kumar *et al.* (2019) |
| **9** | Lack of incentives and policies | Existing taxations, incentives and regulation systems are not aligned with CE principles which restrain the adoption of CE practices | Loon and Wassenhove (2018); Kane *et al*. (2018); Whalen *et al*. (2018); Saidani *et al*. (2019); Kumar *et al*. (2019) |
| **10** | Lack of appropriate metrics and indicators | Existing indicators such as GDP and performance metrics are not aligned with CE practices and do not drive the adoption of CSC | Kravchenko *et al*. (2019); Bressanelli *et al*. (2019); Kumar *et al.* (2019); Gong *et al*. (2020) |
| **11** | Uncertainties regarding product return | The quantity, quality, mix, time and place of return of end-of-use products are uncertain which makes their recovery difficult | Whalen *et al*. (2018); Saidani *et al*. (2018); Ranta *et al*. (2018); Bouzon *et al*. (2018); Kumar *et al.* (2019) |
| **12** | Logistics, transportation and infrastructure | Recovery of end-use products tend to increase the cost of logistics and transportation and often need additional infrastructure for further processing | Whalen *et al*. (2018); Levering and Vos (2019); González-Sánchez *et al*. (2020) |
| **13** | Lack of SC partners aligned with CE vision | Manufacturers and OEMs face difficulty finding suitable supply chain partners, particularly suppliers, who support CE practices | Mangla *et al*. (2018); Bouzon *et al*. (2018); Bressanelli *et al*. (2019); Tura *et al*. (2019) |
| **14** | Information sharing, transparency and visibility | Competing supply chain tiers are cautious whilst exchanging internal and sensitive information. Moreover, there is a lack of full IT integration across supply chains and reverse supply chains | Mangla *et al*. (2018); Saidani *et al*. (2019); Bouzon *et al*. (2018); Bressanelli *et al*. (2019) |
| **15** | Product tracking and traceability | Often products are lost or misplaced along their return and recovery journey owing to a lack of a standardised track and trace mechanism | Saidani *et al*. (2018); Jæger *et al*. (2019); Bianchini *et al*. (2019); Dieckmann *et al*. (2020) |
| **16** | Expensive and inefficient renovation process | Recovery and recycling processes may lead to loss or cross-contamination of materials. Moreover, they may be expensive compared to production from virgin materials | Bouzon *et al*. (2018); Khodier *et al*. (2018); Saidani *et al*. (2019); Agyemang *et al*. (2019) |
| **17** | Product/technology innovation | Innovation/improvement in materials, product, process, or technology in manufacturing drives down return, recovery, and reuse of existing circular products | Kane *et al*. (2018); Saidani *et al*. (2019); Rajput and Singh (2019); Bressanelli *et al*. (2019) |
| **18** | Lack of product ownership | In product-service systems, customers are denied total ownership of the products which decrease their perceived value thus impacting circular product adoption in the market | Lieder *et al*. (2017); De Angelis, Howard and Miemczyk (2018); Vermunt *et al*. (2019); D’Agostin *et al*. (2020) |
| **19** | Abuse and non-realisation of responsibility | Careless attitude of customers inhibits product conservation and often lead to non-recoverable disposal and wastage of goods | Mangla *et al*. (2018); Govindan and Hasanagic (2018); Agyemang *et al*. (2019); Maheswari *et al*. (2019) |
| **20** | Price and quality conscious buyers | Buyers dissuade from purchasing or subscribing to circular products which are expensive than traditional goods. Additionally, reusable and refurbished products are often perceived to have lower quality. | Whalen *et al*. (2018); Loon and Wassenhove (2018); Saidani *et al*. (2019); Ranta *et al*. (2018); Lieder *et al*. (2017); Bouzon *et al*. (2018); Mishra *et al*. (2020) |

**4.1 Data cleaning and coding**

Initially, the survey data highlighted a total count of 359 responses. However, an inspection to check the data completeness revealed a total of 159 incomplete and partially complete responses, which were deleted from the set to exclude them for further analyses. Furthermore, a detailed look at each response highlighted 1 specific observation that had the same rating for all the barriers. Identified as a careless response (Meade and Craig, 2012), this was also deleted and excluded from the data set. Therefore, only 200 responses were determined to be usable, exceeding the initially targeted count of 150 samples, see Section 3.1. The demographic information was denoted by the variable ‘DMx’, where x = 1 to 5. On the other hand, the information related to the rating of barriers was denoted by the variable ‘Bx’, where x = 1 to 20 and coded according to a Likert-scale that ranged from 1 (Not Significant) to 5 (Extremely Significant).

**4.2 Reliability and validity testing**

Reliability and validity of a quantitative survey is an important consideration for researchers to ensure consistency and accuracy of the data being collected, stored, and analysed (Lancaster, 2005). For the present research, the reliability of the data collection and analysis was achieved in two ways. First, reliability was ensured by recording responses using a secure online survey platform and storing data on password-protected drives. Second, the reliability of the data analysis was accomplished by employing sophisticated tools having a higher degree of accuracy and a software for conducting suitable statistical and exploratory data analyses. In this line, a Cronbach’s Alpha reliability test was conducted, cleaned, and coded data (barrier variables - coded rating for barriers: B1 to B20). The overall Cronbach’s Alpha value was 0.835, which was above the threshold value of 0.7 (Hair *et al.,* 2006; Field, 2009). Only internal consistency was used as a measure of reliability given the cross-sectional nature of the study. Since each participant took the survey only once and the data was collected only at one point in time, equivalence and stability were not considered as measures of reliability.

The validity of the collected data was achieved by ensuring the relevance of all information, materials and publications used for this research. Concerning the validity of the questionnaire, the questions included derived their origin from issues identified from the literature published. This ensured content validity. Face validity was ensured by pilot testing the questionnaire with a small group of experts (i.e., 10 in total, 5 individuals from academia and 5 from industry) before its distribution. Not only did the pilot study reflect positive feedback from the pilot test group regarding the research undertaken and resulted in no significant changes being made to the questionnaire but it also helped in ensuring the elimination of probable bias and errors made by the researchers during the design of the survey. Lastly, divergent validity was assessed by computing the correlations between the indicators (rated barriers), which results are presented in Table 3.It was observed that all the variables exhibited weak or low correlations with each other as highlighted by the absolute values of 0.5 or less (Mukaka, 2012). This indicated the fact that no two or more variables (barrier indicators) were alike or measured the same criteria thereby confirming divergent validity (Mukaka, 2012).

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **B1** | **B2** | **B3** | **B4** | **B5** | **B6** | **B7** | **B8** | **B9** | **B10** | **B11** | **B12** | **B13** | **B14** | **B15** | **B16** | **B17** | **B18** | **B19** | **B20** |
| **B1** | 1 | 0.254 | 0.148 | 0.123 | 0.047 | -0.004 | 0.065 | 0.076 | 0.095 | 0.136 | 0.045 | 0.048 | 0.198 | 0.200 | 0.171 | 0.030 | 0.062 | 0.085 | 0.144 | 0.110 |
| **B2** |  | 1 | 0.159 | 0.150 | 0.092 | 0.176 | 0.228 | 0.152 | 0.122 | 0.062 | 0.163 | 0.077 | 0.010 | 0.047 | 0.085 | 0.137 | 0.128 | 0.193 | 0.170 | 0.213 |
| **B3** |  |  | 1 | 0.291 | 0.326 | 0.178 | 0.174 | 0.307 | 0.170 | 0.207 | 0.220 | 0.242 | 0.279 | 0.129 | 0.244 | 0.222 | 0.255 | 0.304 | 0.152 | 0.213 |
| **B4** |  |  |  | 1 | 0.301 | 0.112 | 0.199 | 0.203 | 0.249 | 0.267 | 0.160 | 0.082 | 0.268 | 0.324 | 0.238 | 0.123 | 0.294 | 0.202 | 0.157 | 0.166 |
| **B5** |  |  |  |  | 1 | 0.262 | 0.210 | 0.276 | 0.166 | 0.251 | 0.113 | 0.127 | 0.140 | 0.079 | 0.147 | 0.242 | 0.344 | 0.191 | 0.338 | 0.337 |
| **B6** |  |  |  |  |  | 1 | 0.341 | 0.284 | 0.115 | 0.195 | 0.262 | 0.296 | 0.095 | 0.165 | 0.224 | 0.354 | 0.262 | 0.228 | 0.081 | 0.182 |
| **B7** |  |  |  |  |  |  | 1 | 0.307 | 0.144 | 0.119 | 0.179 | 0.221 | 0.308 | 0.130 | 0.153 | 0.234 | 0.220 | 0.321 | 0.240 | 0.233 |
| **B8** |  |  |  |  |  |  |  | 1 | 0.313 | 0.425 | 0.225 | 0.207 | 0.328 | 0.218 | 0.205 | 0.258 | 0.308 | 0.138 | 0.145 | 0.228 |
| **B9** |  |  |  |  |  |  |  |  | 1 | 0.504 | 0.089 | 0.178 | 0.228 | 0.276 | 0.100 | 0.198 | 0.074 | 0.050 | 0.183 | 0.173 |
| **B10** |  |  |  |  |  |  |  |  |  | 1 | .149 | 0.108 | 0.382 | 0.325 | 0.232 | 0.084 | 0.170 | 0.072 | 0.169 | 0.176 |
| **B11** |  |  |  |  |  |  |  |  |  |  | 1 | 0.318 | 0.246 | 0.264 | 0.209 | 0.201 | 0.142 | 0.235 | 0.092 | 0.136 |
| **B12** |  |  |  |  |  |  |  |  |  |  |  | 1 | 0.156 | 0.159 | 0.190 | 0.491 | 0.226 | 0.208 | 0.253 | 0.296 |
| **B13** |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 0.394 | 0.279 | 0.097 | 0.204 | 0.241 | 0.170 | 0.148 |
| **B14** |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 0.425 | .117 | 0.266 | 0.208 | 0.192 | 0.088 |
| **B15** |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | .213 | 0.222 | 0.227 | 0.083 | 0.099 |
| **B16** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 0.210 | 0.210 | 0.279 | 0.321 |
| **B17** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 0.330 | 0.283 | 0.243 |
| **B18** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 0.290 | 0.245 |
| **B19** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 0.422 |
| **B20** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |

**Table 3.** Factor correlations matrix of barrier variables

**4.3 Demographic, descriptive and Exploratory Factor Analysis (EFA)**

***4.3.1 Demographic Analysis***

The demographic analysis of the survey’s respondents was based on five major criteria: industry, sector, organisation size, region (of location), and (number of years of) experience in CE. The choice of these criteria was made by referring to several studies (Luthra and Mangla, 2018; Silvius and Graaf, 2019) with similar methodologies. The summarised and sorted (decreasing order) results from the frequency analysis of the demographic information (DM1 to DM 5) obtained from the completed survey responses is presented in Table 4.

**Table 4.** Respondents’ demographics

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable: Indicator** | **Response** | **Frequency** | **Percent** | **Valid Percent** | **Cumulative Percent** |
| DM1: Industry | Others | 133 | 66.5 | 66.5 | 66.5 |
|  | Chemical Industry | 13 | 6.5 | 6.5 | 73.0 |
|  | Textile Industry | 11 | 5.5 | 5.5 | 78.5 |
|  | Fast Moving Consumer Goods | 9 | 4.5 | 4.5 | 83.0 |
|  | Automotive Industry | 7 | 3.5 | 3.5 | 86.5 |
|  | Miscellaneous Manufacturing | 6 | 3.0 | 3.0 | 89.5 |
|  | Electronics Industry | 6 | 3.0 | 3.0 | 92.5 |
|  | Plastics Industry | 5 | 2.5 | 2.5 | 95.0 |
|  | Apparel Manufacturing | 4 | 2.0 | 2.0 | 97.0 |
|  | Aerospace Industry | 3 | 1.5 | 1.5 | 98.5 |
|  | Transportation Products or Components Manufacturing | 1 | 0.5 | 0.5 | 99.0 |
|  | Steel Industry | 1 | 0.5 | 0.5 | 99.5 |
|  | Machinery Manufacturing | 1 | 0.5 | 0.5 | 100 |
|  | Total | 200 | 100 | 100 |  |
| DM2: Sector | Private Sector | 111 | 55.5 | 55.5 | 55.5 |
|  | Multinational Corporation | 38 | 19.0 | 19.0 | 74.5 |
|  | Public Sector | 31 | 15.5 | 15.5 | 90.0 |
|  | Others | 20 | 10.0 | 10.0 | 100 |
|  | Total | 200 | 100 | 100 |  |
| DM3: Organisation Size | Large (more than 250 employees) | 95 | 47.5 | 47.5 | 47.5 |
|  | Small (less than 50 employees) | 81 | 40.5 | 40.5 | 88.0 |
|  | Medium (50-250 employees) | 24 | 12.0 | 12.0 | 100 |
|  | Total | 200 | 100 | 100 |  |
| DM4: Region | Europe | 99 | 49.5 | 49.5 | 49.5 |
|  | North America | 36 | 18.0 | 18.0 | 67.5 |
|  | Asia Pacific | 31 | 15.5 | 15.5 | 83.0 |
|  | South America | 24 | 12.0 | 12.0 | 95.0 |
|  | Africa | 7 | 3.5 | 3.5 | 98.5 |
|  | Middle East | 3 | 1.5 | 1.5 | 100 |
|  | Total | 200 | 100 | 100 |  |
| DM5: Experience in CE | Less than 3 years | 104 | 52.0 | 52.0 | 52.0 |
| More than 8 years | 41 | 20.5 | 20.5 | 72.5 |
| 3 - 5 years | 36 | 18.0 | 18.0 | 90.5 |
|  | 5 - 8 years | 19 | 9.5 | 9.5 | 100 |
|  | Total | 200 | 100 | 100 |  |

First, the majority (66.5%) of the respondents out of the total sample of 200 participants reported working in different industries. This segment included medical devices, construction, equipment servicing, manufacturing software, waste management, 3PLs, packaging, government advisory, retail, service design, consulting, and research organisations. A relatively high proportion of this segment was attributed to the fact that CE is still an emerging topic and there was more activity related to CE projects in the academic and consulting areas than on the industry front. Second, more than half (55.5%) of the 200 respondents reported working in the private sector. The sector was comprised primarily of educational and research institutions and consulting organisations working with the manufacturing sector. Third, close to half (47.5%) of the sample responses were obtained from individuals reportedly working for large organisations with more than 250 employees. This, again, reflected the fact that most CE projects and initiatives were being undertaken in large firms as opposed to small and medium-sized organisations, given their bigger financial budgets and resource capacities. Fourth, almost half (49.5%) of the sample responses were reported from Europe, which included Russia, Eastern and Western Europe, and the UK. This is largely attributable to the widespread research on CE conducted in these regions, which is partially attributable to the local presence and network of the researchers, which also facilitated convenience sampling of the survey data. Lastly, more than half (52%) of the respondents reported having less than 3 years of experience in CE. The most probable reason for this observation is the recent adoption of CE and sustainability initiatives by most organisations.

***4.3.2 Descriptive Analysis***

The results (means and standard deviations) from the descriptive analyses of the survey responses of barriers when redesigning SCs into CSCs, with corresponding variables ranging from B1 to B20, are presented in Table 5. All the variables secured mean values were greater than 2.5. This suggested that all the identified barriers were on average reported to be at least somewhat significant. This observation supported the inclusion of all the variables in the EFA (Exploratory Factor Analysis) and was aligned to the reliability test conducted in Section 4.2.

**Table 5.** Descriptive analysis

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **Barrier in Redesigning SCs into CSCs** | **Mean** | **Std. Deviation** |
| B1 | Longer payback period | 3.13 | 0.997 |
| B2 | Financial and operational risks | 3.27 | 0.976 |
| B3 | Product cannibalisation | 2.80 | 1.190 |
| B4 | Patent and knowledge protection | 3.05 | 1.177 |
| B5 | Reduced agility of CSC | 3.04 | 1.173 |
| B6 | Product complexity | 4.03 | 0.977 |
| B7 | Mass customisation | 3.29 | 1.077 |
| B8 | Lack of standards | 3.70 | 1.156 |
| B9 | Lack of incentives and policies | 4.08 | 0.966 |
| B10 | Lack of appropriate metrics and indicators | 3.68 | 1.185 |
| B11 | Uncertainties regarding product return | 3.58 | 1.072 |
| B12 | Logistics, transportation and infrastructure | 3.41 | 1.139 |
| B13 | Lack of SC partners aligned with CE vision | 3.59 | 1.052 |
| B14 | Information sharing, transparency and visibility | 3.47 | 0.940 |
| B15 | Product tracking and traceability | 3.57 | 1.119 |
| B16 | Expensive and inefficient renovation process | 3.54 | 1.129 |
| B17 | Product/technology innovation | 3.22 | 1.174 |
| B18 | Lack of product ownership | 2.84 | 1.198 |
| B19 | Abuse and non-realisation of responsibility | 3.35 | 1.132 |
| B20 | Price and quality conscious buyers | 3.18 | 1.214 |
| Valid N (listwise): 200 | |  |  |

***4.3.3 Exploratory Factor Analysis (EFA)***

The first step in conducting the EFA consisted of checking for inter-variable correlations (Kumar et al., 2022). This was done during the validation of the quantitative data in Section 4.2. This analysis did not show any strong absolute values for the Pearson correlation coefficients, hence all the barriers were considered to be unique and unrelated as collinearity was not observed (Silvius and Graaf, 2019), see Table 3.

The second step consisted of checking the reliability of all the variables. The Cronbach’s Alpha test conducted in Section 4.2 did not highlight any variable(s) that might have suggested their exclusion to improve the reliability of the input data. Moreover, a KMO (Kaiser-Meyer-Olkin) analysis was carried out and a value of 0.818 was obtained as an initial result of the EFA. Since this value was higher than the recommended minimum value of 0.6 (Hair Jr. *et al.*, 2006), the samples were considered adequate to run the EFA. Additionally, Bartlett’s Test of Sphericity resulted in a significance level of 0.00, which is less than 0.05 (Hair Jr. *et al.*, 2006) thereby validating the hypothesis that the correlation matrix of the variables was an identity matrix with unrelated variables (IBM, 2020) and suggesting the relevance and use of EFA for dimension reduction. Thus, it was inferred that all the identified barriers (B1 to B20) were found highly relevant for the EFA.

The third step in the EFA was to determine the number of reduced factors, components, or latent variables, which could explain a significant amount of total variance in the barrier variables. A principal component analysis of the 20 variables (B1 to B20), as shown in Table 6, identified 6 factors that had Eigenvalues above 1 (Luthra and Mangla, 2018) and cumulatively explained about 57% of the total variance. Although this was less than the recommended ‘75% or more’ suggested by Stevens (1996), it was still considered satisfactory as it was more than the reported average of 52% observed by Henson and Roberts (2006) in their EFA analysis.

**Table 6.** Variance explained with 6 component extraction

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Component** | **Initial Eigenvalues** | | |  | **Extraction Sums of Squared Loadings** | | |
| **Total** | **% of Variance** | **Cumulative %** |  | **Total** | **% of Variance** | **Cumulative %** |
| 1 | 4.886 | 24.432 | 24.432 |  | 4.886 | 24.432 | 24.432 |
| 2 | 1.715 | 8.574 | 33.006 |  | 1.715 | 8.574 | 33.006 |
| 3 | 1.325 | 6.625 | 39.631 |  | 1.325 | 6.625 | 39.631 |
| 4 | 1.280 | 6.398 | 46.029 |  | 1.280 | 6.398 | 46.029 |
| 5 | 1.140 | 5.701 | 51.730 |  | 1.140 | 5.701 | 51.730 |
| 6 | 1.058 | 5.290 | 57.021 |  | 1.058 | 5.290 | 57.021 |
| 7 | 0.940 | 4.700 | 61.720 |  |  |  |  |
| 8 | 0.885 | 4.426 | 66.146 |  |  |  |  |
| 9 | 0.817 | 4.084 | 70.230 |  |  |  |  |
| 10 | 0.751 | 3.756 | 73.986 |  |  |  |  |
| 11 | 0.696 | 3.481 | 77.467 |  |  |  |  |
| 12 | 0.681 | 3.406 | 80.873 |  |  |  |  |
| 13 | 0.630 | 3.150 | 84.023 |  |  |  |  |
| 14 | 0.564 | 2.821 | 86.844 |  |  |  |  |
| 15 | 0.504 | 2.522 | 89.365 |  |  |  |  |
| 16 | 0.478 | 2.388 | 91.753 |  |  |  |  |
| 17 | 0.469 | 2.345 | 94.097 |  |  |  |  |
| 18 | 0.443 | 2.216 | 96.313 |  |  |  |  |
| 19 | 0.391 | 1.957 | 98.270 |  |  |  |  |
| 20 | 0.346 | 1.730 | 100.000 |  |  |  |  |
| Extraction Method: Principal Component Analysis. | | | |  |  |  |  |

Lastly, the 6 factors were assumed to be independent or uncorrelated with each other, which suggested the use of Varimax (orthogonal) rotation. Factor rotations helped in interpreting the factor loadings and producing a simplified structure (IDRE, 2020). Additionally, factor loadings below 0.45 were suppressed (based on iterative trial and error heuristics) in order to map all the barrier variables uniquely to one of the 6 components. The varimax rotation based EFA, shown in Table 7, was used to find the new model for the factor loadings of the EFA and demonstrated how the 20 barrier variables were loaded onto 6 different components based on their commonality in EFA (Field, 2009). Furthermore, the 6 factors or components that resulted from the EFA were labelled based on their common underlying theme or classification in order to give them meaning and consequently group the barriers to SC redesign under broader categories as shown in Table 7.

**Table 7.** Structure Matrix for EFA with 6 Components

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Variable | Barriers to SC Redesign | Component / Factor | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 |
| B5 | Reduced agility of CSC | 0.702 |  |  |  |  |  |
| B17 | Product/technology innovation | 0.644 |  |  |  |  |  |
| B4 | Patent and knowledge protection | 0.528 |  |  |  |  |  |
| B18 | Lack of product ownership | 0.472 |  |  |  |  |  |
| B3 | Product cannibalisation | 0.465 |  |  |  |  |  |
| B14 | Information sharing, transparency and visibility |  | 0.766 |  |  |  |  |
| B15 | Product tracking and traceability |  | 0.662 |  |  |  |  |
| B13 | Lack of SC partners aligned with CE vision |  | 0.571 |  |  |  |  |
| B12 | Logistics, transportation and infrastructure |  |  | 0.668 |  |  |  |
| B19 | Abuse and non-realisation of responsibility | | | 0.660 |  |  |  |
| B16 | Expensive and inefficient renovation process | | | 0.652 |  |  |  |
| B20 | Price and quality conscious buyers | | | 0.618 |  |  |  |
| B6 | Product complexity | | |  | 0.723 |  |  |
| B11 | Uncertainties regarding product return | | |  | 0.506 |  |  |
| B7 | Mass customisation |  |  |  | 0.490 |  |  |
| B10 | Lack of appropriate metrics and indicators | | | |  | 0.777 |  |
| B9 | Lack of incentives and policies |  |  |  |  | 0.775 |  |
| B8 | Lack of standards |  |  |  |  | 0.545 |  |
| B2 | Financial and operational risks | | |  |  |  | 0.782 |
| B1 | Longer payback period |  |  |  |  |  | 0.701 |
| Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 27 iterations | | | | | | | |

**Table 8.** Barriers to Redesign of SCs into CSCs and their Categorisation by Author

|  |  |  |
| --- | --- | --- |
| **Factor** | **Category Label** | **Barriers (Variables)** |
| 1 | Organisational, Competitive, and Technology Barriers | * Reduced agility of CSC (B5) * Product/technology innovation (B17) * Patent and knowledge protection (B4) * Lack of product ownership (B18) * Product cannibalisation (B3) |
| 2 | Supply Chain Integration Barriers | * Information sharing, transparency and visibility (B14) * Product tracking and traceability (B15) * Lack of SC partners aligned with CE vision (B13) |
| 3 | Customer Behaviour and Reverse Supply Chain Barriers | * Logistics, transportation and infrastructure (B12) * Abuse and non-realisation of responsibility (B19) * Expensive and inefficient renovation process (B16) * Price and quality conscious buyers (B20) |
| 4 | Product and Process Barriers | * Product complexity (B6) * Uncertainties regarding product return (B11) * Mass customisation (B7) |
| 5 | Standardization and Regulatory Barriers | * Lack of appropriate metrics and indicators (B10) * Lack of incentives and policies (B9) * Lack of standards (B8) |
| 6 | Financial and Economic Barriers | * Financial and operational risks (B2) * Longer payback period (B1) |

1. **Discussion**

This section includes a discussion on each of the identified factors.

**5.1 Organisational, Competitive, and Technology Barriers: Factor 1**

The first factor identified is ‘Organizational, competitive and technology barriers’ which contains five barriers, namely: Reduced agility of CSC (B5), Product/technology innovation (B17), Patent and knowledge protection (B4), Lack of product ownership (B18), and Product cannibalisation (B3) with the factor loading of 0.702, 0.644, 0.528, 0.472, and 0.465 respectively. The factor takes the barrier of reduced agility of CSCs (B5) into account as circular products are designed to last and are not likely to respond well to changes in fashion. This challenge is relatively new (Bressanelli *et al.,* 2019) since from a conventional linear supply chain viewpoint, the competition among products is typically based on aspects such as their price, quality, brand and promotion rather than their useful life. For example, customers are less likely to purchase clothes that are designed to last as opposed to those which are constantly redesigned to match market trends. Moreover, long-lasting products are not able to participate in continuous improvement in product, process and manufacturing technology which hampers innovation (Saidani *et al.*, 2019). This has been explained by the product/technology innovation barrier (B17), which is also accounted for by this factor. However, it is surprising to note that the barrier of lack of product ownership (B18) was grouped with the above barriers since it associates more closely to customer or user’s behaviour as argued by Lieder *et al.* (2017). The probable reason for such grouping by EFA is the perception of respondents regarding the extension of the product lifecycle offered by servitised business models the makes circular products competitively and technologically unattractive (Bressanelli *et al.,* 2019).

Linder and Williander (2017) suggest the risk of product cannibalisation (B3), which is yet another implication of higher durability of circular products resulting in a slower rate of their substitution. This reduces the primary sales of manufacturers for similar products. This barrier was taken into account by Bressanelli *et al.* (2019) under their classification of market and competitive factors restraining the redesign of SCs into CSCs, which is in alignment with the current study’s findings. Furthermore, they raise the issue of patent and knowledge protection (B4) to be prevalent amongst manufacturers when 3rd parties are involved in the supply chain. Kane *et al.* (2018) support this presumption by arguing that OEMs are likely to safeguard their IP through proprietary technology or by limiting access to knowledge to maintain a competitive advantage. This limits the application of CE related activities and thus poses as a competition related barrier to CSC implementation, which is in agreement with the current findings. From the descriptive analysis, all the five barriers obtained mean scores in the range of 2.8 to 3.3. This suggests their relatively lower significance compared to other barriers to CSCs redesign.

**5.2 Supply Chain Integration Barriers: Factor 2**

The second identified factor named “*Supply Chain Integration Barriers*” refers to barriers arising from the lack of integration in SCs, and it includes three barriers, namely: Information sharing, transparency and visibility (B14), Product tracking and traceability (B15), and Lack of SC partners aligned with CE vision (B13) with the factor loading of 0.766, 0.662, and 0.571 respectively. Information sharing, transparency and visibility (B14) stems from the challenges observed in value chain configuration (Bouzon *et al.,*2018).Saidani *et al.* (2019) argue that in the absence of a close collaboration and information sharing network, the development and subsequent collection of circular products becomes almost impossible.Even if this challenge is overcome, manufacturing companies are faced with difficulties in finding suitable supply chain partners to collaborate with, which gives rise to the barrier of lack of SC partners aligned with CE vision (B13). For example, in the automotive sector, OEMs face trouble finding suppliers that can not only perform CE activities but are also able to adhere to strict environmental guidelines to achieve the CE vision (Bressanelli, Perona and Saccani 2019). Furthermore, these two barriers are supplemented by challenges in product tracking and traceability (B15), which also arise from misconfigurations of value chains. Bianchini, Rossi and Pellegrini (2019) and Dieckmann *et al.* (2020) argue that the absence of product tracking and tracing information systems and devices lead to the unavailability and inaccessibility of crucial product information to relevant SC partners. This decreases the efficiency of the return flow of goods and worsens the capability of the network to generate accurate forecasts. An instance of this is the inaccurate planning of renovation activities for WEEE due to failure in capturing information regarding the status of products during their lifecycle (Bressanelli, Perona and Saccani 2019). The observation of a close association amongst the three barriers is not outside expectations as similar findings were reported by Bressanelli *et al.* (2019).

**5.3 Customer Behaviour and Reverse Supply Chain Barriers: Factor 3**

The third factor encompasses barriers concerning customer or end-user’s behaviour and the reverse flow of goods. This group of barriers includes four barriers, namely: Logistics, transportation and infrastructure (B12), Abuse and non-realisation of responsibility (B19), Expensive and inefficient renovation process (B16), Price and quality conscious buyers (B20) with the factor loading of 0.668, 0.660, 0.652, and 0.618 respectively. Mangla *et al.* (2018) argue that customers devoid of product ownership tend to exhibit careless behaviour towards the use of the product, which increases the repair and maintenance costs being borne by manufacturers or service providers and can often result in legal issues in a servitised business model. Such a situation is depicted by the challenge of abuse and the non-realisation of responsibility (B19). To support the finding, Bressanelli, Perona and Saccani (2019) present an example of a careless operation by an operator of a machine tool procured under a leasing scheme and grouped this barrier under the classification of user’s behaviour.Another aspect of user’s behaviour is the unwillingness to pay a higher price for circular products (Bouzon *et al.,* 2018). Moreover, customers feel reluctant to buy recycled or remanufactured products owing to perceptions of lower quality and reliability (Ranta *et al.*, 2018). Such behaviour has been explained by the barrier of price and quality conscious buyers (B20) in the study that Bressanelli *et al.* (2019) also categorised as user’s behaviour.

Bressanelli *et al.* (2019) consider the barriers of logistics, transportation and infrastructure (B12) and expensive and inefficient renovation process (B16) as challenges in reverse logistics. However, the term ‘reverse supply chain’ has been used here to label the factor correctly as consumers of circular products play an important role in connecting forward and reverse flow of goods and their needs must be integrated with the business enterprise (Lieder *et al.*, 2018). Moreover, whilst the return of goods drastically increases the cost of transportation and logistics, there is no evidence that a renovation process such as recycling will result in 100% recovery of materials without any signs of contamination (Khodier *et al.,* 2018; Saidani *et al.*, 2018). The factor, thus, explains the linkage between the customer and the supply chain, which emerged from both the literature and the analysis.

**5.4 Product and Process Barriers: Factor 4**

The fourth group contains barriers related to product and process barriers and it includes three barriers, i.e. Product complexity (B6), Uncertainties regarding product return (B11), and Mass customisation (B7) with the factor loading of 0.723, 0.506, and 0.490 respectively. Bressanelli, Perona and Saccani (2019) refer to product complexity (B6) as the proliferation in the design and inclusion of new materials during product development and categorising it under well-established challenges of product renovation, which coincides with the findings of the current study. Mass customisation (B7) of products poses another challenge for renovation processes in reverse supply chains as frequent changes in processes and procedures increase the cost and complexity of operations and render circular products unattractive to manufacturers. This challenge has also been studied under the umbrella of product-related barriers to CE by Kane *et al.* (2018) and Khodier *et al.* (2018). What contrasts with the current findings is the barrier of uncertainties regarding product return (B11), which Bressanelli, Perona and Saccani (2019) classified under challenges in SCM. Although a common expectation would have been to see this barrier grouped under Factor 3, it does not entirely contradict the findings from other studies (Whalen *et al.,* 2018; Saidani *et al.*, 2019). This suggests the association of challenges in product returns with product characteristics (quality, usage cycle, location and complexity) and reverse logistics processes (such as capacity planning).

**5.5 Standardization and Regulatory Barriers: Factor 5**

The fifth factor corresponds to challenges associated with industry and governments in creating standards, providing incentives, and developing measurable indicators for the widespread adoption of CE practices. This group includes three barriers, namely: Lack of appropriate metrics and indicators (B10), Lack of incentives and policies (B9), and Lack of standards (B8) with the factor loading of 0.777, 0.775, and 0.545 respectively. First, industry standards regarding CE processes and circular materials are generally missing as reported by Bouzon *et al.* (2018) and Ranta *et al.* (2018), which is explained by the barrier of lack of standards (B8) in this study. Second, lack of incentives and policies (B9) leads to misalignment between the government and industry towards achieving the CE vision (Linder and Williander, 2017; Kane, Bakker, and Balkenende, 2018; Ranta *et al.*, 2018). Finally, Masi *et al.* (2017) and Kumar *et al.* (2019) stress the challenges arising due to the lack of appropriate metrics and indicators (B10), which are built around the circular economy. The scholars further stress the importance of building a more comprehensive perspective that encompasses economic, environmental, and social dimensions. Notably, all the three barriers are grouped under a common dimension, as expected, and follow the classification proposed by Bressanelli *et al.* (2019). Furthermore, from the descriptive analysis, the three barriers scored mean values in the range of 3.6 to 4.1. This places them higher in mean rankings amongst all the barriers and is suggestive of their relatively higher significance in hindering the implementation of CSCs.

**5.6 Financial and Economic Barriers: Factor 6**

The last group shows financial and economic barriers. It consists of two barriers, i.e. Financial and operational risks (B2) and Longer payback period (B1), with the factor loading of 0.782 and 0.701 respectively. The sixth factor presents commonly cited challenges of servitisation (Homrich *et al.*, 2018; González-Sánchez *et al.*, 2020). Whilst, on one hand, servitised business models lead to a longer payback period (B1) for manufacturers, which negatively affect their financial cash flows, the same firms, on the other hand, also face financial and operational risks (B2) arising from product damage, repair and maintenance on customers’ side. This contrasts with the conventional purchase agreement under which the customer bears all the operating costs of the product during its lifecycle. The explanation of these two barriers by a single factor has also been reported by Bressanelli et al. (2019), who classify them as ‘economic and financial viability challenges’.

**6. Conclusions**

This research identified the challenges in the redesign of traditional linear supply chains (SCs) into circular supply chains (CSCs) in the context of the manufacturing sector. Redesigning existing SCs into CSCs poses several challenges that must be identified and studied so effective strategies can be formulated and deployed to mitigate them and realise, in this way, the implementation of CE through entire supply chain networks.

The research underlines the implications of lengthening the life of products within the domains of an organisation, competition, and technology, which explained the significance of the first factor that emerged from the EFA. Second, barriers regarding supply chain integration were found to stem from challenges observed in value chain configurations. Third, the role of customers in linking the forward and reverse supply chains was highlighted and the barriers emanating from their abuse and carelessness towards the products thereof were discussed to interpret the third factor. Fourth, the barriers related to product and supply chain processes were investigated. This described the association between product characteristics and reverse logistics. Fifth, the relatively higher significance of the barriers emerging due to the lack of standards and regulations was pointed out. Lastly, the last factor from the EFA suggested commonly occurring challenges of servitisation which generated financial and operational risks for the manufacturers.

This study fills a research gap as previously highlighted in Section 1, thereby contributing to the accumulation of theoretical knowledge in the field of CE and SSCM as well as providing practical implications for industry. Thus, the present study extends our knowledge by determining and classifying the barriers in redesigning SCs into CSCs for the specific characteristics of the manufacturing sector. The study, thus, contributes to filling a research gap since a systemic view of these barriers in the context of the manufacturing industry had not been previously proposed in the scholarly literature.

This contribution is valuable for manufacturing organisations that may aim to be more sustainable through the implementation of CE practices in their supply chains and operations. The adoption of circular practices in supply chains will help in ensuring the attainment of sustainable development goal 12 (SDG 12) i.e., responsible production and consumption. Due to the wide applicability of CE practices and the similarities in terms of supply chain and sustainability activities, other industrial sectors such as transport and logistics, healthcare, services, among others, are also possible to benefit from the results provided by this study. All these sectors are under immense pressure to become more environmentally sustainable and the redesigning of their supply chains into CSCs provides them with this prospect.

Generally, the paper provides some insight into the barriers that may hinder the redesign of traditional linear SCs into CSCs. Therefore, it offers trustworthy evidence for industrialists of the roadblocks that will need to be overcome to achieve such endeavour. Nevertheless, this can only be claimed within the associated resource and time constraints bounding the study. First, the generalisation of the findings can be challenged as convenience sampling was employed for the selection of the respondents owing to time constraints. This resulted in the unequal proportions of participants from different regions, industrial sectors, and experience groups, thereby under- or over-representing the population and biasing the results. Such limitation could be overcome by using random sampling for the survey after identifying the qualified population for the research, which would require a larger time frame and additional resources for data collection. Second, the findings of the research are based on a bottom-up approach that investigated barriers to CSC implementation from individual manufacturing industries and then generalised them for the entire manufacturing sector. The reverse process of associating the generalised results equally to individual sectors would not yield the same granular and reliable information as each sector is characterised by its own set of challenges which also differ in their level of significance. Future studies following a similar methodology but aimed at each sector or region will yield more reliable and robust results within their respective contexts. In future research, Confirmatory Factor Analysis could be used to confirm the factor structure and hypotheses can be proposed. Third and lastly, although the correlations amongst the barriers were considered to be insignificant, a study of their interrelations, such as a contingency analysis, can further help develop a deeper understanding of their implications to build more robust mitigation strategies for manufacturing firms. There is no doubt that with more advanced empirical research on this area supported by initiatives and efforts from the private and public sectors, most manufacturing organisations will be able to transition to circular supply chains in the future, which would be a big step towards creating a sustainable ecosystem.

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