Product Recovery Options in Closed Loop Supply Chain Networks: A Literature Review

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Abstract. The growth of the environmental concerns and resource scarcity have motivated organisations to rethink and reconfigure their supply chains. Closed loop supply chains (CLSC) have evolved from being merely a compliance requirement toward crucial capability to maximise profitability and resilience. One open question in the CLSC setting is to explore recovery policies in case of disruptions. This review focuses on analysing literature on recovery options and stakeholders involved during the past ten years. The results reveal that recycle and remanufacture are the mostly discussed options where other CLSC-related aspects have been rather neglected. Refurbish recovery option, in particular, is the least discussed area that offers extensive profit potential. Clear definitions are needed to distinguish recovery options from each other. Comparatively, the reverse supply chain needs more stakeholders due to the complexity involved. Our analysis reveals an increased demand for studies, which focus on maximum possible recovery options and optimum stakeholder configurations that match with the forward supply chains.

Keywords: Recovery Options, Stakeholders, Closed Loop Supply Chain.

1 Introduction

The growing attention on sustainability and circular economy concepts made the roadmap to the closed loop supply chain (CLSC) network which has attracted a growing interest among researchers and industry alike [40]. CLSC is a management practice stemming from circular economy. Circular economy focuses on economic revalue creation alternatives while CLSC focuses on logistics network management in addition to revalue creation mechanism [57]. Creating a return value (i.e., revalue) by designing, operating and controlling the system throughout a specific products' lifecycle "on a planned time horizon" [39] is known as closed loop or circular supply chain. Closed loop enabled systems comprise both forward and reverse logistics networks which creates continuous loops. The more stakeholders enter the system, the more complicated the system becomes [6]. CLSC practice started as a solution for reducing the waste after consumption. However, after having identified its potential, the concept is now moving towards the social, economic and resilience capabilities [27].

In order to be able to implement a successful CLSC strategy, the product in the forward supply chain should have the physical convertible ability [41] and a financial gain after initial consumption [27] by the end user (e.g. clothes, glass bottles). However, if the initial consumption has not been performed, the reverse logistics procedure can be initiated at the final node of the supply chain right away (e.g. vegetables, fruit). The supply chain should be responsive and flexible enough to react for such quick situational changes in order to take the maximum advantages from the CLSC strategy. Simultaneously, understanding the essential stakeholders and processes involved, different recovery options [27], economic, social and environmental trade-offs [18], and optimised network structures are imperative.

Number of recovery options in relation to reverse supply chains have already been identified and discussed explaining their potentials. These options are arranged and presented using the 9R model (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recovery) under three main categories: Smart product use and manufacture, Extend lifespan of product and its parts, useful application of material [31, 47]. The first category consists of refuse, rethink and reduce which are smart manufacturing techniques. CLSC models are mainly discussed based on the second (Re-use, Repair, Refurbish, Remanufacture, Repurpose) and third (Recycle, Recover) categories as it directly connects with the physical attributes of the product. At the same time, some recovery options are informatively identified and analysed in the past papers than the other options. Literature is silent about the frameworks where all possible recovery options are considered in an integrated manner.

Industry frequently considers sustainable supply chain management practices merely to fulfil the business responsibilities due to unclear economical benefits [20]. Often the transition from linear models to CLSC networks is focused on environmental concerns [15]. This can lead to demotivating the practitioners and industry experts. To uncover the full potential of a CLSC network, all possible reverse processors should be considered and optimised. We address this research need by setting two research quenstions in order to understand the most and least analysed recovery options and stakeholders, and most importantly to identify the models where all possible recovery options and stakeholders are considered.

Therefore, to analyse the present knowledge related to different recovery options, the first question of this paper is set as follows:

01) Which recovery options have been highlighted and analysed in relation to CLSC networks?

Unlike in the forward supply chains, these recovery options play a pivotal role in the reverse logistics network as they require different logistics operations, variety of stakeholders and unpredictability of the supply. Therefore, after identifying the most discussed recovery options, the importance of the stakeholders of the forward and reverse supply chain network will be analysed as the next step.

02) Who are the key stakeholders in a CLSC network where recovery options are involved?

The knowledge of to what extent different recovery options and stakeholders have been analysed in the previous studies will help to determine possible network configurations for future studies.

2 State of the Art

The aim of this section is to describe the key concepts related to CLSC. According to the focus of the research questions, a specific attention is given to understand where CLSC currently stands and which different recovery options have been discussed. In particular, the meaning of different recovery options are listed following the current knowledge.

2.1 Closed Loop Supply Chains

Treating both forward and reverse supply chains with the same priorities is becoming highly practical and demanded due to the rising concerns in environmental, social and economical areas [8, 39]. The value creation process from the first hand products "on a planned time horizon" [39] is known as closed loop or circular supply chain. The forward chain starts from the procurement until transferring to the customers and backward/reverse process starts from customer to remanufacturing plant [6] where reverse process can be more complex, beneficial and challenging [39]. The more supply chain nodes involved in the reversing processing process, the more chaotic it becomes and more additional complexities (knock-on effects) it generates [6]. Guevara-Rivera et al. (2021) explain that these CLSCs are not readily available and can make the stakeholders discouraged depending on the complexities involved. As the reversing process is complex and less monetary attractive in nature, researchers are finding ways to utilize the concept at its maximum [10] due to the rising social and environmental concerns. While emphasizing the benefits such as "reducing wastes and saving costs, improving product quality, boosting customer service", practitioners are focusing on connecting the supply chain resilience concept with CLSC [39], opening a new branch in sustainable supply chain management to encourage the industry stakeholders.

2.2 Different Product Categories

Reversing materials are called by several names depending on the purpose of the study. Sometimes, the definition of these materials can also be changed depending on several factors such as industry. He et al. (2020) name those materials as recycling modes according to their study of the vehicle industry. Waqas et al. (2021) describe them as reverse logistics activities which help companies to convert their opportunities into profit. Krykawskyy and Fihun (2015) define them as recovery options (fig. 1) which can be further subdivided as direct recovery and process recovery. However, these recovery options differ significantly from the recovery options discussed in the 9R model.

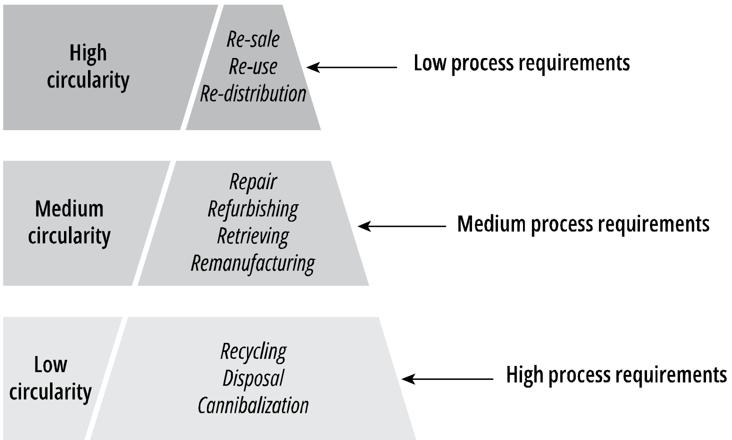

Fig. 1. Recovery options hierarchy (adopted with changes from Krykawskyy and Fihun, 2015)

Unlike forward logistics, reverse logistics consists of recovery options which cannot be predicted before reaching the products from customers to the reverse supply chain [21]. These networks focus on several complex recovery options which create a number of complicated closed loops [34].

The 9R framework is considered as the most updated version of the recovery options analysis which evolved from 3R, 4R, and 6R frameworks [34]. The framework consists of three main pillars and the last two pillars which consist of 7 recovery options are directly interacted with CLSC networks. Table 1 shows those recovery options and their characteristics. We note that the last recovery option in Table 1 is "recover" carrying the meaning "disposal" and should not be confused with "recovery options".

Table 1. Different recovery options (adopted with changes from Okorie et al., 2018)

Recovery practice	Product characteristics
Reuse	According to the 9R model, products that can be used again with its original functions are coming under this category [32]. The products should be improved with minor changes and should not increase the cost considerably [34]. Defect products which have already been transferred to the customers can also be collected and processed as reused [53].
Repair	Products which need further considerable maintenance to bring back to their original purpose are coming under this category [32]. Damaged products can be disassembled and add new parts to upgrade the product [31].
Refurbish	Restoring old products with new major parts and bringing them up to date is called refurbish [32]. However, the old product needs to be in serviceable condition and recycling should be less cost effective [32].
Remanufacture	According to the 9R framework, the products which are made from the parts of the discarded product are remanufactured products [32]. Sometimes it is described, remanufacture, and refurbish recovery options have similar characteristics. However, in remanufacturing, the collected product cannot be upgraded due to major malfunctions [34].
Repurpose	Products which can be further processed or disassembled and used as a new product for a different purpose can be defined as a repurposed product [32]. Kovtun (2020) explains “products which could not achieve the expected targets in the forward path” can be collected and promoted with a different purpose.
Recycle	Breaking down the returned products to base material that can be used again for the original purpose with the highest possible value are called recycled products [31]. The reprocess quality can be lower than the original product which may need further treatments to enhance the quality [32].
Recover	The definition of the recover is controversial in the literature. According to the 9R model, recover is incineration of material which cannot be further recycled [32]. However, Kovtun (2020) states that recover is the product which is not financially viable to convert as a full product. She further explains that those products can be disassembled and sold as spare-parts.

3 Methodology

A systematic literature review (SLR) is carried out to answer the stated research questions of this work. SLR is an effective technique to “summarise the findings of existing studies, and to assess consistency among previous studies" [48]. They further explain that this approach has been initially used in the medical sciences and recently used in the supply chain management studies to assess the existing practices as a rigorous method. Therefore, using the SLR, it is expected to analyse the existing knowledge related to reverse supply chains as the identified gap falls between the current knowledge related to CLSCs and the industry practice. Using SLR method, our study aims to help finding future research directions that can convince practitioners and industry experts on potentials of CLSC networks. Carefully selected journal articles were thoroughly analysed to generate useful information for future research works. To ensure the credibility of the result, only recently published journal articles which are related to CLSC were examined.

The searching process of suitable articles for the analysis is performed using the SCOPUS database. Due to the novelty of the research area, a limited number of journal articles could be found through more focused search terms. Conversely, individual terms such as "reuse", "repair" included search results generated a huge amount of papers. Therefore, to reduce the complexity and to select an accurate favorable sample, more relevant and broader terms as below were used to generate an adequate amount of papers to choose from. In order to select the papers which are analysed reverse product categories, "reverse product*" OR "reverse option*" OR "recovery option*" OR "recovery product*" OR "circular product*" OR "9R" terms were used whereas to combine it with the supply chain, "Reverse logistics" OR "circular supply chain*" OR "closed loop" search terms were used using Boolean operator AND to combine. Journal articles of the last ten years (2014-2023) were considered while limiting the subject areas to engineering, business studies and decision science. This search was performed in titles, abstracts and keywords.

53 journal articles were queried during this initial search. Few papers which are not directly focused on the work were also generated. After reading through the abstracts, 11 more papers were rejected. For instance, the empirical analysis done by Al-Awlaqi and Aamer (2022) using the logistic regression model, merely focuses on individual entrepreneurial factors that help to determine the circular model adaptation. The study conducted by Tseng et al. (2021) as well focused more on circular supply chain capabilities in the seafood processing industry. Those papers were therefore rejected. Eventually, 33 articles were selected for further analysis to answer the research questions.

4 Results

In order to get a holistic preview of the selected articles, a co-occurrence analysis is conducted using VOSviewer software. This visual representation shows the important clusters of the analysis. The co-occurence test is limited to "titles" and "abstracts" sections and the threshold is set as the minimum of four co-occurrence. Then, the outcome is further narrowed down to 60 percent. The result (53 word) is manually checked and the irrelevant words and phrases are then unselected. Fig. 2 shows the outcome of the analysis.

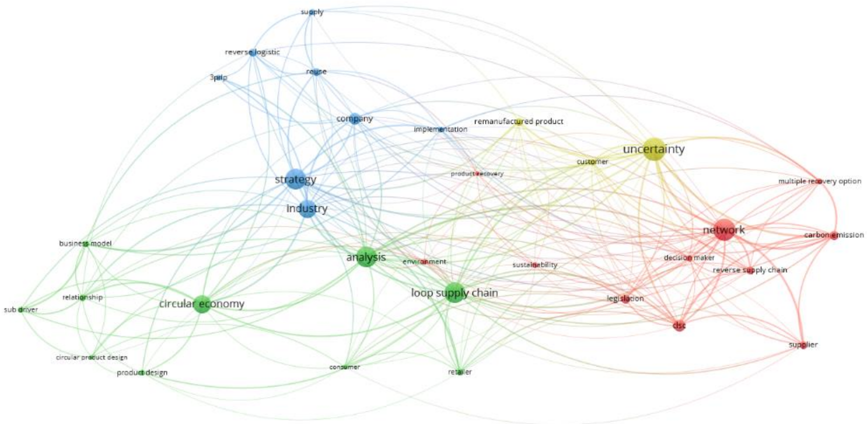

Fig. 2. Bibliographic co-occurrence data map.

There are three major clusters that can be seen in the co-occurrence analysis as circularity (green color), recovery options (blue color) and related stakeholders (red color). However, noticeably, some stakeholders are discussed in relation to circularity (customer and retailer) and recovery options (third party reverse logistics partners (3PRLPs)). Additionally, the term “multiple recovery option” is used more in connection with network and other stakeholders than separate recovery options. Therefore, it falls in the red cluster. There is a yellow cluster predominantly consisting of “uncertainty” which represents the uncertainty of the collection rate. As expected, “loop supply chain” and “circular economy” are highlighted as main terms in the analysis whereas “uncertainty” and “network” are also mentioned as key terms. It can be seen that researchers use the term “closed-loop supply chain” with a hyphen which tends to be considered as separate words by the software. According to this analysis, “remanufactured” and “reuse” alternatives emerged as main recovery options. “Suppliers”, “customers” and “3PRLPs” are highlighted as stakeholders.

The selected articles were thoroughly analysed to understand recovery options that are used to conduct the experiments. From the selected sample, four papers consider qualitative approaches whereas the other 29 papers use quantitative approaches. Mixed integer linear and non-linear models were the most popular approaches to find the optimum solution (13 papers). Other approaches such as agent-based modelling, game theory, matrix of standardization saturation and economic order quantity (EOQ) model were used only once. Often, real-life case studies have been carried out to validate the developed models. In this analysis, 18 papers out of 33 used different products in different countries to run their sensitivity analysis. Washing machines were examined in 3 papers whereas home appliances, Mobile phones/ digital cameras, Photocopiers/

Printers were analysed in 2 papers respectively. Surprisingly, the textile industry was analysed once even though it has different recovery options applicability. Products such as tires, furniture, automotive, air conditioners, belt lifters used in the automobile assembly line and construction machineries were also analysed once. Different recovery options that are used depending on the applicability and the suitability will be discussed in the next section.

4.1 Recovery Options Analysis

As identified in the state of the art section, there are seven direct recovery options available according to the present knowledge. Depending on the attributes and the economic viability of the products, recovery options can vary. For example, refurbishing is not viable or practical for glass bottles but can be recycled or reused. Same applies for papers and tires. Fruit and vegetables may not be reused but can be repurposed. Nevertheless, according to this analysis, it could be noticed that products have more than one recovery option in general that can be effectively used to strengthen the supply chain. Fig. 3 shows how many papers consider each recovery option for their analysis.

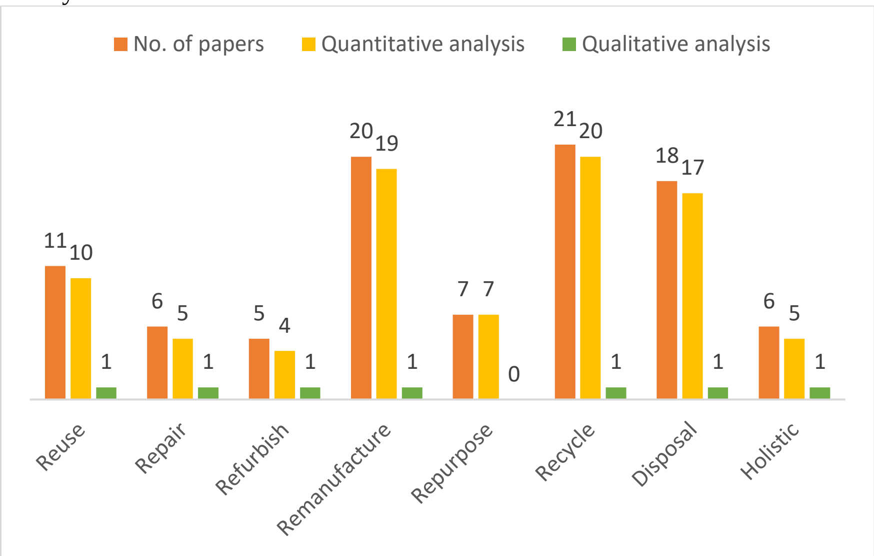

Fig. 3. Recovery options analysis

There are three papers that are not focused on recovery options. Two of these papers are qualitative analysis written by Wang et al. (2022) and Al-Sinan and Bubshait (2022) where they examine the barriers of circular product designs and the procurement agenda for transition from linear to circular respectively. The quantitative analysis [57] is based on the expert opinions and focuses more on 3PRLPs when outsourcing the supply chain operations. As shown in Fig. 3, six studies are conducted assuming the reverse network as a single supply chain. For instance, Masoudipour et al.

(2017) solves their model using the mixed-integer nonlinear programming approach where they categorise the recovery options into “high, medium and low quality” products. A qualitative analysis conducted by Boorsma et al. (2020) using literature review and in-depth interviews, also analyses their framework with a single reverse network. In this study, they describe “remanufacturing” as a process of absorbing the “cores and restoring them as a new product or even better”. Rest of the four studies [26, 37, 42, 59] use complex mathematical modelling approaches for their analyses. In these studies, integrating recovery options separately can lead to complex and unsolvable scenarios.

According to our analysis, recycle and remanufacture are the most discussed recovery options where 21 and 20 studies are carried out using those products respectively. It can be seen that every study in which a real-life case study is involved, has taken the recycling or remanufacturing or both into consideration. However, studies which one of the above options was considered limit themselves to reduce the complexity. For instance, the CLSC of the photocopiers analysed by Nonaka and Fujii (2015) using EOQ model focus only on “reuse and recycle” options, even though the remanufacture can also be applied. Further, the CLSC of furniture (IKEA sofas) analysed by Koszewska and Bielecki (2020) employing matrix of standardization saturation focus more towards the remanufacturing capabilities, even though recycling is another possibility. “Refurbish” is the least discussed recovery practice. Only five papers consider this option where all of them are mathematical modelling approaches. Only one study out of five conducted by Nag et al. (2021) analyses their model integrating a real-life example (Automotive sector). However, they combined refurbish with remanufacture when preparing the questionnaire. In other four studies, the sensitivity analyses to validate the models are carried out by using hypothetical or previously analysed examples. Repair and repurpose also have not received sufficient attention. In this study, “spare-part” components are considered as “repurposed products” as they do not offer the entire original purpose anymore. In this sense, there are seven studies conducted analysing “repurpose” recovery option. Simultaneously, repair is also examined only in six papers. Reusing firsthand products and disposing the material environmentally friendly are also discussed in most analyses (11 and 18 papers respectively).

4.2 Stakeholder Analysis

In order to acquire maximum benefits from the CLSC network, identifying the required but optimum number of stakeholders is imperative. The required number of direct stakeholders can vary depending on the supply chain strategy (efficient or responsive). Additionally, there are mandatory players to perform specific supply chain functions. Fig. 4 depicts the frequency of stakeholder appearance with respect to forward and reverse supply chain networks. Analyses involving indirect stakeholders such as the media, competitors, government and pressure groups are neglected.

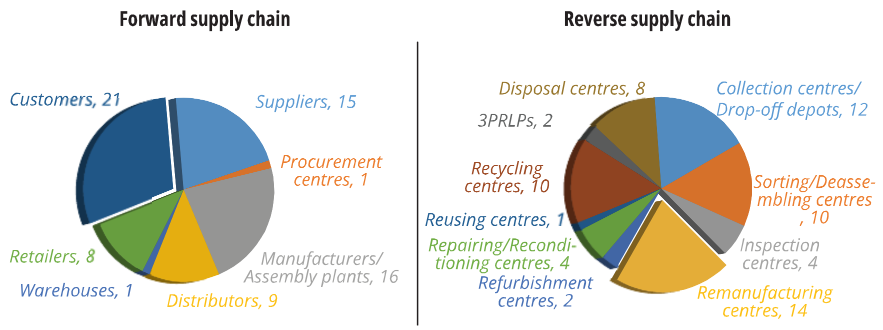

Fig. 4. Stakeholder analysis of forward and reverse supply chain

In 9 studies, no separate stakeholders analysis is carried out. Instead, the focus is given to a specific area/process of the supply chain. For example, Tarin et al. (2019) develop an integrated reverse logistics model specifically focusing on "inventory and production planning" in case of different return qualities where they consider mainly the material flow than the stakeholders. Additionally, Franco (2019) in her analysis focuses more on system dynamics such as disassembly and the disassembly index, functional risk and the green image factor rather than stakeholder engagement. Those were not included in the fig. 4.

As expected, suppliers, manufacturers and customers are the key players in the forward supply chain. In a closed loop environment, distributors, warehouse centres and retailers can also play a vital dual-role. However, those stakeholders were not analysed as much as the other 3 key stakeholders. It can be seen that in most cases, the functions of the warehouse have been transferred to the distribution centres to reduce the complexity of the models. There is only one paper produced by Alimoradi et al. (2014) where they consider the functions of the warehouse and distribution centre separately.

Comparatively, the reverse supply chain consists of more stakeholders due to the complexity and the uncertainty of the product portfolio. Due to that, companies tend to outsource some functions of the reverse logistics network to 3PRLPs which again increases the complexity of the analysis. Remanufacturing centre is the mostly analysed node (14 papers) where in some instances the only stakeholder in the reverse process [37, 42]. Collection centre, sorting/disassembling centre, recycling centre and disposing centre are also included in most of the studies as key players. Reusing, refurbishing and repairing centres are also considered in some studies. Nevertheless, it can be noticed that functions of those centres have been allocated to the remanufacturing centre in many cases. In addition to that, 2 studies were conducted focusing on outsourcing the reverse process to 3PRLPs.

5 Discussion and Conclusion

The aim of this study is to review the mostly discussed recovery options (question 01) and analyse the significance of different stakeholders in a closed loop network (question 02). 33 papers were thoroughly analysed and discussed with respect to the stated research questions. In order to select the sample papers, the search terms were set such as "recovery option", reverse product*" rather than individual options such as "recycle" and "reuse".

Our study highlights the possible recovery options and their relative significance and key stakeholders in a CLSC environment. Among the recovery options, recycle and remanufacture are the most discussed options. Refurbish and repair are the least discussed recovery options. Products which include electronic parts such as computers, mobile phones can be efficiently refurbished. Even though there are papers related to such analyses [46, 18], refurbish has not been considered. On the other hand, repair is defined as "replacing damaged parts with new parts to upgrade the product" [31] and can be integrated with products such as washing machine [27], construction machinery [49] but have not been considered. While answering question 01, this raises two other important practical implications; 1) supply chain complexity due to number of recovery options, 2) Accurate definitions for recovery options.

We found out that the more recovery options involved, the more complex the analysis becomes due to additional operations, delivery routes and stakeholders. Therefore, most of the proposed mathematical models are solved limiting the number of recovery options as complex scenarios can lead to long unsolvable equations. Additionally, there is a gap in knowledge on the accurate definition for the recovery options [50]. For instance, Mawandiya et al. (2022) consider "remanufacture" as all returned products irrespective of the conditions of the returned product while Lieder et al. (2017) consider it as a separate recovery practice. Parellelly, Chen et al. (2015) explain that remanufacturing has the same qualities as reuse. Additionally, "repurpose" recovery option is not mentioned in most of the cases rather analysed as "spare-part" [44, 3, 27, 18, 45, 12] or "by-products" [50].

In several studies, it can be observed that the increase in the number of recovery options also led to an increase in the number of stakeholders [11, 27]. This amplifies the model complexity. However, according to this analysis, some stakeholders are significant in CLSC networks and must be included irrespective of the complexity involved. In particular, suppliers, manufacturers and customers in the forward supply chain and remanufacturing centres in the reverse supply chain should be considered as key stakeholders. Depending on the focus of the study, other nodes such as distributors, retailers, collection centres, sorting/disassembling centres can also be included.

This review makes a valuable contribution to those who are working with CLSC networks. It highlights the key recovery options and corresponding stakeholders to consider when developing a CLSC network. Number of recovery options and stakeholders have a strong positive correlation with complexity. Due to that, studies tend to limit their focus. Therefore, one promising research direction would be to use simulation approaches such as agent-based modelling, discrete event simulations which can capture those complexities. Additionally, focusing on optimum configurations of recovery options and stakeholders would be another promising research direction. Novel mathematical models and simulations focused on network optimisation can be effective tools. Apart from that, studies which streamline the definition of each recovery option according to their behaviour and characteristics are essential.

The findings of this review should be interpreted considering the below limitations as well. In order to select the sample papers, broader search terms were used. However, this can lead to unselecting the papers which are focused on a specific recovery option or a stakeholder. Therefore, another potential research avenue for future work would be to increase the sample with more narrow terms and analyse. The study was limited to seven recovery options from the 9R model as they analysed in line with CLSC networks. Researchers interested in reverse supply chain flows are encouraged to develop frameworks which can integrate all possible recovery options. In order to limit the complications and to have a fair result, this study is considered spare-parts and by-products as repurposed products unless otherwise specified since they do not provide the same functionalities as of the original product but a portion of it. Nevertheless, comprehensive analysis with detailed definitions can improve the generalizability of the findings.

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