Closed-Loop Supply Chain: A Systematic Review

by

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AUTHOR’S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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ABSTRACT

The extraction of virgin materials from nature depletes existing resources and creates huge waste problems both in the extraction process itself and at the product's end-of-life. There is a propensity for this waste to be reduced by adopting an effective product-recovery process, which can ensure that future consumption needs are met for the ever-growing population and eventually result in low rates of landfill. A closed-loop supply chain (CLSC) system provides an efficient sustainable production process where the most used products, parts, and other waste materials are recovered to improve material efficiency and ultimately reduce environmental degradation. Over the last few decades, companies have started to advance in their efforts to implement CLSC systems that contribute to value creation and reduce waste. The objective of this thesis is to map and assess the performance of different product-recovery choices (remanufacturing, recycling, and hybrid) in reducing environmental risks and enhancing the end-of-life of used products, parts, and other waste materials. While the concept of CLSC has been adopted by many companies, there remains a lack of knowledge as to how to identify the criteria with which to evaluate what factors are crucial in adopting different product-recovery choices. Therefore, to learn how to close this knowledge gap, a systematic review of the extant literature surrounding three different product-recovery choices (remanufacturing, recycling, and hybrid) was conducted through the lens of transaction cost economics (TCE). Previous studies have provided information by choosing a specific product-recovery option or choosing between different product-recovery options at a given point in time from the companies' perspectives. This thesis expands upon the critical literature surrounding different product-recovery choices by identifying patterns across industries. Also, this study ascertains the impacts of take-back legislation across industries and across geographical locations with respect to these different product-recovery choices. The results of this study identify distinct characteristics of product-recovery choices and posit how companies might weigh the benefits of remanufacturing and recycling through the integration of CLSC. The findings imply that all relevant intra- and inter-organizational production processes must be channelled to improve the effectiveness and efficiency of CLSC. This thesis contributes to the existing CLSC literature, and fills an important literature gap by exploring industrial patterns with respect to different product-recovery choices; it also highlights important implications for companies seeking to drive their production activities towards being more sustainable.

Keywords: sustainable supply chain management, circular economy, closed-loop supply chain, transaction cost economics, remanufacturing, recycling, take-back legislation

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1 INTRODUCTION

1.1 BACKGROUND OF SUSTAINABLE PRODUCTION

The idea of sustainable production has received significant attention in the past few decades. Sustainable production can be introduced into the existing manufacturing system by preserving the intrinsic value of used products, and manufacturers are able to reproduce like-new products through product-recovery processes. Alternatively, the recovered parts or components can be sold in the secondary market so that used parts or components can be utilized in manufacturing other products. By preserving the intrinsic value of the used products, sustainable production becomes an effective and appealing way to address ever-growing environmental issues, and it can play a vital role in the reduction of landfill.

The main theme of sustainable production is using less virgin materials, and bringing used products back to life through the processes of remanufacturing, recycling, refurbishing, etc. Sundin and Bras (2005) argue that the extraction of virgin materials from nature not only depletes existing resources, but also creates a huge waste problem that is directly related to the extraction process. The existing rate of extraction of materials is not a sustainable practice, and it certainly compromises the ability of future generations to meet their own needs (Sundin & Bras, 2005). Hence, companies need to focus on sustainable production practices by closing unsatisfactory material flows. Companies can close unsatisfactory material flows by adopting an effective product-recovery process, which eventually can ensure future consumption needs for an ever-growing population. Tsiliyannis (2014) proposes that companies can reduce their manufacturing impacts if they rely more and more on processes featuring lower marginal impacts, i.e. instilling sufficient cleaner process innovation in the existing production system. Tsiliyannis (2014) argues that sustainable production has become far more significant as remanufacturing and recycling flows increase, noting, “under uncertain and expanding markets, recovering, reusing and recycling more products and materials, necessitates continual innovation towards cleaner manufacturing processes and pollution abatement technologies, to ensure environmental enhancement” (p. 30). Hence, companies should design production systems that encourage product-recovery processes in their existing manufacturing systems and place them in compliance with sustainable production practices.

1.2 THE CONCEPT OF SUSTAINABLE SUPPLY CHAIN MANAGEMENT

From a management perspective, sustainable production is captured under the concept of sustainable supply chain management (SSCM). Tseng, Lim, & Wong (2015) suggest that SSCM is categorized by integrating environmental, social, and economic aspects that allow companies to achieve long-term economic viability in supply chain management (SCM). Hence, companies are able to accomplish environmental and social objectives along with economic goals through the practical application of the SSCM concept (Tseng et al., 2015). Brandenburg, Govindan, Sarkis, & Seuring (2014) differentiate between SCM and SSCM, such that SCM focuses on the management of physical, logistical, and financial flows via intra- and inter-organizational relationships that jointly add value and achieve customer satisfaction. However, SSCM goes beyond the single-flow perspective of SCM, and not only focuses on the forward supply chain, but is also complemented by reverse flow management, including product recovery and reverse logistics (Brandenburg et al., 2014). Hence, Brandenburg et al. (2014) state that SSCM includes the movement and storage of sustainable raw materials and green products from the point of origin to a point of sustainable consumption. Similarly, Busse, Meinlschmidt, & Foerstl (2016) argue that companies engage in SSCM practices with the goal of influencing the sustainability performance of their supply chain partners to meet their internal sustainability plans, or to meet external stakeholder demands. Genovese, Acquaye, Figueroa, & Koh (2017) draw a parallel between SSCM and circular economy (CE), and suggest that both concepts try to integrate environmental concerns into organisations by reducing the negative consequences of production and consumption processes on the environment. However, Genovese et al. (2017) comment that the concept of CE pushes the frontiers of environmental sustainability further than SSCM. CE is not just concerned with reducing the negative consequences of production and consumption processes, it also creates self-sustaining production systems in which materials are used over and over again (Genovese et al., 2017). This is why integrating the principles of CE within SSCM can provide clear advantages from an environmental point of view.

1.3 CIRCULAR ECONOMY

The concept of CE is based on closing loops through different types and levels of recovery, such that materials are transformed into useful goods and services through resource efficiency (Witjes & Lozano, 2016). Witjes and Lozano (2016) propose that companies need to adopt a prudent use of raw materials and energy consumption throughout all stages of the value chain, and that products should be used for as long as possible, hence reducing waste. Rios and Charnley (2017) suggest that companies can create multiple kinds of closed-loop cycles within a CE, and note, "Some loops involve companies maintaining economic value of material assets during their entire lifecycles, avoiding products to end up in landfill for as long as possible; some others involve the adoption of resources that can be reintegrated into nature, or fed into another supply chain" (p. 110). Hence, companies need to design tools that can help them assess how well a product performs in the context of a CE, and allow them to estimate how advanced they are on their journey from linear to circular (Rios & Charnley, 2017).

CE offers a more comprehensive solution for effective product-recovery management when compared to the already known concept of cradle-to-cradle (Urbinati, Chiaroni, & Chiesa, 2017). Urbinati et al. (2017) propose that companies need to understand two key elements that can contribute to value creation and reduction in waste. First, companies must advance in their efforts regarding product design, with the aim to ensure an effective disassembly for reuse purposes, once the product finishes its useful life (Urbinati et al., 2017). Second, the adoption of CE involves companies extending their responsibility over users to the ownership of products, such that the products are offered as a service, in order to enable a more effective closing of loops (Urbinati et al., 2017). Geissdoerfer et al. (2017) characterise CE as adopting effective business-model strategies and design management, and define it "as a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops" (p. 759).

CE motivates companies to engage in sustainable business innovation to close, slow, and narrow resource loops, and infers a whole-system change through technological and non-technological innovations within an organisation (Heyes et al., 2018). Heyes et al. (2018) state that these innovations range from product design and production efficiency to the conception of completely new business models that involve the way value is created, captured, and delivered to consumers. However, Tukker (2013) argues that companies are not properly assessing intangible value and factors that influence consumers' acceptance of CE, and hence, companies are only focused on the technical design criteria and disregard the bigger picture related to corporate strategies for sustainability. Likewise, Korhonen, Nuur, Feldmann, & Birkie (2018) argue that CE is viewed only from the production and consumption system perspective. However, CE must be analyzed for its holistic contribution to more sustainable societal development; for instance, the concept should be in line with the current academic and industry consensus that production systems should utilize nature's cycles for preserving materials, energy, and nutrients for sustainable use (Korhonen et al., 2018). Geissdoerfer, Savaget, Bocken, & Hultink (2017) also caution that CE appears to exclude large parts of the social dimension by over-emphasising economic benefits and simplifying the environmental perspective. The aspect of ignoring the social dimension is challenging for the transition to a more sustainable economic system since attention and resources are diverted from more comprehensive and holistic approaches (Geissdoerfer et al., 2017).

Overall, CE has a high potential to contribute towards developing green businesses due to its strategic position between product manufacturers and end-users (Heyes, Sharmina, Mendoza, Gallego-Schmid, & Azapagic, 2018). Additionally, CE influences the way in which products are used by customers through innovative business models that are designed to slow, close, and narrow resource loops (Heyes et al., 2018). Heyes et al. (2018) argue that CE can actively engage consumers in the design and management of green business models, noting, "The business models generated fit within the interactions and value drivers of the CE to maximise the utilisation of assets and keep them in the inner loops of their resource-use cycles" (p. 631). Companies should consider CE as a move towards an effective business model where product wellbeing is decoupled from resource consumption (Ghisellini, Cialani, & Ulgiati, 2016). However, Ghisellini et al. (2016) suggest that companies should be mindful of not just growth, but also a zero-growth state and a declining state in their business operation, noting, "CE could help the transition to a degrowth path (less resource use with increasing wellbeing) that seems inevitable in particular in industrialized economies having surpassed ecological limits" (p. 27). One of the most emphasized concepts in CE is closed-loop supply chain (CLSC), which is an alternative to adopting a one-way flow of single use products.

1.4 CLOSED-LOOP SUPPLY CHAIN

CLSC creates environmentally friendly practices by utilizing the end-of-life product in a relatively efficient manner, rather than adopting inefficient flows of single-use products that go to landfill. Similarly, the underlying concept of take-back legislation assumes that companies will recover larger quantities of used materials, and utilize the recovered items through different sustainable practices such as remanufacturing, recycling, etc. By doing so, companies actively play a vital role in the reduction of environmental impact. Neto, Walther, Bloemhof, Nunen, & Spengler (2010) describe the concept of CLSC as an alignment between business and the environment in supply chains, and discuss two opposing approaches in terms of business rationale. First, CLSC creates environmental gains even if business economics is the main driver, and such situations are called ‘win-win’ or ‘double dividend’ (Neto et al.,, 2010). Alternatively, there is a ‘trade-off’ situation comparing what is economically rational in the supply chain and what is sustainable for the population as a whole (Neto et al., 2010). The trade-off situations do not attempt to resolve the conflict between economic and environmental aspects. Instead, they try to explain the competing considerations (economic versus environmental), examine what gives them weight, and explore their relationship (Margolis & Walsh, 2003). Hence, Neto et al. (2010) argue that ‘trade-off’ situations are more relevant than ‘win-win’ situations when companies are planning to integrate sustainability in their supply chain models.

Whether it is a ‘trade-off’ situation or a ‘win-win’ situation, it is extremely important for companies to move their businesses from participating in a flow economy (i.e., generating high amounts of useless waste) to participating in a CLSC-based economy, where most used products, parts, and other waste materials are remanufactured or recycled to improve material efficiency; this ultimately reduces environmental degradation. A single business function cannot implement and effectively run a CLSC system. Instead, it is a holistic consideration of production and waste management that can help companies in closing the loop (Winkler, 2011). Winkler (2011) argues that inter- and intra-company economic and environmental measures help the overall performance of production systems, and notes, "the application of certain sustainable supply chain networks is recommended to close process chains; it is also recommended that all types of waste be used as valuable resources for different production processes in other companies" (p. 243). Subsequently, this leads to two different concepts in CLSC. The first is intra-company production practices in CLSC, in which two or more business functions within the same company preserve the intrinsic value of used products, and subsequently remanufacture like-new products through a product-recovery process. The second is inter-company production practices in CLSC, in which the waste generated by one of the companies can be used as a valuable resource by another company through the recycling process.

1.5 PROBLEM STATEMENT

As CLSC becomes a more prominent way of dealing with product-recovery and waste-management problems, there is a need for a closer examination of this tool and its ability to adequately address issues related to environmental degradation. CLSC systems play the role of bridge and connect the traditional form of manufacturing with more sustainable production in the form of remanufacturing, recycling, etc. While the concept of CLSC was adopted by many environmentally friendly organisations over the last few decades, there remains a lack of knowledge as to how companies adapt to various product-recovery options, and what factors are considered important in making certain decisions, such as remanufacturing, or recycling, or even hybrid models (combining both remanufacturing and recycling). To fill the knowledge gap, this thesis will assess the various product-recovery options through the theoretical lens of transaction cost economics (TCE). Oliver Williamson, a founder and chief developer of TCE, explains through his earlier work (1971, 1973, and 1979 papers) why different kinds of transactions are better mediated through the firm or the market. Williamson (1971) defines TCE as a mechanism that offers a natural way to understand transaction costs between market and firm, and notes that, "the analysis of transaction costs is uninteresting under fully stationary conditions and that only when the need to make unprogrammed adaptations is introduced does the market versus internal organization issue become engaging" (p. 113). The objective of this paper is to examine different product-recovery choices (remanufacturing, recycling, and hybrid) embraced by companies across industries. Both the scholarly and business worlds are questioning sustainable production and its ability to deliver what it has pledged to do (i.e., less use of virgin materials and relatively lower rates of landfill). Understanding the key factors and strategic guidelines for companies in relation to different product-recovery choices can lead to more optimal business results in transitioning to a more sustainable production model.

1.6 SIGNIFICANCE AND CONTRIBUTION

As discussed in the background section of this paper, sustainable production is gaining considerable attention and represents an effective business model to curb environmental degradation. As the consumer market continues to grow, and as the use of virgin materials continues to increase, there is a risk of exhausting the resources available to humans for production purposes. CLSC is an effective tool to utilize used products, and substantively increases the life of products. However, the costs (both financial and non-financial) associated with CLSC systems need to be properly examined, and the purpose of this thesis is to explore the options that are available to companies in the wider context of product recovery. To date, most research on product recovery has sought to either explain cases of choosing a specific product-recovery option or choosing between different product-recovery options at a given point in time. Moreover, the majority of the research to date provides only a conceptual framework of CLSC in managing and improving environmental risks. Through the lens of TCE, this thesis goes beyond the conceptual framework of CLSC and identifies criteria against which to evaluate what factors are crucial in adopting each product-recovery option. Overall, this thesis attempts to fill the knowledge gap by conducting a systematic review of the extant literature of various product-recovery options for companies across different geographical locations, and under different regulatory requirements. The following section further breaks down the research objectives of this paper.

1.7 RESEARCH QUESTIONS AND OBJECTIVES

This thesis is organized around the below research objectives, and the research questions that follow:

- To map three different product-recovery options (remanufacturing, recycling, and hybrid) available through CLSC systems to evaluate their significance in reducing environmental risks.
- To assess three product-recovery options (remanufacturing, recycling, and hybrid) as different sustainability-driven choices for enhancing the end-of-life of used products, parts, and other waste materials.

- To contribute to the critical literature on CLSC systems by examining different product-recovery options (remanufacturing, recycling, and hybrid) as tools for reducing environmental risks.

What are the patterns/strategic priorities across industries in relation to remanufacturing (in-house) and recycling (secondary market)?

What are the impacts of take-back legislation across industries and across geographical locations in relation to remanufacturing (in-house) and recycling (secondary market)?

2 LITERATURE REVIEW

2.1 INTRODUCTION

This section provides a review of the existing literature surrounding CLSC through the lens of TCE. In order to understand the existing literature on CLSC, it is equally important to review the traditional concept of SCM, which is essentially an open-loop concept or forward supply chain. This literature review will also look at the existing literature on take-back legislation, and its potential impact on the implementation of CLSC through TCE.

First, a review of traditional supply chain process (i.e., forward or open-loop supply chain) is undertaken to understand the background of how the one-way flow of single-use products is performed. Then, the concept of reverse supply chain is introduced, and this is where companies collect back the used products from end users, and use a cyclic delivery schedule to put end-of-life products back into the production system. The third and forth sections discuss remanufacturing and recycling, respectively, in the context of CLSC. The fifth section discusses the impact of take-back legislation with respect to CLSC. The next section provides a detailed insight on TCE, and discusses different layers of CLSC through the theoretical perspective of TCE. The last section draws attention to the research objectives, and describes the framework that will be used for this thesis. Finally, the research questions are formed based on the critical literature review surrounding CE and CLSC concepts.

2.2 SUPPLY CHAIN MANAGEMENT AND THE ENVIRONMENT

2.2.1 FORWARD OR OPEN-LOOP SUPPLY CHAIN AND ITS IMPACT ON BUSINESS EFFICIENCY

Traditional open-loop or forward supply chain is a business model in which the customer is typically at the end of the process. The concept of forward supply chain started during the supply chain revolution of the 1990s, during which time it was argued that the efficient and effective movement of goods takes place from raw material suppliers to production facilities, component assembly plants, finished goods assembly plants, distribution centres, retailers, and finally to the customers (Alimoradi et al., 2011). Dowlatshahi (2000) considers a number of factors critical for forward supply chains, including the cost of land, availability of materials, labor, logistics, competitiveness, warehouse capacity, demand for products, and infrastructure. Forward supply chains are designed based on a combination of processes with a forward flow of products, and the ultimate objective is fulfilling the customers' requests (Masoudipour, Amirian, & Sahraeian, 2017). Ellram, Tate, & Billington (2014) define the forward supply chain as "The management of information, processes, capacity, service performance and funds from the earliest supplier to the ultimate customer" (p. 4). Essentially, the entities involved in the forward flow of products include suppliers, original equipment manufacturers, shippers, warehouses, retailers, and customers. Alternatively, He et al. (2016) propose that a traditional supply chain can be analyzed as a network of production processes, such that each process can be defined as a system that produces output flows as a consequence of input flows. In this manner, forward supply chains involve the flow of non-physical inputs and outputs, or bundles of physical and non-physical inputs and outputs; subsequently, these inputs are transformed into service outputs. (He et al., 2016). Hence, the main objective of a forward supply chain system is converting raw materials into finished goods.

Shamsuddoha (2013) suggests that forward supply chains create both economic and social impact, noting, "[t]he forward supply chain can create a smooth distribution channel that accommodates new employments and economic benefits for society" (p. 47). Guide, Harrison, & Wassenhove

(2003) believe that corporate managers contemplate forward supply chains as an integral process in the overall success of the business operation. Forward supply chains create supportive services by incorporating many interdisciplinary elements, such as governmental policies, legal matters, environmental concerns, and strategic collaborations with business partners (Guide et al., 2003). Kocabasoglu, Prahinski, & Klassen (2007) argue that companies invest in forward supply chains to improve performance in areas such as procurement, demand management, and order fulfilment, amongst others. Forward supply chains can further be strengthened if companies invest in supplier-development programs and customer relationship management (Kocabasoglu et al., 2007). Fleischmann, Beullens, Bloemhof-Ruwaard, & Wassenhove (2001) suggest that forward flows, in general, lead to the optimal network structure, since they are more important than reverse flows in terms of volumes and values. However, it is argued that the reverse flows can be expected to influence the overall network structure significantly in cases where there is a major cost difference between the structures of the forward and reverse channel (Fleischmann et al., 2001). Hence, the reverse supply chains, or CLSC, can become more significant if the economic incentive for product recovery is high. Reverse channel allows companies to collaborate with their supply chain partners in order to keep the used products, components, and materials in valuable circulation (Shi, Nie, Qu, Chu, & Sculli, 2013). Shi et al. (2013) suggest that companies can develop three different reverse channels to undertake a remanufacturing or recycling model – retailer collection, manufacturer collection, or third-party collection. The next section will discuss the business viability of reverse channels in detail.

2.2.2 REVERSE CHANNELS AND EFFECTIVE BUSINESS PLANNING

The management of reverse channels involves a mechanism in which a manufacturer delivers a fixed quantity of a product to customers using a cyclic delivery schedule, and at the same time, collects back the used products from customers delivered in the previous cycle (Huynh, So, & Gurnani, 2016). Subsequently, these products might be remanufactured by the original manufacturer and/or some of the components might be recycled through the secondary market. In essence, CLSC is comprised of both a forward supply chain and a reverse supply chain, in which the forward supply chain involves the flow of products from upstream suppliers to end-use customers, and the reverse supply chain involves the flow of used products from customers to upstream suppliers (Huang, Song, Lee, & Ching, 2013). Dobos, Gobsch, Pakhomova, Pishchulov, & Richter (2013) argue that consumers are able to collect used items for return to the manufacturer at the end of each order cycle, and the supplier manufactures new items and also produces as-good-as-new items by remanufacturing the used ones. Forward and reverse supply chains both provide consumers with various options (new products and as-good-as-new products), and hence, servicing consumer demand is assumed to be a deterministic constant and is known to both manufacturers and customers (Dobos et al., 2013).

Companies need to implement a product-exchange policy in customer outlets, and this eventually helps in increasing the collection rate of used products (Das & Dutta, 2013). In a more recent paper, Das and Dutta (2015) analyze the economic performance of the CLSC system for different incentive amounts given to consumers. It is observed that more incentives result in more returns of used products, but at the same time, they add more to the cost to the manufacturers (Das & Dutta, 2015). Additionally, Das and Dutta (2015) discuss the optimal incentive amount that needs to be offered to consumers, noting, "the average profit of the CLSC increases initially when companies increase the incentive amount but starts reducing as soon as the incentive crosses a threshold (optimum) value" (p. 636). Similarly, Heydari, Govindan, & Jafari (2017) also suggest that the discounts offered to consumers increase the number of remanufactured products and thus enhance the environmental efficiency of the system. Consumers can be offered a discount on the wholesale price for future purchases in exchange for the returned end-of-life products, which then can increase the returned amount of products in the reverse supply chain (Heydari et al., 2017). However, Heydari et al. (2017) argue that it is not just the consumers' willingness to return end-of-life products that increases the number of remanufactured products, but that governments can also play a vital role in increasing product returns. Governments can introduce a variety of incentives, including tax exemptions or subsidies, to manufacturers implementing CLSC models (Heydari et al., 2017).

Giovanni, Reddy, & Zaccour (2015) argue that there are two main motivations for companies to adopt a CLSC system. First, companies are able to achieve relative cost savings, because producing with returned materials or parts is cheaper than manufacturing with new materials (Giovanni et al., 2015). Second, companies can expect demand expansion with customers who are returning their used products to replace them with new products (Giovanni et al., 2015). Likewise, He (2017) suggests that companies benefit from implementing CLSC, since a positive market response is established due to the environmentally friendly image, and there are reduced costs for raw materials and parts from recycling and remanufacturing, etc. However, He (2017) cautions that it is extremely crucial for companies to achieve balance among all stakeholders in the forward and reverse supply chains, noting, "how to convince or motivate the suppliers/collectors to improve the collection channels (in terms of both quantity and quality) can be crucial to the success of CLSC" (p. 40). Chen and Chang (2016) also highlight the significance of collecting efforts and market demand in the context of CLSC, and suggest that companies need to optimize the supply of returned cores via collecting efforts with the demand for remanufactured goods in the market, i.e., balancing product returns with demand.

A number of choices are deliberated when designing an effective CLSC. These include which companies should be included in the reverse channel, which activities should be included and where, and the relationship between the forward and reverse channels (Lundin, 2011). However, it is equally imperative for companies to quantify the unintended effects of CLSC that come from the structure and processes of business operations (Lundin, 2011). Huynh et al. (2016) highlight two key operational considerations associated with CLSC. First, the manufacturer needs to determine an effective replenishment strategy for its products, such that the portion of the products that is wasted during each delivery cycle is replaced by purchasing new products; this is to maintain an adequate supply of products to customers (Huynh et al., 2016). Second, the manufacturer needs to maintain an appropriate capacity in its production facility such that the returned products can be channelled to the CLSC system in a timely manner (Huynh et al., 2016). Georgiadis and Athanasiou (2013) argue that reverse channels need to be modeled on a new basis to cope with the increased uncertainty associated with CLSC, noting, "The lack of planning tools and guidelines has been identified as a limit to the growth of remanufacturing sector" (p. 46). Additionally, companies need to embed risk management approaches in reverse supply chains to strategize under different remanufacturing settings; for instance, the remanufacturing process may produce not only as-good-as-new products but also B-class products directed to secondary markets (Georgiadis & Athanasiou, 2013).

2.3 REMANUFACTURING IN THE CONTEXT OF CLSC

Remanufacturing began establishing itself as a research area in the late 1990s, and it is a process in which used, durable products, such as photocopiers, are restored to a 'like new' condition (Lieder & Rashid, 2016). Lieder and Rashid (2016) argue that the key aspect of remanufacturing is to evaluate the profitability of reverse supply chains, and this makes companies more interested in product return management, remanufacturing operations, and re-marketing of remanufacturing products. Remanufacturing consists of industrial processes whereby an original equipment manufacturer (OEM), an OEM-contracted third party, or a third party licensed to carry the OEM brand name, disassembles obsolete products into components to a level as far down as needed to manufacture new products of a similar type and specification (Hollander, Bakker, & Hultink, 2017). However, Hollander et al. (2017) argue that the success of a remanufacturing design depends on how quickly the products are returned to the OEM to be remanufactured, and this requires efficient reverse channels that allow the remanufacturers to retain economic control of their product over time. Industrial remanufacturing primarily consists of disassembly, cleaning, inspection and sorting, reconditioning, and reassembly. Vanegas et al. (2018) highlight the importance of ease of disassembly in remanufacturing to support CLSC. Companies need to design a metric that can assess the ease of disassembly and quantify the extent to which it is realistic to disassemble components without destroying the components themselves for the purposes of remanufacturing (Vanegas et al., 2018). Vanegas et al. (2018) argue that the reduction in disassembly time and effort can make product remanufacturing the preferred end-of-life strategy over recycling.

A significant amount of attention is given in the literature to markets for remanufactured products that primarily focus on business-to-business customer issues or on firm-related outcomes of remanufacturing marketing strategies (Hazen, Mollenkopf, & Wang, 2016). Hazen et al. (2016) believe that it is equally important to focus on consumers' willingness to pay for remanufactured products vis-a-vis new products, and on product and consumer attributes relating to consumers' perceptions of remanufactured products. Consumers' inclination to purchase remanufactured products is critical to the long-term success of CLSC and ultimately to society's transformation to a CLSC system (Hazen et al., 2016). However, Hazen et al. (2016) argue that most consumers have not shown an inclination toward adopting remanufactured products as a substitute for new products. Hence, a remanufacturing marketing system may positively impact consumers' inclination toward remanufactured products. Kalverkamp and Raabe (2017) suggest that the remanufacturing marketing system is becoming relevant to reach sustainability objectives, noting, "A competitive environment in the remanufacturing marketing system fosters innovation that may contribute to the realization of sustainability objectives" (p. 127). However, Kalverkamp and Raabe (2017) caution that companies which intend to control resources by increasing component specificity and protectability will end up threatening the advantages of the overall remanufacturing marketing system.

The core issues involved in remanufacturing include the improvement of lead times and the tackling of remanufacturing process challenges (Kurilova-Palisaitiene & Poksinska, 2018). Kurilova-Palisaitiene and Poksinska (2018) argue that companies have to face long and variable lead times for the remanufacturing process because of core unavailability; irregular material and information flows; and incomplete and defective cores when additional time is needed to compensate for insufficient core quality. Additionally, Matsumoto, Yang, Martinsen, & Kainuma (2016) discuss that the total costs, including transportation costs, in remanufacturing are significant economic barriers for a lot of companies. Also, companies must make an initial investment in remanufacturing, and this requires strategic decision-making (Matsumoto et al., 2016).

2.4 RECYCLING IN THE CONTEXT OF CLSC

Recycling is a process by which the end-of-life product is retained, based on its substantial worth, and subsequently one or a number of components of the product are separated into isolated forms that are used in the production of new products (Sultan, Lou, & Mativenga, 2017). Additionally, products that are built from a single type of material do not require material separation, and these products can directly proceed to the recycling process if the technology permits (Sultan et al., 2017). George, Lin, & Chen (2015) contemplate that the concept of recycling is now a more significant aspect of developed economies, and a significant number of companies have started to accept the concept of the CLSC in their business models. Companies have started to believe that economic waste and economic resources are interrelated, and they can no longer be considered independent (George et al., 2015). Hence, George et al. (2015) believe that the concept of recycling has weaved the concepts of economic waste and economic resources together.

It is extremely important for companies that are trying to implement CLSC to explore the complex, interdependent challenges faced in finding secondary markets for recycled materials. The conventional, unidirectional, growth-oriented concept of production and consumption is less competitive in the current industrial environment. Product design requirements are changing through CE, because of the need to innovate while optimizing the use of resources and closing the loops (Virtanen, Manskinen, & Eerola, 2017). Pringle, Barwood, & Rahimifard (2016) argue that recycling initiatives require companies to develop resource-efficient recycling processes that are tailored to the specific needs of their manufacturing products. However, it is observed that companies face challenges when their existing commercial lines, based on current recycling technologies, are not suitable for processing waste associated with the production of goods (Pringle et al., 2016). Pringle et al. (2016) suggest that companies need to consider the effectiveness of the whole system, and the authors present two options that can deal with challenges associated with recycling technologies. Companies need to either adapt existing processes to suit the waste feedstock, or they need to create new processes that are specifically tailored to recycling their manufactured products (Pringle et al., 2016). Sultan et al. (2017) also discuss that in order for recycling to be successful, companies are required to implement mature recycling technology in their operations. A 'Technology Readiness Level' can be implemented by companies and can measure the technical and physical challenges of material separation (Sultan et al., 2017). Companies can improve their environmental quality by increasing the recycling ratio in their production operations (George et al., 2015). George et al. (2015) consider that even by adding fixed recycling costs into their production operations, companies can still benefit from the effectiveness of recycling.

Similarly, the use of recycled materials is also often delayed by the lack of expertise in the product design phase. Virtanen et al. (2017) argue that the advantages of using recycling in business operations can be relatively small compared to their 'time-to-market' costs and risks. Hence, it is highly significant to take recycled materials from the existing value chain instead of creating an entirely new value chain (Virtanen et al., 2017). Virtanen et al. (2017) caution that if companies start to re-create an entire value chain, the time to market for recycled products is likely to be too long, or the return on investment too low, especially for smaller companies.

While the use of secondary materials is an essential part of CLSC, a majority of companies do not have comprehensive knowledge about recycled materials' properties and potential uses (Virtanen et al., 2017). Virtanen et al. (2017) suggest that the concept of the 'Circular Material Library' can be used as an innovative tool of user-oriented design to promote regional CE and competencies in companies. This design tool helps companies to understand a product's environmental impacts throughout its life cycle, and it receives input from many stakeholders, including the supply chain (Virtanen et al., 2017). Subsequently, the design tool helps companies to build a deep knowledge of materials, engineering techniques, and operational processes, as well as recycling design skills and an understanding of different stakeholder perspectives (Virtanen et al., 2017). However, it is also important to understand that the advantages from recycling materials tend to decrease until it reaches a point where recycling could be environmentally or economically too expensive to provide a net benefit (Ghisellini et al., 2016). Because of this, Ghisellini et al. (2016) argue that the research on CLSC implementation is still mainly rooted on the concept of benefits in terms of physical, rather than monetary, flows. Hence, the implementation of CLSC cannot guarantee 100% recycling, and this points to the impossibility of an economic system becoming fully circular with products turning back into raw materials forever (Ghisellini et al., 2016).

2.5 TAKE-BACK LEGISLATION AND ITS IMPACTS ON CLSC

Take-back legislation reduces the amount of waste going to landfill by increasing product take-back by manufacturers and creating incentives for environmentally friendly product designs (Atasu & Wassenhove, 2011). Ji, Gunasekaran. & Yang (2014) propose that environmental regulations are best implemented through the concept of CLSC. Take-back regulations force manufacturers to internalize product externalities and convert open-loop supply chains of linear production and distribution into a CLSC system that encourages manufacturers to recycle, remanufacture, and improve product design (Ji et al., 2014). Hence, take-back legislation creates an accountability mechanism whereby producers are responsible for managing products at the end-of-life, and the assumption is that manufacturers are then incentivized to implement design for environmental strategies that can facilitate remanufacturing and recycling (Albino, Balice, & Dangelico, 2009).

Take-back legislation is exercised in practice through two different options, i) manufacturer operated take-back legislation ii) state operated take-back legislation (Atasu, Özdemir & Wassenhove, 2012). First, manufacturer operated take-back legislation refers to the type of system in which the manufacturer is held responsible for managing product take-back through collection and recycling rate targets, such as Waste Electrical and Electronic Equipment (WEEE) directives in the European Union (Atasu et al., 2012). Second, state-operated take-back legislation refers to the type of system in which governments or local authorities undertake take-back operations by imposing recovery fees on manufacturers, for instance, tax models in Washington and Taiwan (Atasu et al., 2012). Atasu et al. (2012) argue that the state-operated tax model makes the manufacturer worse off, since manufacturers are imposed potentially higher recovery fees and the recovery fees target pollution prevention in the form of consumption reduction, rather than pollution control (in the form of product take-back). However, if the environmental cost of landfill is higher than the take-back costs, the state operated legislation is a preferred choice over the manufacturer operated model, since both manufacturers and the environment can benefit from the state-operated tax model (Atasu et al., 2012). The manufacturer operated take-back legislation is further divided into two practical forms, i) Individual Producer Responsibility (IPR); ii) Collective Producer Responsibility (CPR) (Atasu & Wassenhove, 2011). IPR is a take-back system in which a producer determines the fate of its own products and incurs individual recovery costs associated with those products. Alternatively, CPR is a take-back system in which products are collected and recycled jointly from a set of producers. Atasu and Wassenhove (2011) suggest that CPR puts undue stress on producers who are required to join, noting, "Collective take-back costs are shared on the basis of producers' market shares, no matter what their actual product return volumes are" (p. 411). However, Botelho, Dias, Ferreira, & Pinto (2016) propose that a collective take-back system is more viable for businesses, as recyclers have a greater incentive to offer lower rates, and it allows remanufacturers to earn higher profits and boost their competitiveness. Botelho et al. (2016) caution that the advantages of CPR depend on the degree of substitutability, market size, and unit production costs. Alternatively, producers may not find IPR to be an effective system due to the loss of economies of scale; each producer has to set up an individual logistics system to collect its products and find facilities in which to recycle them in the context of IPR (Atasu & Wassenhove, 2011).

The concept of a take-back system is that it not only reduces the negative environmental impacts of waste, but also incentivizes manufacturers to create environmentally friendly product designs. Spicer and Johnson (2004) emphasize the importance of minimizing the environmental impact of end-of-life products through take-back legislation, and requiring manufacturers to design products and systems that take end-of-life into account. However, Spicer and Johnson (2004) propose that take-back legislation needs to focus on design considerations in order to fully integrate product retirement challenges. Such design considerations should have the capacity to receive feedback and internalize costs and data (Spicer & Johnson, 2004). Gui, Atasu, Ergun, & Toktay (2013) discuss three stages of take-back legislation that can help in the reduction of environmental harm. First, a legislative framework needs to be identified and developed that can shape take-back system principles (Gui et al., 2013). Second, the legislative framework needs to transition into a take-back program consisting of detailed operational rules and monitoring of the legal compliance of the manufacturers (Gui et al., 2013). Third, the interaction among multiple stakeholders affected by the take-back legislation should be observed, and each stakeholder's perspective towards the take-back program should be documented.

The participation of companies in take-back programs is essential for the collection, recycling, and remanufacturing of products, and the level of engagement can be attributed to country-specific determinants (Neto & Wassenhove, 2013). However, Neto and Wassenhove (2013) suggest the documentation to ensure OEM participation in product take-back initiatives, and how OEMs are engaged with consumers' end-of-life products, are both important factors in order to identify the challenges that hamper take-back programs. Esenduran, Kemahlıoğlu-Ziya, & Swaminathan (2015) suggest that there is a negative impact of take-back legislation on consumers and total welfare (the sum of manufacturer profits and consumer surplus minus environmental impact). A producer's profit is decreased as the legislation increases the effective cost for the manufacturer, and the customer surplus is reduced as some of the cost is transferred onto customers (Esenduran et al., 2015). Esenduran et al. (2015) argue that the reduction in environmental impact through legislation does not always make up for the loss in consumer surplus and manufacturer profits, and this impacts negatively on overall welfare.

2.6 THEORETICAL LITERATURE

2.6.1 UNDERSTANDING TRANSACTION COST ECONOMICS CONCEPTUALLY

The concept of TCE was developed through Ronald Coase's paper "The Nature of the Firm" in 1937. The paper for the first time argued against the notion that the distribution of economic activity between a firm and the market is 'given,' noting, "the costs of carrying out exchange transactions through the price mechanism will vary considerably as will also the costs of organising these transactions within the firm" (Coase, 1937, p. 396). Hence, the paper proposed that the economic activity between a firm and the market is 'derived.' However, the misconception about the economic activity between a firm and the market as 'given' was ignored until the late 1960s. Williamson's 1971 paper, "The Vertical Integration of Production: Market Failure Considerations," proved to be a major effort that pushed the logic of positive transaction costs in the context of vertical integration, and formed the basis of TCE. The concept of 'market failure' or 'transactional failure' is based on a firm's decision relating to the make-or-buy problem, i.e., which upstream inputs should a downstream business purchase and which should it manufacture?

(Williamson, 1971). Furthermore, Williamson (1973) emphasizes the significance of comparative institutional analyses in the context of firms, noting, "The problems of efficient economic organization need to be examined in a comparative-institutional way" (p. 316). Additionally, Williamson (1973) suggests that if there are many upstream and downstream players in the market, then competition amongst them is likely to produce an efficient outcome, and market exchange will be attractive for manufacturers (p. 318). The earlier concept to resolve the make-or-buy problem is based on analyzing a firm's production function, and it primarily focuses on markets versus hierarchies (Williamson, 1971 & 1973). However, the main discussion in the two papers (Williamson, 1971 & 1973) revolves around the disadvantages of hierarchies (internal organization) in the context of a firm's production functions. The two papers (Williamson, 1971 & 1973) do not provide much insight about the advantages of contracting between firms i.e., favoring markets over hierarchy. However, Williamson's paper in 1979 discusses the governance of contractual relations between firms in the context of TCE, noting, "Markets are especially efficacious when recurrent transactions are contemplated, since both parties need only consult their own experience in deciding to continue a trading relationship or, at little transitional expense, turn elsewhere" (p. 248). More recently, Williamson and Ghani (2011) define TCE as a mechanism to understand the costs resulting from selecting an appropriate exchange partner, negotiating and crafting contracts, resolving conflicts, and revising the existing agreements when conditions change. Gibbons (2010) suggests that Williamson's work emphasizes that production functions are not the way to analyze the make-or-buy problem, noting, "The substitution of internal organization for market exchange is attractive less on account of technological economies associated with production but because of what may be referred to broadly as 'transactional failures' in the operation of markets for intermediate goods" (p. 266).

The key aspect of TCE is based on transactions, which essentially are exchanges of goods across firm boundaries, and how they affect organizations' design (Martin, V, Jr., & Craighead 2010). One of the main arguments from TCE is that certain exchange characteristics increase transaction costs, and this can be resolved by different governance mechanisms with different cost minimizing initiatives. For example, "transaction costs may occur ex ante (e.g., costs of drafting and negotiating contracts) or ex post (e.g., costs of monitoring and enforcing agreements) – the key premise of TCE is the trade-offs between costs associated with various governing mechanisms" (Martin et al., 2010, p. 302). Yang, Wacker, & Sheu (2012) propose that TCE is a theoretical framework that determines an effective institutional structure (markets versus hierarchies) and associated governance mechanisms for supply chain transactions. In essence, TCE tries to determine different degrees of transactional efficiencies in certain institutional arrangements, and "the alignment of transaction attributes (asset specificity, uncertainty, frequency of transaction, ease of performance assessment) and institutional structure leads to higher transactions efficiency" (Yang et al., 2012, p. 4463). Yang et al. (2012) argue that the three transaction attributes (asset specificity, uncertainty, and frequency of transactions) predict the efficiency of outsourcing decisions. McNally and Griffin (2004) suggest that the outsourcing decision directly impacts the outcomes of make-or-buy decisions, although outsourcing differs from make-or-buy decisions because make-or-buy decisions relate to the sourcing of new products, while outsourcing refers to the decision to move production of an existing component outside the firm. However, McNally and Griffin (2004) argue that an outsourcing decision is associated with decreasing vertical integration (less joint action) in make-or-buy decision outcomes. Also, the institutional structure, such as legislation, regulations, legal contracts, etc. can be used to mediate the effectiveness of outsourcing transactions (Yang et al., 2012).

Schneider, Bremen, Schönsleben, & Alard (2013) argue that suppliers from different regions show variances in how transactions and governance structures are aligned. For instance, European suppliers are more integrated in terms of their transactions than the suppliers from other regions, and hence, TCE is an insightful theory for studying supply management related transactions (Schneider et al., 2013). However, Schneider et al. (2013) propose that there is a need to augment the classic TCE model by taking additional parameters into consideration, such as risk preferences, market environment, and sourcing strategy, and combining them with other factors impacting the outcome of business decision-making. This will allow companies to effectively align transactions and governance structures in their supplier relationships, and make sure that such transactions are appropriate according to the geographic location of the suppliers (Schneider et al., 2013). However, one of the criticisms of TCE is that it does not provide clarification of variations in the costs of integration the same way it does for the costs of non-integration (Gibbons, 2010). Gibbons (2010) argues that it is extremely challenging to know which factors responsible for market failures are correlated with factors responsible for organizational failure without knowing about variations in the costs of integration.

2.6.2 EXPLORING CLSC THROUGH TCE

The transaction attributes of TCE (asset specificity, uncertainty, and frequency of transactions) can be operationalized in many different ways, and there is more capacity for interpretation of TCE in various different fields and applications (Schneider et al., 2013). Brahm and Tarzijan (2016) suggest that assessing the make-or-buy decision through the lens of TCE can help companies weigh the benefits of internal production against the costs of outsourcing. The fundamental inquiry of TCE here is based on the notion that whether a transaction is more efficiently performed within a firm (vertical integration) or outside it by autonomous contractors (market governance), can be drawn upon to study remanufacturing (in-house) versus recycling (outsourcing) options. Hence, there is room for exploring CLSC through TCE, and companies would be well advised to factor transaction-cost concerns into their decision-making in closing the loops.

Arnold (2000) explains a make-or-buy decision from the TCE perspective, and considers specificity as the most important aspect of a transaction. Products with low specificity require little information to be exchanged with the transaction partner, and hence, external outsourcing partners are able to bundle demand and exploit economies of scale through recycling options (Arnold, 2000). Alternatively, products with high specificity are based on the company's core competencies, and a lot of information is exchanged before, during, and after the exchange of goods with high specificity (Arnold, 2000). Hence, companies need to take full responsibility for and control over products with high specificity through in-house manufacturing or remanufacturing (Arnold, 2000).

McNally and Griffin (2004) suggest three discrete forms of governance structures through the lens of TCE: market transactions; vertical integration; and hybrid. First, market transactions refer to a governance system in which parties transfer ownership of products (McNally & Griffin, 2004). Second, vertical integration refers to a governance structure in which one single owner has authority over all matters (McNally & Griffin, 2004). Third, hybrid refers to a governance structure in which there are intermediate levels of ownership and coordination (McNally & Griffin, 2004). Geyskens, Steenkamp, & Kumar (2006) suggest that one of the assumptions of TCE is that market governance is more efficient than vertical integration (in-house), owing to the benefits of competition. However, there are certain dimensions (asset specificity, uncertainty, and transaction frequency) of TCE that increase transaction costs and create market failure, making vertical integration more efficient than market governance (Geyskens et al., 2006). Geyskens et al. (2006) argue that business transactions often take place in a hybrid mode, a compromise mode that is located between market and vertical integration regarding the level of control and the use of contract law regime.

Brahm and Tarzijan (2016) explain a few limitations of the make-or-buy decision that can ultimately affect relational contracts and collaboration in the context of CLSC. First, it is extremely difficult to extend the results of a make-or-buy decision to all industries alike, since each industry has specific features (Brahm & Tarzijan, 2016). Second, each region will have a different set of regulations, and thus, care should be taken with make-or-buy decisions when applied to different geographical settings (Brahm & Tarzijan, 2016). Third, a pure form of analysis (i.e., the make-or-buy decision) is not always feasible, since there are always intermediate organizational forms (e.g., choosing the make and buy options simultaneously) that fall beyond the make-or-buy dichotomy (Brahm & Tarzijan, 2016). Fourth, there are location specific factors other than regulations that can influence the behaviour of manufacturers with respect to the make-or-buy decision (Brahm & Tarzijan, 2016).

2.7 RESEARCH OBJECTIVES

2.7.1 THE PROBLEM CONTEXT – REMANUFACTURING (IN-HOUSE) VERSUS RECYCLING (SECONDARY MARKET)

This thesis deals with an issue between two parallel cross-channels in a CLSC system. The key goal is to investigate the conditions under which a company would be best suited to remanufacture the returned cores by itself, or to let a third-party independent operator close the loop through recycling. In the former case, the company takes direct control over its production line by engaging in the remanufacturing activity and by collecting the used products. In the latter case, the components of the returned products are sold in the secondary market to third-party independent operators for recycling purposes. Overall, both remanufactured and recycled products are subsequently made available to consumers in the market.

McNally and Griffin (2004) suggest that manufacturing managers are inclined towards remanufacturing products to maintain high levels of equipment and personnel usage, while engineers choose to buy components from the secondary market since external suppliers are more responsive to design changes. Hence, the transaction can be either between different departments within the same firm (when vertical integration, or make, is chosen) or different firms (when market transactions, or buy, is chosen) within the context of make-or-buy decisions (McNally & Griffin, 2004). Consistent with TCE, the findings of Martin et al. (2010) show that asset specificity is a significant factor distinguishing the transaction costs of alternative governance structures. For instance, if a company manufactures a special product in such a way that the product's components are purchased from only one supplier, then that supplier can put the exchange at risk because the supplier knows the company is dependent on it (Martin et al., 2010). The supplier can hold up its supply or demand a higher price for the component once the company invests in manufacturing the specialized product (Martin et al., 2010).

Similarly, the company involved in reverse engineering has no option but to opt for remanufacturing in the case of product specificity, because the product's components are specific to that company's production line only. Alternatively, Martin et al. (2010) suggest that companies may intend to engage in a pure market transaction when product specificity is not required. Hence, this may allow companies to adopt the recycling option in case they are interested in reverse engineering. However, contrary to asset specificity, Martin et al. (2010) argue that brand reputation, technological uncertainty, condition uncertainty, and volume uncertainty do not directly influence companies' decisions to adopt the remanufacturing option.

Yet another dimension of TCE, 'uncertainty,' also impacts the remanufacturing versus recycling decision for companies. For instance, Craighead et al. (2007) suggest that the overall cost of recovery may be uncertain because the number of returned products might become absolute in the pipeline, or more parts might become unavailable over time because the supplier may not foresee any customer issues related to remanufacturing. Craighead et al. (2007) recommend that companies consider the remanufacture-versus-recycling decision when making the original make-or-buy decision, in order to achieve optimal results from reverse engineering.

While companies' adoption of CLSC systems is increasing, there is a gap in our understanding of what drives the decisions of companies to remanufacture in-house or to recycle components in the secondary market. Hence, this research intends to allow companies to evaluate their product return choices and to gain further understanding of the economics of the remanufacturing-versus-recycling options of returned products through the lens of TCE. Additionally, examining the impact of take-back legislation such as Extended Producer Responsibility, etc., and different geographical settings, on the remanufacture-versus-recycle decision will further add to and advance the existing literature on product-recovery options.

2.7.2 CONCEPTUAL FRAMEWORK

This thesis explores the patterns across industries and business considerations for companies that opt for reverse engineering in their manufacturing units. This paper is limited to an exploration of three choices, i.e., to participate in the remanufacturing process (in-house), to participate in the recycling process (secondary market), or to participate in both remanufacturing and recycling at the same time.

First, in order to decide amongst the different product-recovery choices, it is extremely important to look at the economic interests of companies. Winkler (2011) suggests that companies need to develop strategies, structures, and systems to effectively help production managers make environmentally responsible decisions without sacrificing economic interests. Hence, companies should integrate their remanufacturing or recycling strategies into their overall business strategy to gain competitive advantage from CE (Winkler, 2011).

Additionally, companies can integrate the design, planning, sourcing, manufacturing and delivery of goods and products along the entire supply chain through longer-term agreements (Winkler, 2011). However, Winkler (2011) proposes that all relevant inter-organizational information and material processes must be coordinated to improve the effectiveness and efficiency of both forward and reverse supply chain.

Kuik, Nagalingam, & Amer (2011) argue that companies are responsible for making green products that are designed, re-used, re-manufactured, and recycled through coordination and communication with customers and suppliers or collaborative partners. However, Kuik et al. (2011) suggest that companies need to focus not merely on their respective manufacturing and production systems, but on multiple collaborative manufacturing networks in order to gain the economic benefits associated within intra- or inter-organisational sustainability activities.

Lai, Wu, & Wong (2013) suggest that some companies are still unaware of the value of reverse engineering, and that the design for reverse engineering could generate a positive economic impact, leading to improved revenue, increased market share, and new market opportunity.

However, the profitability of product returns depends on product design such that manufacturers are able to disassemble component parts for capturing residual values of returned products based on standardized materials and modular design (Lai et al., 2013). Similarly, Krikke, Blanc, & Velde (2004) suggest that the profitability of returned products depends on design for reverse logistics, noting, “pioneering firms have learned that making returns profitable relies on good design of reverse chain business processes—including the possible integration with the forward chain” (p. 24).

Second, the decision between remanufacture-or-recycle options can be seen through the operational efficiencies of companies. Reverse engineering helps companies create technical cycles that can restore the value of post-consumption products through repair, reuse, remanufacture, and recycling. Cong, Zhao, & Sutherland (2017) propose a guideline to integrate dismantling operations into a value recovery plan for end-of-life products in support of CE. Cong et al. (2017) suggest that production efficiencies lead to a better end-of-life product-recovery plan, and ultimately this can also reduce operation time and cost.

De Sousa Jabbour, Jabbour, Filho, & Roubaud (2018) suggest that companies can optimize their business operations by creating cyber-physical systems that are able to collect data from processes and objects, such as machines, and identify possible failures that might create waste. Cyber-physical systems can help production managers monitor and control the performance of operations, intervene in processes through the use of sensors, and assess the efficiency of machines in real time; this all avoids excessive use of resources (De Sousa Jabbour et al., 2018).

Additionally, the resources of cyber-physical systems can optimise delivery routes according to operational and environmental indicators, and ultimately the logistics decisions of sustainable operations would be adaptable, based on the data provided by the cyber-physical systems (De Sousa Jabbour et al., 2018).

Third, the green business debate is receiving increased attention in leading companies, and a large number of companies are strategically transforming their supply chains into CLSC. However, Defee, Esper, & Mollenkopf (2009) caution that companies may fall short of effectively managing a CLSC system, as the management and integration of reverse flows may suffer from a lack of strategic focus. Hence, companies that are interested in leveraging CLSC will have to adopt a broader supply chain perspective, and companies will have to recognize the environmental implications of activities and processes involved in managing and integrating the forward and reverse flows of CLSC (Defee et al., 2009).

Similarly, Larson, Teisberg & Johnson (2000) suggest that green technology offers a powerful perspective for businesses, and companies can achieve innovation, cost savings, new designs, and competitive advantage with early awareness of environmental issues (Larson et al., 2000). Companies should design a sustainability framework that can assess and evaluate the environmental impact of products. Such a sustainability framework can ultimately assist managers in assessing which existing or potential products have the best environmental profiles so that they can integrate environmental considerations effectively in their business decisions (Larson et al., 2000). Larson et al. (2000) believe that companies will be able to make reasonable and well-informed comparisons among products with the adoption of green products into their business operation.

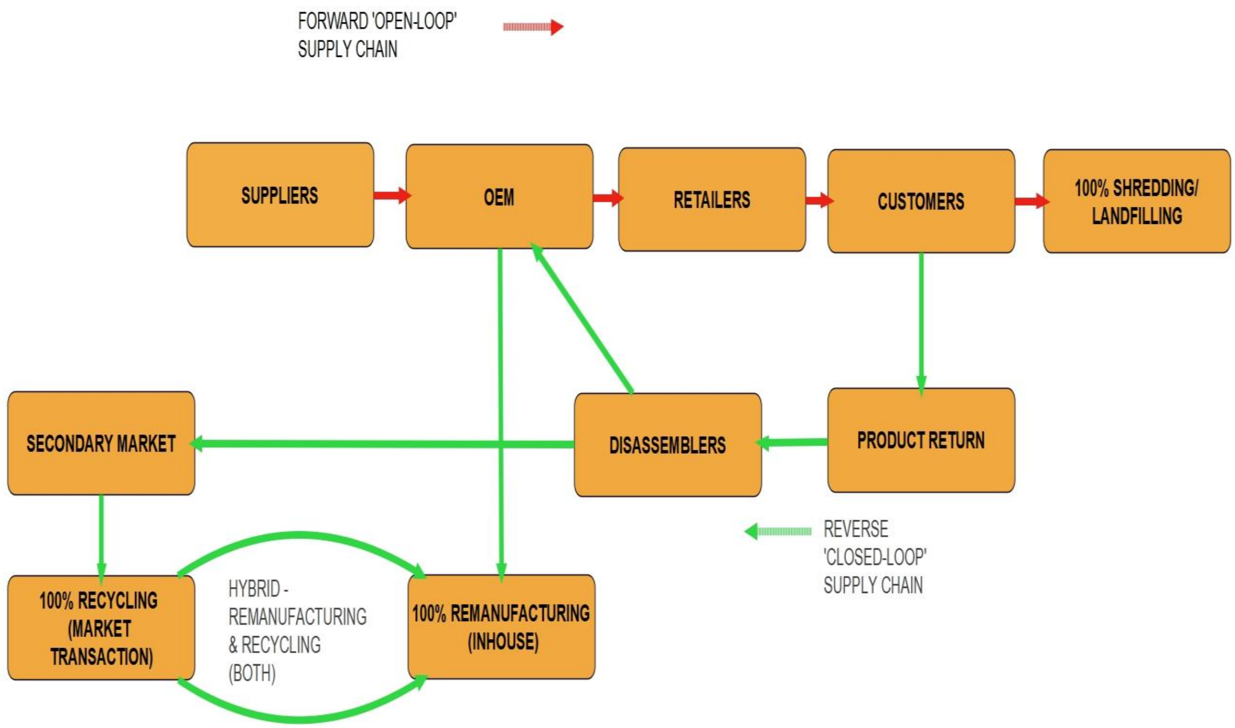
Fourth, consumers play an important role in promoting remanufacturing and recycling-related business policies. Guo, Geng, Sterr, Zhu, & Liu (2017) argue that the CLSC concept is still new for most consumers, and hence it is essential to strengthen social awareness related to resource conservation and environmental protection.

Additionally, Guo et al. (2017) argue that peoples' environmental awareness is created only by researchers in different countries, and social awareness regarding the environment needs to be broadened: "The entities related to CE development could be categorized into the general public, governmental agencies and enterprises, the CE awareness of whom are of vital importance for promoting CE and putting CE into practice" (p. 2178).

Similarly, Liu, Li, Zuo, Zhang, & Wang (2009) state that green consumption is the direct involvement of consumers in resource conservation and environmental protection, and hence, consumers can encourage the production of environmentally friendly products by realizing the essence of CLSC in business operations. However, consumers do not have basic information concerning what role they can play in promoting CLSC, and hence a lot more attention needs to be paid to motivating consumers to establish a new culture of CLSC (Liu et al., 2009).

Figure 1, below, shows the conceptual framework for exploring the three different product-recovery choices (remanufacturing, recycling, and hybrid) through the concept of CLSC.

FIGURE 1: CONCEPTUAL FRAMEWORK



2.7.3 RESEARCH QUESTIONS

While the research on integrated CLSC and the forward and reverse supply chains is widespread, there is limited research which explores the industrial tendencies that are present across regions and that pertain to choosing between remanufacturing and recycling in the context of CLSC. This thesis seeks to fill the gap by exploring different industrial patterns of product-recovery choices within CLSC from a TCE lens.

Schenkel, Caniëls, Krikke, & Laan (2015) argue that though CLSC was initially developed for purposes other than maximizing value, many existing value-adding supply chain concepts are now meant to create win–win situations in CLSC. Since CLSC is a topic shared by many disciplines, the necessity arises to conduct an overview and summarize the existing knowledge in both the remanufacturing and recycling literature. A systematic literature review is undertaken that encompasses relevant cross-disciplinary literature on CLSC, reverse supply chains, remanufacturing, and recycling. The following research questions are then answered:

What are the patterns/strategic priorities across industries in relation to remanufacturing (in-house) and recycling (secondary market)?

What are the impacts of take-back legislation across industries and across geographical locations in relation to remanufacturing (in-house) and recycling (secondary market)?

In order to do so, the indicators of both remanufacturing through in-house production and recycling through secondary markets are identified. A classification of four types of strategic priorities is used to explore industrial tendencies of remanufacturing and recycling across industries and across geographical locations. Additionally, the impact of take-back legislation is identified that leverage the process of reverse supply chain across industries and across different geographical settings.

There are clear practical and managerial contributions from this research. By developing a framework of CLSC through a TCE lens, and identifying several manifestations of remanufacturing and recycling, existing conceptual and empirical research is complemented, and this demonstrates the evolution towards reverse supply chains. Moreover, the systematic approach will identify important patterns across industries and develop a comprehensive agenda for future research. The practical contribution of this paper lies in the relevance of findings for companies, which are increasingly pressured to adopt reverse engineering in their business operations. This is evident because companies have shown more interest in activities related to topics such as CLSC, reverse logistics, sustainable sourcing, etc. over the last few decades.

Overall, the goal of this research is to examine the effects of factors associated with CLSC on different product-recovery choices (remanufacturing, recycling, and hybrid) and to compare the predictive ability of these factors in the current business environment.

3 METHODS

3.1 INTRODUCTION

This section presents the methodology used for conducting this research. The main objective of this study is to identify the patterns across industries concerning different product-recovery choices (remanufacturing, recycling, and hybrid). Apart from determining these industrial patterns, the research also intends to explore the impacts of take-back legislation across industries and across geographical locations with respect to different product-recovery choices (remanufacturing, recycling, and hybrid).

In order to explore different product-recovery choices in the context of CLSC, this thesis undertakes a systematic review of the extant literature to identify factors and associated patterns. As such, this research considers factors beyond economic determinants that may impact organizational decision-making on different product-recovery choices.

The subsequent sections of this chapter will detail the exact procedures used in conducting research on this topic. First, an initial architecture for reviewing different product-recovery choices (remanufacturing, recycling, and hybrid) will be developed as an extension to the conceptual framework developed in the previous chapter. Second, a general description and justification of the research methodology (i.e., systematic review) will be explained. Then, the outcomes from data extraction will be discussed in the next section. The data extraction process will adopt a transparent procedure in which the resulting literature base will be represented as a complete sample; the analysis will portray the structure, foundations, and main themes in present CLSC research. The fourth section will synthesize the data collected from this research, and explain the results through the final model for reviewing different product-recovery choices (remanufacturing, recycling, and hybrid). This section will also confirm that that all relevant work/case studies on different product-recovery choices surrounding CLSC are included and synthesized. The last section of this chapter will acknowledge the limitations of the research method, specifically discussing the limitations of the inclusion and exclusion criteria used in the systematic literature review.

3.2 RESEARCH DESIGN

3.2.1 DEVELOPING AN INITIAL ARCHITECTURE FOR REVIEWING DIFFERENT PRODUCT-RECOVERY CHOICES

The significance of CE in the production of goods is crucial to promote sustainable production, and is viewed as a potential paradigmatic shift that could result in industrial transformations (Korhonen et al., 2018). One key sustainability question is: What are the optimal product-recovery choices for companies that are engaged in sustainability activities? This question implies studying organizational behavior and patterns, and adopting a dynamic approach, because the CE concept is now predominant in the policy and business development debate on sustainable development of industrial production.

The first key element in doing research on different product-recovery choices is to explore the 'strategic priorities' for companies that plan to undertake reverse engineering in their business operations. Talbot, Lefebvre, & Lefebvre (2007) argue that the group of firms called "closed-loop visionaries" differs from the "internally focused" group of companies with respect to forward and reverse supply chain activities and, more prominently, with respect to the benefits they derive from these activities. The forward or reverse supply chain activities may result in fewer rewards when taken individually at a tactical level, than when applied simultaneously in accordance with some strategic priorities (Talbot et al., 2007).

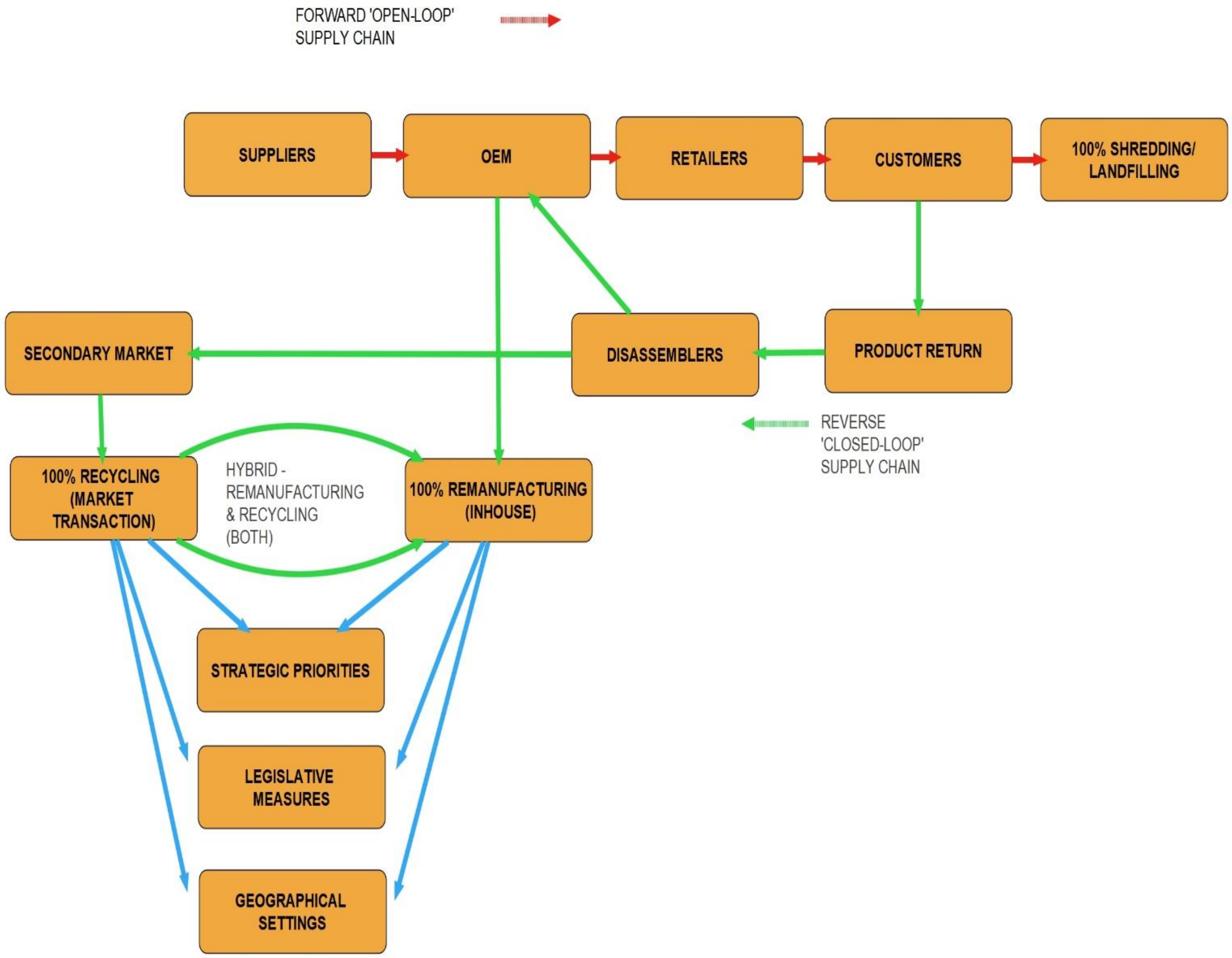
Apart from strategic priorities, companies have to consider the kind of 'legislative measures' that are in place in the context of different product-recovery choices. Similar to a natural ecosystem, consumer products are vulnerable to legislative measures that could subsequently change ecosystem-level flows of nutrients and waste materials (Ryen, Gaustad, Babbitt, & Babbitt, 2018). Ryen et al. (2018) suggest that the complex and quickly evolving nature of consumer-product manufacturing is different from the slow pace at which traditional waste management approaches are being developed to safely recover and return components and materials back into the value chain. Hence, legislative measures are introduced by different governments to encourage the recovery of products and materials for a range of consumer products entering the waste stream (Ryen et al., 2018). However, Ryen et al. (2018) argue that these legislative measures are at times not fully implemented, noting, "third parties involved with the collection and recovery of materials are often not collaborating with manufacturers or designers and there is limited ability to reintegrate recovered products, components, and materials back into the same industry" (p. 2). Similarly, Fareeduddin, Hassan, Syed, & Selim (2015) suggest that the growing importance of green supply chain (by the integration of forward supply chain and reverse supply chain) stems not only from the economic benefits of product recovery but also from legislative initiatives. The different legislative measures impose a constraint on the amount of waste generated in supply chain operations, and impose financial responsibility on companies in order to reach certain waste-reduction targets (Fareeduddin et al., 2015). Hence, Fareeduddin et al. (2015) argue that companies have to restructure their supply chains in terms of strategic and operational decisions to meet the targeted emissions due to varying levels of legislative measures.

Lastly, geographical settings also play an important role in exploring different product-recovery choices across different regions. It is quite significant to identify and establish CLSC markets in order to achieve higher levels of waste collection, and thus, societal needs should be widely defined across regions based on their recycling and remanufacturing commitments (Velis, 2015). Hence, this paper will explore CLSC patterns in the context of Europe, Asia, and North America.

In order to explore the optimal product-recovery choices for companies engaged in sustainability activities, an initial architecture is developed by drawing on and integrating the theoretical perspective of TCE with the concept of CLSC. The integration of these two concepts will help in exploring the optimal product-recovery channel for companies. This architecture provides the starting point for evidence synthesis, and takes better account of the wide range of considerations (strategic priorities, legislative measures, and geographical locations) through wide bodies of academic literature. This process will eventually provide a complete picture in terms of establishing patterns across industries in the context of CLSC. The goal of the study is to explore the patterns across industries in relation to remanufacturing and recycling that can eventually help companies to drive their production activities towards more sustainable production and consumption.

Figure 2, below, illustrates the initial architecture derived from the conceptual framework for identifying different product-recovery choices (remanufacturing, recycling, and hybrid) through the concept of CLSC.

FIGURE 2: INITIAL ARCHITECTURE FOR REVIEWING DIFFERENT PRODUCT-RECOVERY CHOICES



3.2.2 SYSTEMATIC REVIEW OF PRODUCT-RECOVERY CHOICES

The systematic review is considered a well-documented, replicable, and transparent search process founded on a theory-based understanding of the phenomenon of interest, and this method eventually results in improving the quality of the review process (Gast, Gundolf, & Cesinger 2017). Gast et al. (2017) argue that the systematic review method is frequently applied in recent business research, and is a useful research process to conduct a comprehensive analysis within the field of ecological sustainable entrepreneurship.

For the purpose of this thesis, the systematic review will facilitate comparability across studies, which results in elaborating the core characteristics of different product-recovery choices (remanufacturing, recycling, and hybrid) as a subdomain of CLSC research. Ultimately, this research will help advance the current and growing body of literature on CE and CLSC by presenting future research directions.

Adams, Jeanrenaud, Bessant, Denyer, & Overy (2015) discuss five steps in producing a systematic review: formulating research question; locating studies; study selection/evaluation; analysis/synthesis; and reporting/using results. Focusing specifically on locating studies, Adams et al. (2015) argue that it is crucial for researchers to identify the right keywords and search strings in relation to the research topic or questions. Alternatively, Voegtlin and Greenwood (2016) argue that researchers can effectively undertake conceptual exploration by means of a systematic review and conceptual analysis of academic literature that precisely includes these two constructs. Voegtlin and Greenwood (2016) propose that a systematic review can be performed in four steps. First, the researcher should develop a database by undertaking a comprehensive and systematic search to identify and extract all the relevant literature in relation to the research topic published in academic papers (Voegtlin & Greenwood, 2016). Second, the researcher needs to develop a template for analyzing each journal article, which is an iterative process between theoretically derived and empirically emerging themes (Voegtlin & Greenwood, 2016). Third, the researcher should then extract descriptive and qualitative conceptual data based on the content of retrieved articles (Voegtlin & Greenwood, 2016). Lastly, the researcher should interpret the results and synthesize the findings in the most meaningful manner.

This research will leverage the findings of Voegtlin and Greenwood (2016) and perform the systematic review using the four steps mentioned above; this is to explore the patterns across industries in relation to different product-recovery choices (remanufacturing, recycling, and hybrid) from companies' perspectives, and also to study the impact of take-back legislation on different product-recovery choices for businesses.

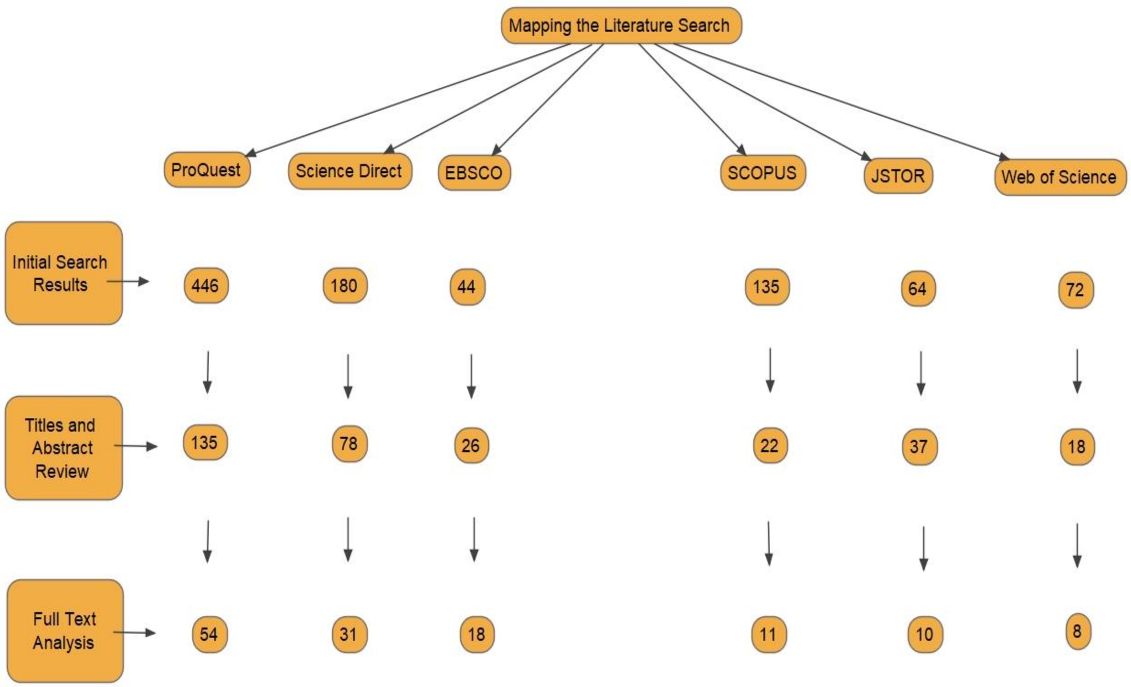
3.2.3 DEVELOPMENT OF THE DATABASE: KEYWORDS, SAMPLE, AND PERIOD

An initial review of the literature was undertaken to help to identify keywords to use when constructing search strings. Below is the list of the keywords developed for the purpose of this research:

"Circular Economy" OR "Closed-loop supply chain" OR "Reverse Logistics" OR "Reverse Engineering"; "Remanufacturing" OR "In-house Reverse Production"; "Recycling" OR "Secondary Market"; "Take-back legislation" OR "Extended Producer Responsibility" OR "Collective Producer Responsibility" OR "Individual Producer Responsibility"; "Businesses" OR "Corporations" OR "Companies"

The research strategy involves looking for relevant studies, represented by academic studies in peer-reviewed papers. In order to better understand the current state of research on different product-recovery choices (remanufacturing, recycling, and hybrid) in business and management, a systematic review is conducted of top business journals and their related sub disciplines. This research included a primary search of the ProQuest, ScienceDirect, EBSCO, Scopus, JSTOR, and Web of Science databases for articles published between January 1, 2000 and December 31, 2017. Figure 3, below, maps the literature search for this paper.

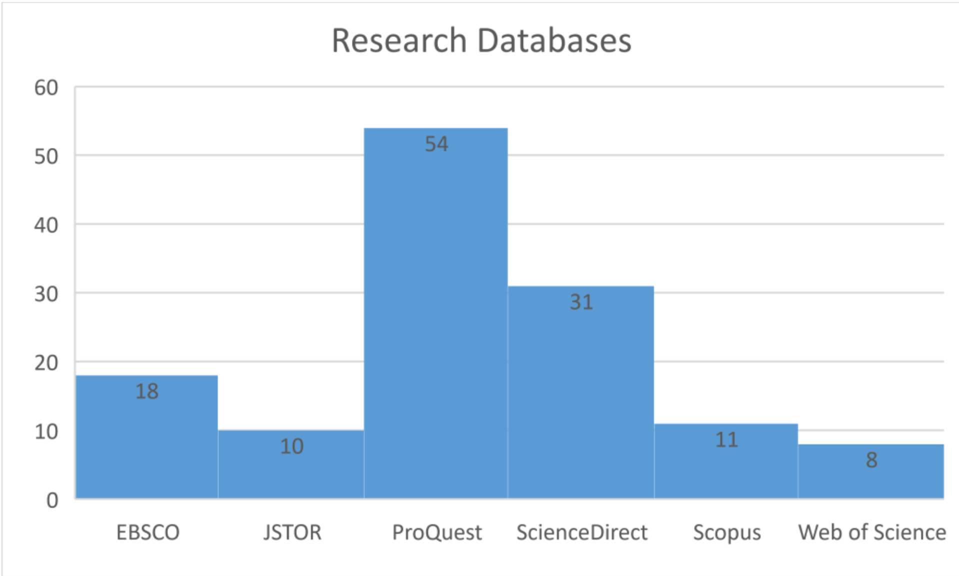
FIGURE 3: MAPPING THE LITERATURE SEARCH



Overall, 809 articles were disqualified from the initial search results of 941 papers. The 809 articles were eliminated based on review of the abstracts and titles. This high number of excluded articles reflects that even though aspects of remanufacturing and recycling in the context of CLSC are included in the titles, abstracts, or keywords, they were not key aspects of the research questions. The final dataset of articles consists of 132 academic papers published between January 2000 and December 2017.

A review of databases in the context of this research, and as reflected in Figure 4, below, reveals that 54 academic papers were collected from ProQuest. Additionally, 31 papers were collected from ScienceDirect, 18 papers from EBSCO, 11 papers were collected from Scopus, 10 papers were collected from JSTOR, and eight papers were collected from Web of Science.

FIGURE 4: LIST OF RESEARCH DATABASES



The criteria to determine which academic papers are included for full-text analysis for the purpose of this research is detailed in Table 1, below.

TABLE 1: INCLUSION AND EXCLUSION CRITERIA

Inclusion and Exclusion Criteria		
Criteria	**Inclusion**	**Exclusion**
Study type	Empirical studies: Qualitative or quantitative	Theoretical or conceptual studies
Study length	> 5 pages/2500 words	<5 pages/2500 words
Language	English	Any other language
Time period	2000 to 2017	Any study published before 2000
Relevance	1.Directly related to the research questions: a) Identifies companies that are involved in remanufacturing and recycling decision-making. Case studies/empirical research consistent with the research questions: 100% remanufacturing (vertical integration/in-house remanufacturing) or 100% recycling (market transaction/secondary market) or hybrid (between remanufacturing and recycling); b) Assesses the impacts of take-back legislation in relation to remanufacturing and recycling decision-making	1.Not directly relevant to the research questions: a) No clear information available about companies involved in remanufacturing and recycling decision-making; b) No clear information available to assess the impacts of take-back legislation in relation to remanufacturing and recycling decision-making
	2. Level of analysis: Firm-level practices and processes	2. Level of analysis: Not firm-level practices and processes
	3. Management and organizational studies literature	3. Not the management and organizational studies literature

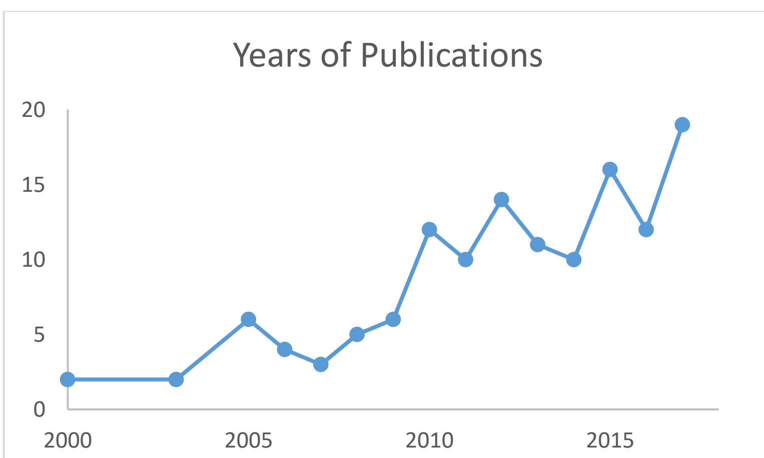
Source: Reprinted [adapted] from "Innovating for Sustainability: A Systematic Review of the Body of Knowledge," by Network for Business Sustainability, 2012

Based on the systematic search and exclusion-inclusion criteria, a sample of 132 academic papers was collected, and these are directly related to the goal of exploring the patterns across industries in relation to different product-recovery choices. The sample consists of journals such as *European Journal of Operational Research; Institute for Operations Research and the Management Sciences; International Journal of Logistics Management; International Journal of Physical Distribution & Logistics Management; International Journal of Production Research;*

International Journal of Sustainable Engineering; Journal of Cleaner Production; Journal of Manufacturing Systems; Journal of Operations Management; Journal of Remanufacturing; Production and Operations Management; Resources, Conservation and Recycling; Supply Chain Management; The Journal of the Operational Research Society; and Waste and Resource Management.

The search period was between January 1, 2000 and December 31, 2017. Figure 5, below, shows the years of publication of the academic papers which are directly related to the research questions of this paper, i.e., study of companies that are involved in different product-recovery choices (remanufacturing, recycling, and hybrid). Figure 5 clearly demonstrates that the CLSC system is attracting a greater level of interest. Notably, the scope of this research has in fact grown immensely over the last 10 years, as research questions pertinent to this thesis have become more relevant, and research findings ever more in demand by companies across almost all geographical settings. Of the 132 academic papers, 104 of the papers collected were published between 2010 and 2017.

FIGURE 5: YEARS OF PUBLICATIONS



3.2.4 DEVELOPMENT OF THE TEMPLATE AND SYSTEMATIC REVIEW OF THE EXTANT LITERATURE

Once the database was created, a systematic analysis was performed to gather relevant information from the 132 academic papers with regard to research data, research process, and research content. A template was developed to help extract descriptive data as well as text from the data pool. The template used for the analysis of all the articles is comprised of two sets of categories – bibliographical data and conceptual content data. Analysis of each article using the two sets of categories helped to gather descriptive data and key emerging themes around CE and TCE in the context of remanufacturing versus recycling decision-making.

The first set of categories pertains to bibliographical data, including type of journal, type of industry, size of the industry, and geographical location of the study. This process deals with analyzing the articles on the basis of studying different case studies relating to various industries, different firm sizes, and diverse geographical locations. Figure 6, below, illustrates the number of articles provided by different academic journals. Eleven journals provided three or more articles. The most number of articles (28 papers) were taken from the *Journal of Cleaner Production*.

FIGURE 6: JOURNALS PROVIDING 3 OR MORE PAPERS

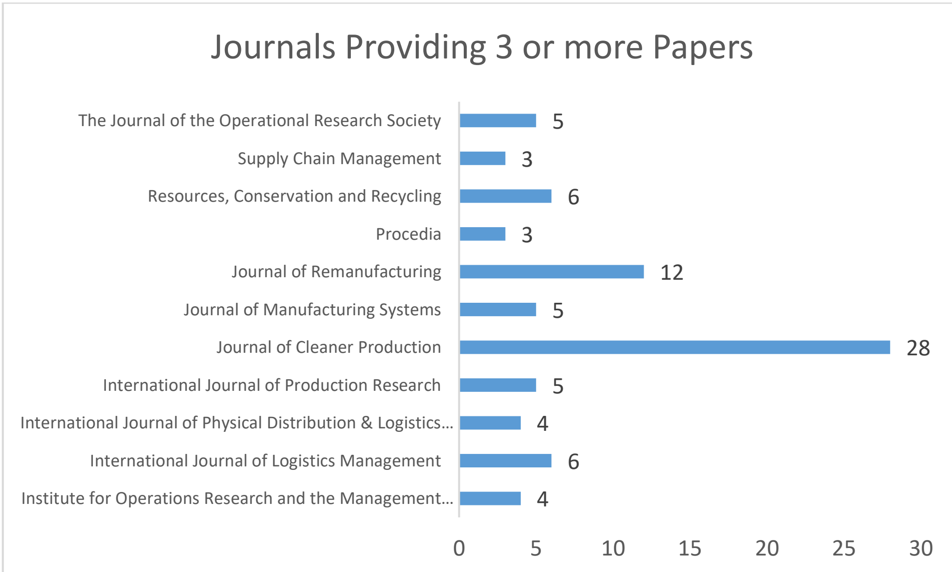


Figure 7, below, illustrates the industrial focus of academic papers included in the systematic review. Of the 132 papers, 53 papers focused on the electronics industry, 32 papers on the automotive industry, and 27 papers focused on industries other than the electronics and automotive sectors. There are 20 articles that do not clearly involve a specific sector, and these were categorised as undefined.

FIGURE 7: INDUSTRY COVERED

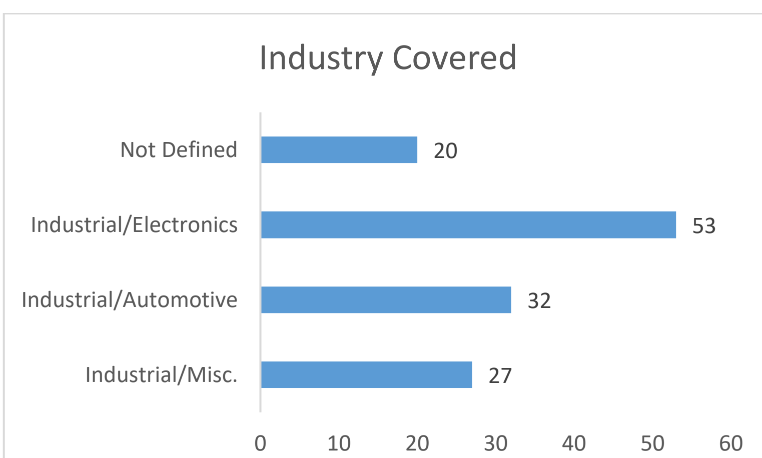


Figure 8, below, shows the size of the companies included in this study. The data show 38 articles that discuss companies categorised under large-scale manufacturing and technical consumer goods. Also, there are 31 articles that discuss companies categorised under small- and medium-scale manufacturing and technical consumer goods. Twelve academic studies in the systematic review are primarily about small- and medium-scale manufacturing and non-technical consumer goods, and five articles in the review involve large-scale manufacturing and non-technical consumer goods. Note that there are 46 academic studies that are categorised as undefined, since these papers do not clearly specify the firm size of the selected companies.

FIGURE 8: FIRM SIZE

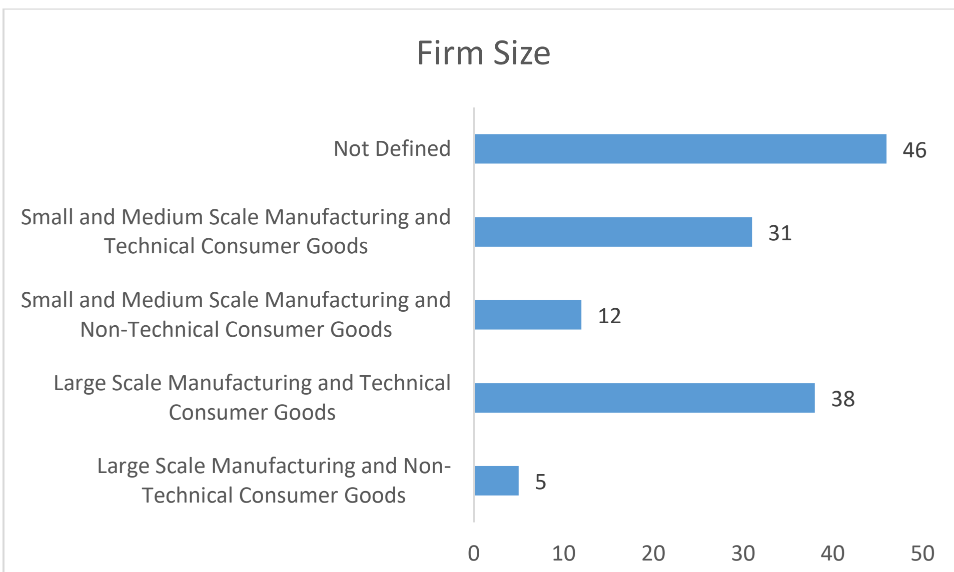
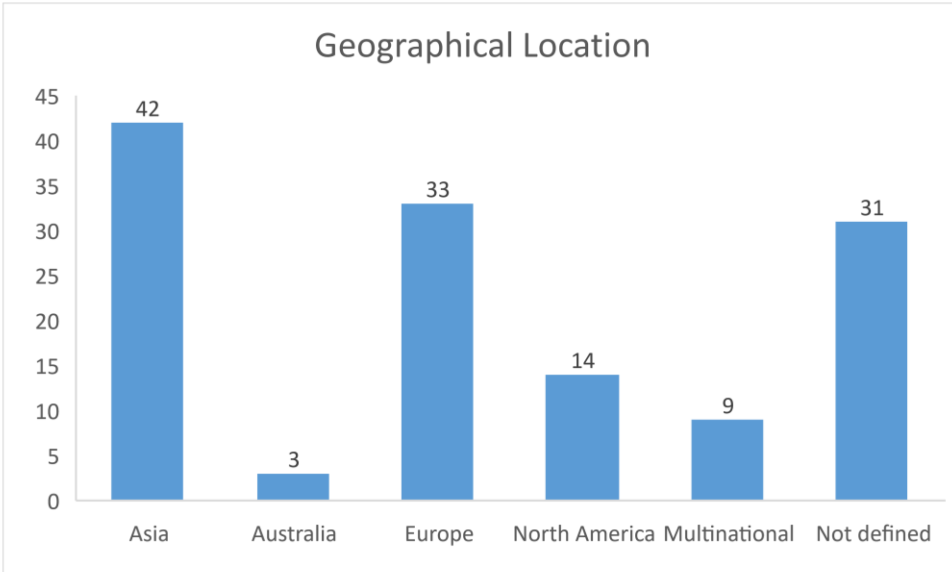


Figure 9, below, shows the geographical distribution of the scientific studies. This distribution illustrates global interest in CLSC. There are only nine papers that have a multi-country focus, and these are categorised under multinational.

FIGURE 9: GEOGRAPHICAL LOCATION



The second set of categories pertains to the conceptual content data, which includes key themes of the papers, key factors involved in deriving the results, and important findings derived from the study. The conceptual categories include definition/approach towards product-recovery process through CE/CLSC, and the relation between the two constructs of TCE and CE in the context of remanufacturing-or-recycling options.

The conceptual content data helped to make assumptions about what positions companies took in relation to remanufacturing versus recycling, and the impact of regulations on product remanufacturing and recycling decision-making. Figure 10, below, illustrates the number of papers from the sample that address each of the three different choices available to companies in the context of CLSC: remanufacturing; recycling; and hybrid model (a mix of both remanufacturing and recycling). Within the data set, 68 academic papers show a trajectory towards remanufacturing, and provide evidence of firms' activities in pursuit of that objective; 39 academic papers indicate a trajectory towards recycling, and provide evidence of firms' activities in pursuit of that objective; and 25 academic papers indicate a trajectory towards the hybrid model, and provide evidence of firms' activities in pursuit of that objective.

FIGURE 10: PRODUCT-RECOVERY CHOICES (REMANUFACTURING, RECYCLING, AND HYBRID)

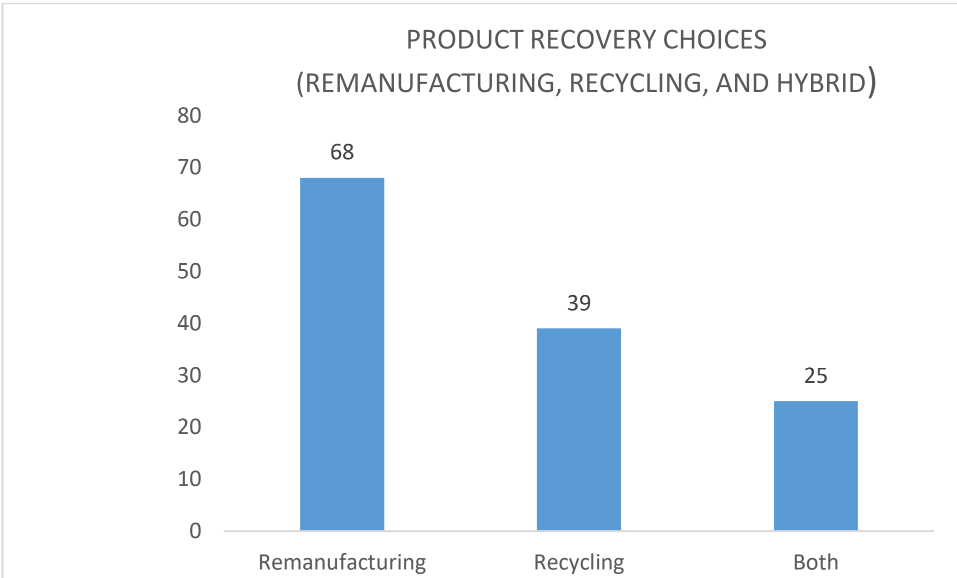
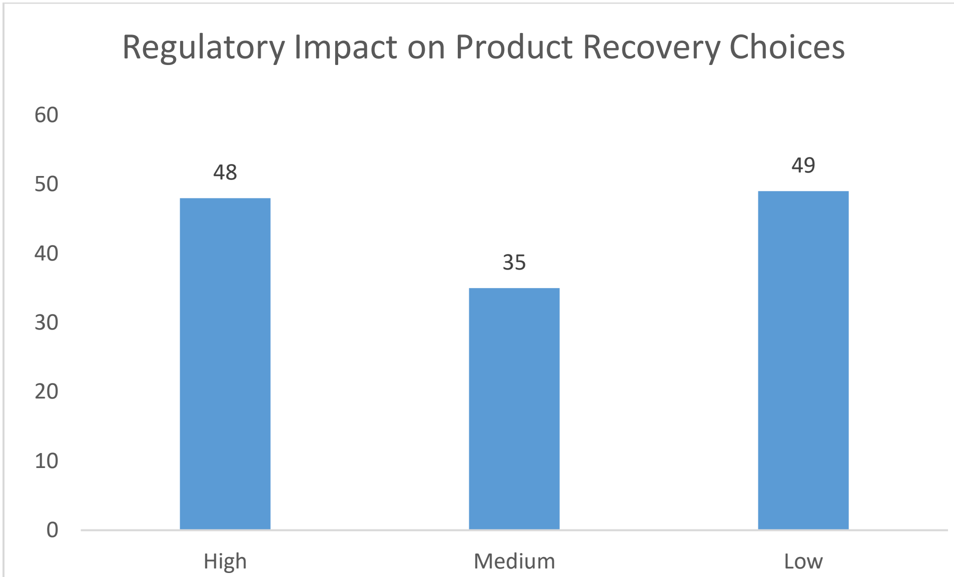


Figure 11, below, represents the impact of regulations on companies that have adopted a CLSC system. No distinct pattern is observed in this case. There are 49 academic papers that reflect companies adopting CLSC under the influence of low regulations and 48 academic papers that reflect companies adopting CLSC under the influence of high regulations. Additionally, there are 35 academic papers that reflect companies adopting CLSC under the influence of medium regulation.

FIGURE 11: REGULATORY IMPACT ON PRODUCT-RECOVERY CHOICES



3.2.5 DEVELOPMENT OF KEY VARIABLES ASSOCIATED WITH TCE AND CLSC

The next step in the systematic review was to develop key variables extracted from key themes and findings at the intersection of TCE and CSCL. The key variables include different strategic priorities (i.e., cost & value, operational optimization, environmental consideration, and customer awareness), different levels of regulatory measures, and different geographical locations.

The relationship between CLSC and cost & value (CV) was coded based on four common sub-factors found in the systematic review of the literature: 1. Cost of product recovery, such as transportation cost, collection cost, collection point coverage rates, coverage of third-party coverage points, rate of recovery, dismantling cost, and failure percentage, etc.; 2. return on investment (rate of return versus demand rate); 3. Quality of returned products, including the expected lifetime of the returned product; and 4. Landfill/disposal cost including, but not limited to, total penalty cost and total tardiness cost. The relationship between CLSC and operational optimization (OO) was coded based on three common sub-factors found in the systematic review of the literature: 1. Material recovery planning including, but not limited to, transfer time, queue in the system, material matching technology, and information technology; 2. Dismantling process, such as separation technology, inspection/testing of returned products; and 3. Design efforts, including durable design, design solutions, and design difficulties. The relationship between CLSC and environmental consideration (EC) was coded based on two common sub-factors found in the systematic review of the literature: 1. Energy consumption; and 2. Energy usage. The relationship between CLSC and customer awareness (CA) was coded based on two common sub-factors found in the systematic review of the literature: 1. Return attitude, which includes environmental friendliness; and 2. Perceived risks and benefits.

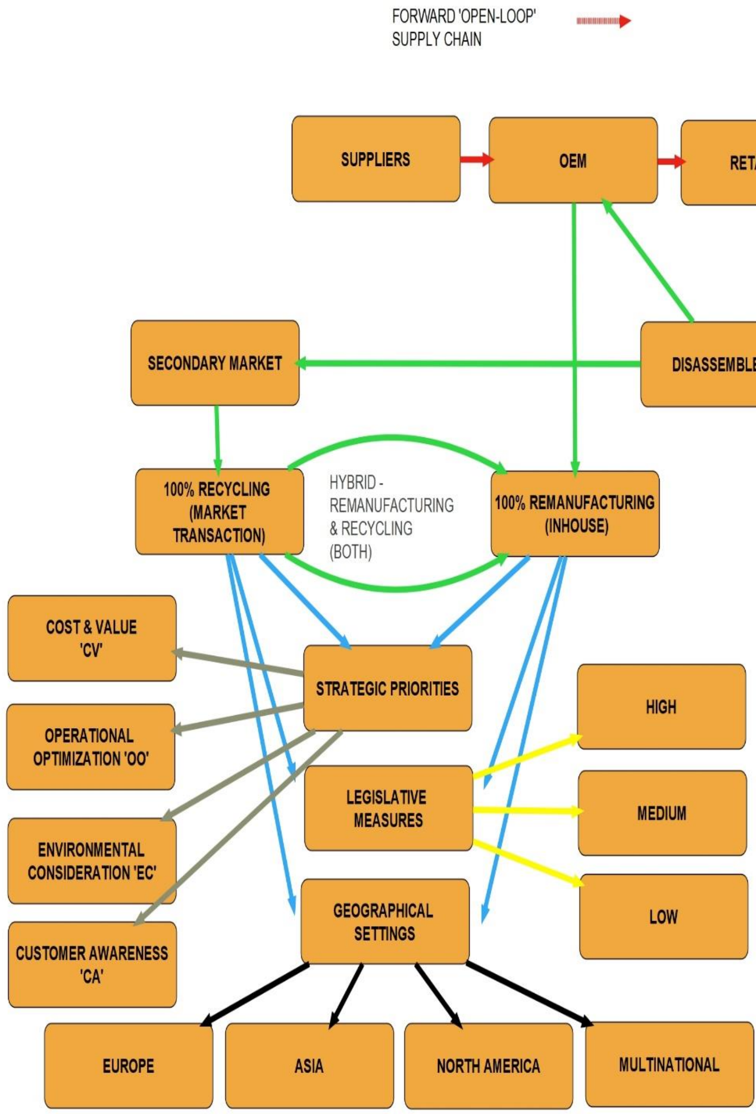
Similarly, there were three levels of regulatory measures extracted from the systematic review of the literature, i.e., low, medium, and high regulations. Low regulations are coded in cases where the country of origin (country of manufacture, production, or growth) does not institute take-back legislation, which makes manufacturers not responsible for reclaiming their end-of-life products. A lot of poor and underdeveloped countries have no take-back legislation. Medium regulations are coded in cases where the country of origin institutes take-back legislation, but does not implement the policy. In these instances, manufacturers are only partially reclaiming their end-of-life products. For example, China’s electronic waste policy is inefficient and irregularly enforced, and it involves a large number of departments publishing regulations and imposing disposal fees (Wang, Zhang, & Guan, 2016). High regulations are coded in cases where the country of origin institutes and implements the take-back legislation, which makes manufacturers completely responsible for reclaiming their end-of-life products. For example, European Union’s WEEE

Directive is fully committed to sustainable and social development, and it integrates industrial policies and environmental protection. According to the WEEE Directive, EU member states are obliged to reach a 55% municipal recycling rate by 2025, 60% by 2030 and 65% by 2035 (Cole, 2018).

3.2.6 FINAL MODEL FOR REVIEWING DIFFERENT PRODUCT-RECOVERY CHOICES

Companies have embraced the practices of CLSC based on some key common factors as explained in the last section, and this has helped the companies to engage in the wider implications of sustainability thinking. By adding key common factors involved for sustainable production in the context of CE in the initial architecture, the final model for reviewing different product-recovery choices (remanufacturing, recycling, and hybrid) is developed, and it is illustrated in Figure 12, below.

FIGURE 12: FINAL MODEL FOR REVIEWING DIFFERENT PRODUCT-RECOVERY CHOICES



3.2.7 DATA LIMITATIONS

This paper deals with a number of data limitations. First, the inclusion and exclusion criteria used in the systematic literature review does not assure that all relevant case studies pertaining to remanufacturing-versus-recycling decisions are included and synthesized. Nevertheless, the sample of 132 papers extracted through systematic data collection between January 1, 2000 and December 31, 2017 tries to cover all of the main themes and practices of CE and CLSC systems from the perspective of corporations. Second, there is a chance that other researchers may interpret the systematic review differently, and therefore the replicability of the results can be challenged. Similarly, Gast et al. (2017) argue that some of the data collection in a systematic literature review can be based on subjectivity, raising the question of the objectivity of the entire data analysis. However, the conceptual framework and model developed in this paper presents a useful building block, and has the potential to advance our understanding of patterns across industries and for companies across geographical locations.

4 RESULTS

4.1 INTRODUCTION

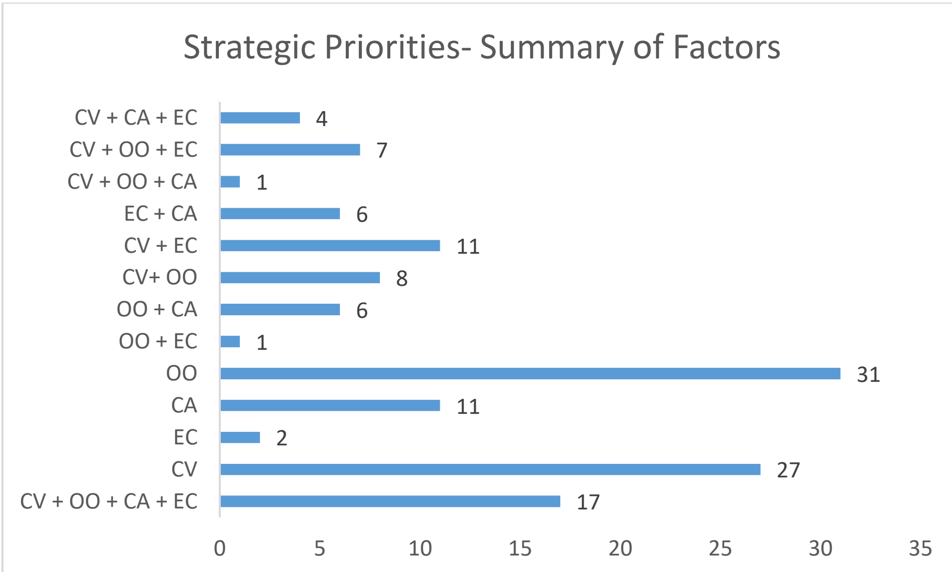
This chapter provides the results from the systematic review of 132 academic papers discussing three different product-recovery choices (remanufacturing, recycling, and hybrid) from the companies' perspectives and published between 2000 and 2017. The sample consists of 68 academic papers that addressed instances where companies preferred to choose remanufacturing in their business operation; 39 academic papers in which companies preferred to choose recycling as an effective business model; and, finally, 25 academic papers where the companies opted for both remanufacturing and recycling (hybrid model) in their business activities. The above-stated information needs to be explored further by doing an analysis based on the four strategic priorities (OO, CV, EC, and CA), the three levels of legislative measures (high, medium, and low), and across different geographical settings. The second section of this chapter discusses the summary of factors based on the strategic priorities, legislative measures, and different geographical locations. The third section then discusses the patterns across industries based on strategic priorities, and the legislative measures being taken in the context of different product-recovery choices for companies. Lastly, the fourth section summarizes the results, as drawn out from the systematic review of the literature.

4.2 RESULTS BY FACTOR

4.2.1 STRATEGIC PRIORITIES

The first result is based on analyzing four strategic priorities when companies are performing any of the three product-recovery choices; here the results are drawn regardless of whether companies are planning to adopt remanufacturing, recycling, or both in their business model. These four strategic priorities are mapped across 14 different sub-categories, including OO, CV, EC, CA, OO+CA, CA+CV, CV+EC, OO+EC, OO+CV, CA+OA+EC, OO+CV+CA, OO+EC+CV, CA+CV+EC, OO+CV+CA+EC. Based on the 14 subcategories, it is observed that OO alone is the most frequently identified factor in choosing to adopt a CLSC system in business activities. There are 31 academic papers that discuss that OO is the most frequently identified factor for a successful transition to CLSC. The next factor, which comes close to OO, is CV, since there are 27 academic papers which discuss that CV is the most frequently identified factor in the transition to the CLSC model. There are 17 academic papers where CV, OO, EC, & CA are the most frequently identified factors in transition to the CLSC model. There are 11 academic papers that discuss that CA alone is the most frequently identified factor in the transition to the CLSC model. Likewise, there are 11 academic papers that discuss that CV+EC are the most frequently identified factors in transition to CLSC system. Figure 13, below, summarizes factors based on the strategic priorities derived from the systematic review of the literature.

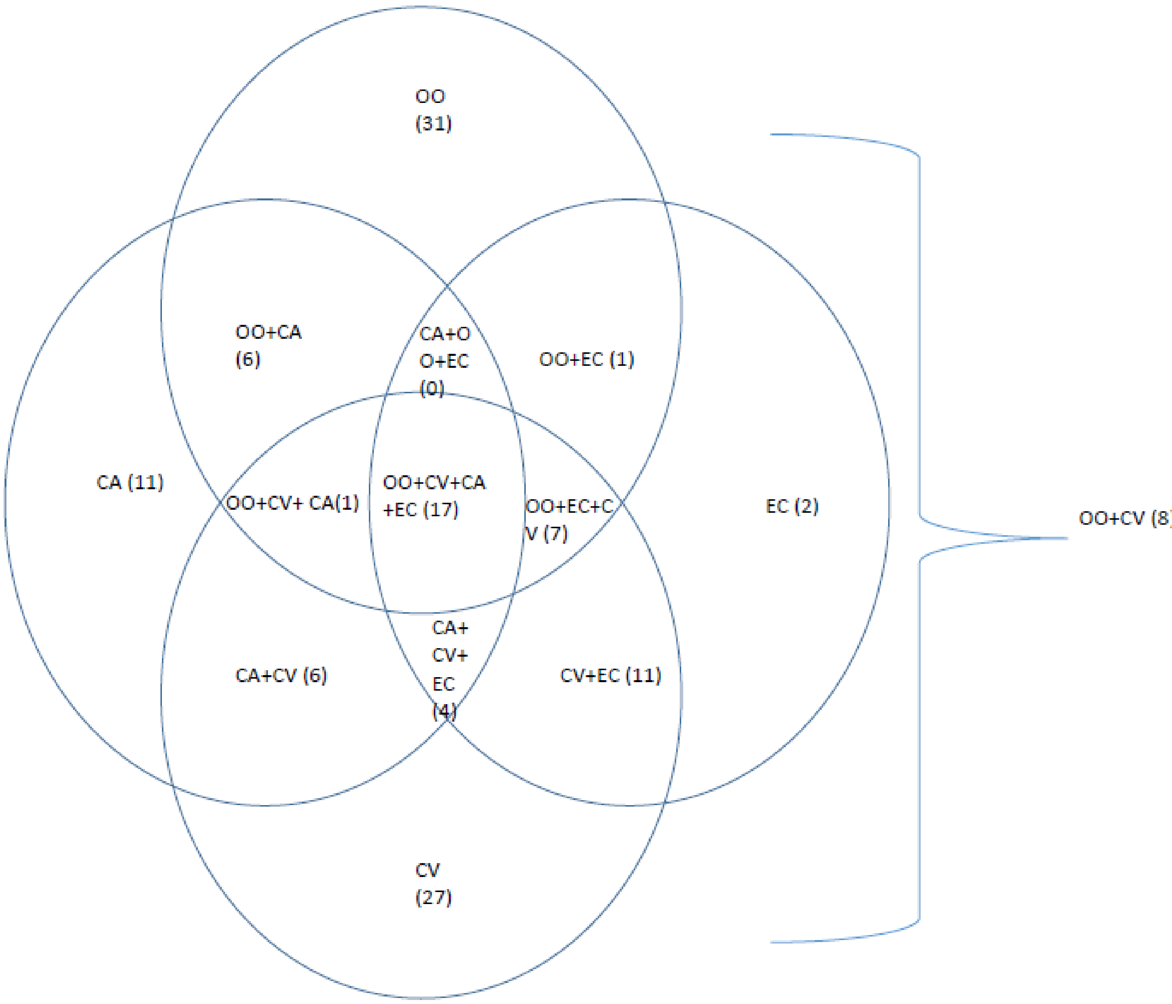
FIGURE 13: STRATEGIC PRIORITIES – SUMMARY OF FACTORS



***CV = Cost & Value; OO = Operational Optimization; EC = Environmental Consideration; CA = Customer Awareness*

Figure 14, below, is a Venn diagram that illustrates the factors in regards to the strategic priorities set by the companies pursuing the CLSC model.

FIGURE 14: STRATEGIC PRIORITIES – VENN DIAGRAM



The second result drawn from the systematic review is based on analyzing four strategic priorities when companies have adopted the remanufacturing model. These four strategic priorities are mapped across 14 different sub-categories. The summarization of factors based on the 14 subcategories in the context of remanufacturing is illustrated in Figure 15. Based on the 14 subcategories, it is observed that OO is the most frequently identified factor for companies that plan to adopt remanufacturing in their business model. There are 18 academic papers that discuss

OO by itself as the most frequently identified factor for successful transition to the remanufacturing model. There are 11 academic papers where CV, OO, CA, & EC are the most frequently identified factors in transition to remanufacturing model. There are 10 academic papers that discuss CV as the most frequently identified factor in the transition to the remanufacturing model. There are nine academic papers that discuss how CA is the most frequently identified most factor in the transition to the remanufacturing model.

Figure 15 below summarizes factors based on the remanufacturing model.

FIGURE 15: REMANUFACTURING – SUMMARY OF FACTORS

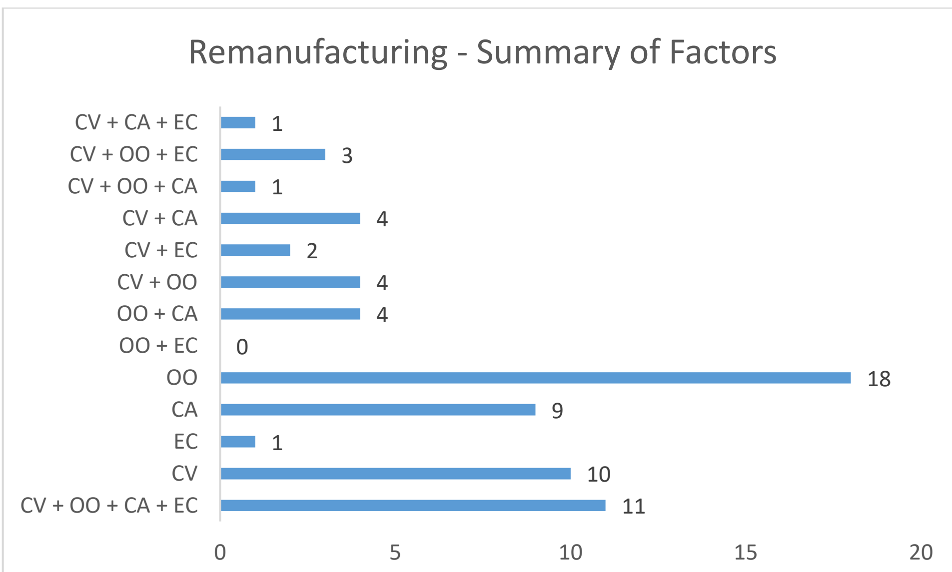
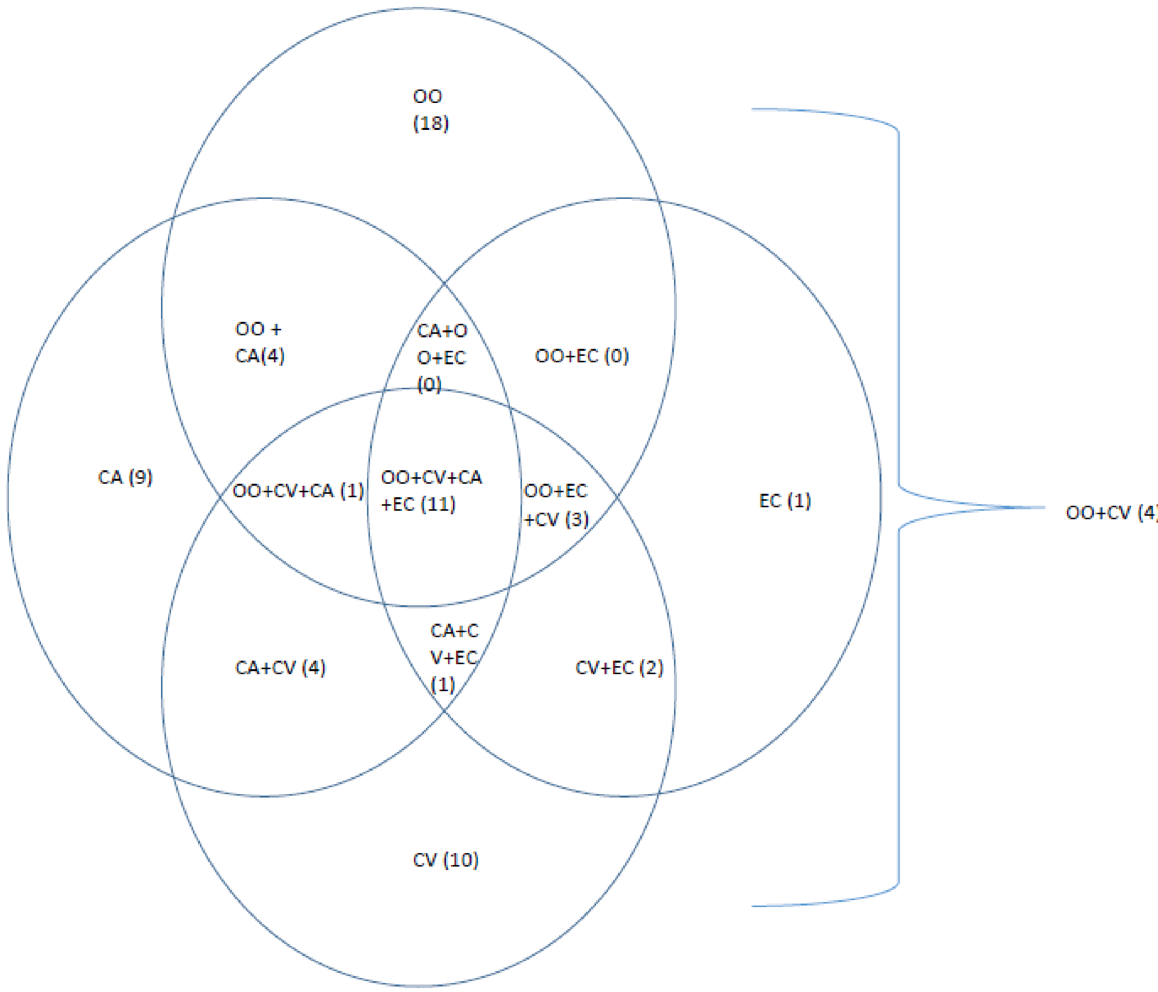


Figure 16, below, is a Venn diagram that illustrates the factors based on the remanufacturing model.

FIGURE 16: REMANUFACTURING – VENN DIAGRAM



The third result drawn is based on analyzing four strategic priorities against situations where companies are performing only recycling in their business model. These four strategic priorities are mapped across 14 different sub-categories. The summarization of factors based on the 14 subcategories in the context of recycling is illustrated in Figure 17. Based on the 14 sub-categories, it is observed that CV is the most frequently identified factor for companies who plan to adopt recycling in their business model. There are 10 academic papers that discuss that OO alone is the most frequently identified factor for successful transition to the recycling model. There are 6 academic papers that discuss that OO is the most frequently identified factor in transition to the recycling model. There are 6 academic papers that discuss that CV+EC are the most frequently identified factors in transition to the recycling model. There are 4 academic papers that discuss that CV+OO are the most frequently identified factors in transition to the recycling model. Figure 17 below summarizes factors based on the recycling model.

FIGURE 17: RECYCLING – SUMMARY OF FACTORS

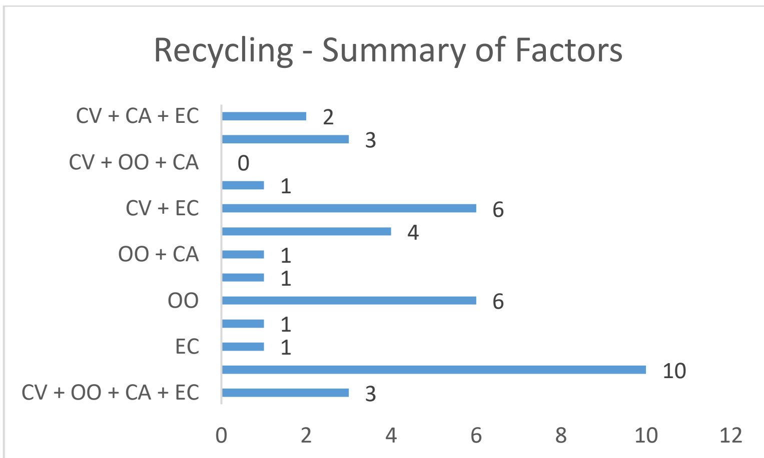
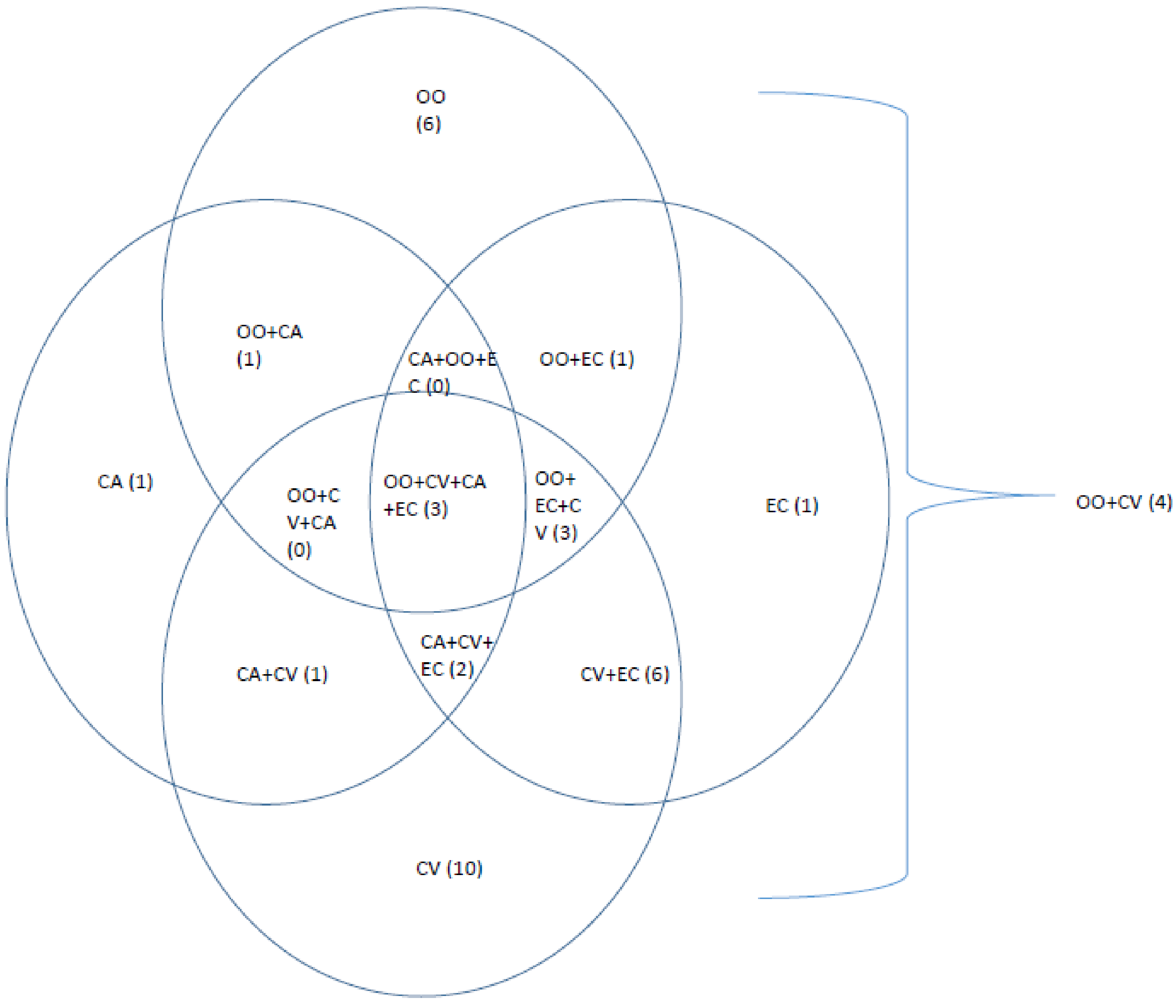


Figure 18, below, is a Venn diagram that illustrates the factors based on the recycling model.

FIGURE 18: RECYCLING – VENN DIAGRAM



The fourth result drawn is based on analyzing four strategic priorities against situations where companies are performing both remanufacturing and recycling simultaneously in their business model. These four strategic priorities are mapped across 14 different sub-categories. The summarization of factors based on the 14 subcategories in the context of remanufacturing and recycling (simultaneously) is illustrated in Figure 19. There are 7 academic papers that discuss that OO alone is the most frequently identified factor for successful transition to the hybrid model. Also, there are 7 academic papers that discuss that CV is the most frequently identified factor in transition to the hybrid model. There are 3 academic papers that discuss that OO+CV+CA+EC (all together) are the most frequently identified factors in transition to the hybrid model. There are 3 academic papers that discuss that CV+EC are the most frequently identified factors in transition to the hybrid model.

Figure 19 below summarizes factors based on the hybrid model.

FIGURE 19: HYBRID MODEL – SUMMARY OF FACTORS

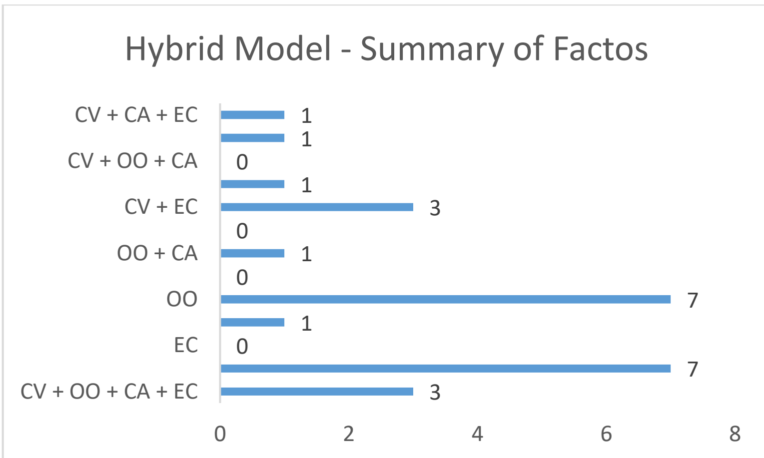
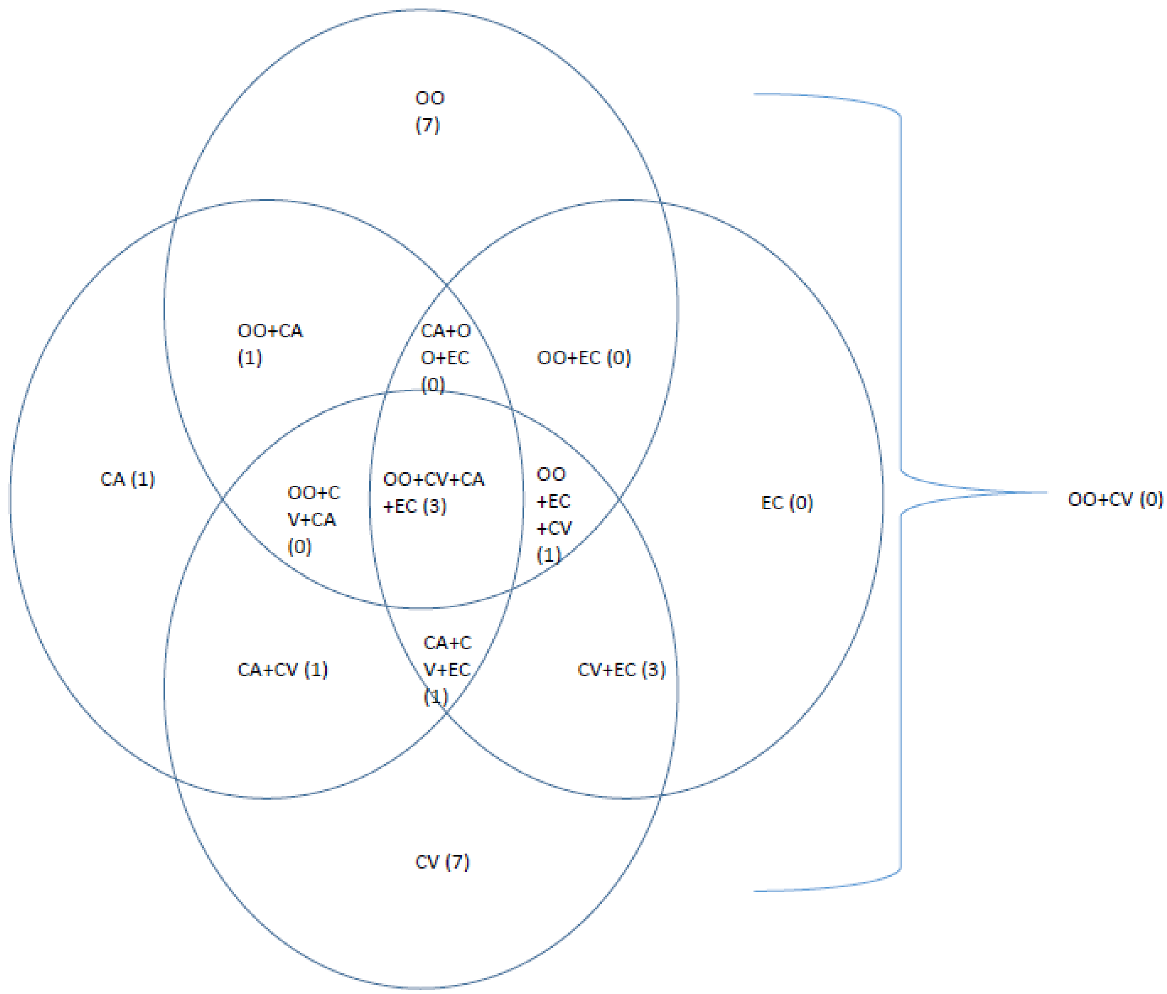


Figure 20, below, is a Venn diagram that illustrates the factors based on the hybrid model.

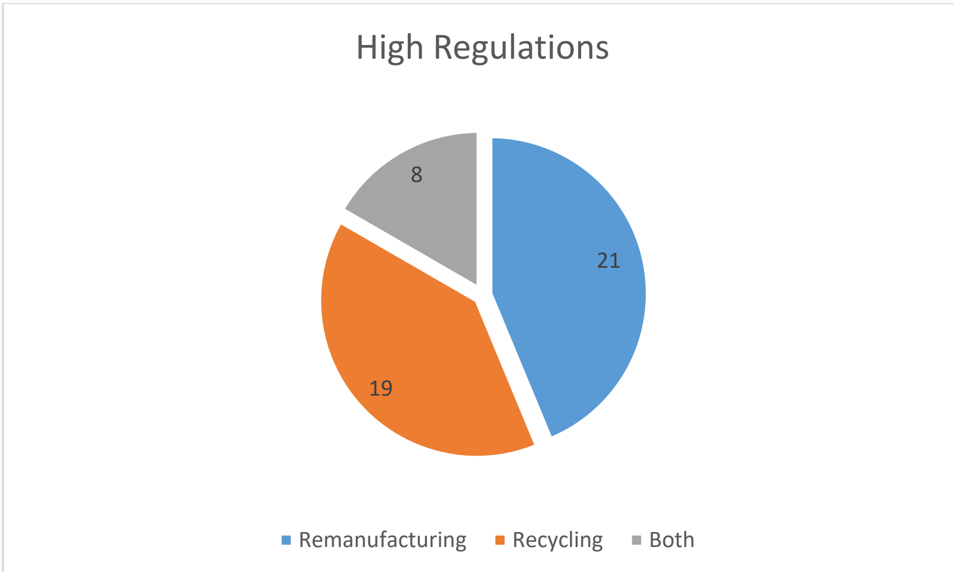
FIGURE 20: HYBRID MODEL – VENN DIAGRAM



4.2.2 LEGISLATIVE

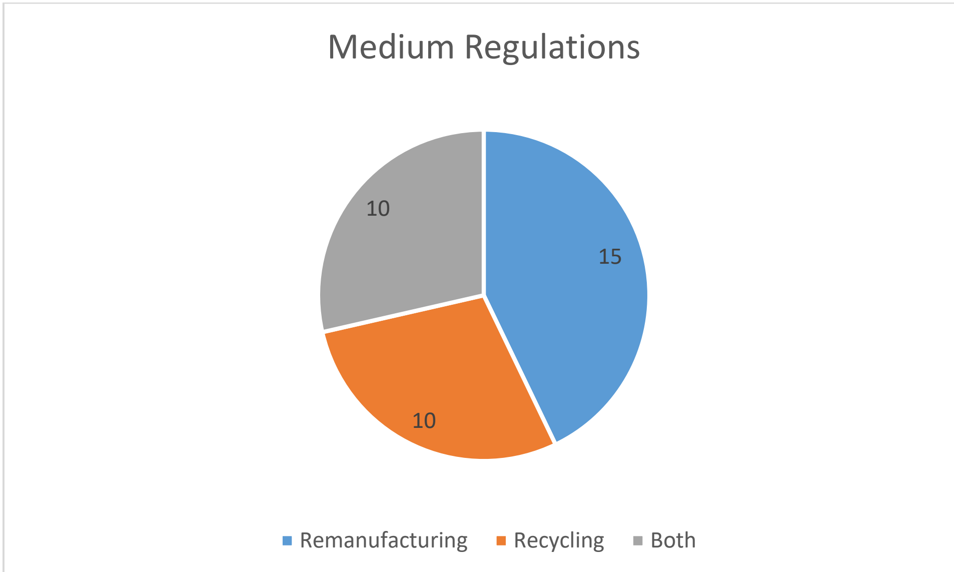
Out of the sample of 132 academic papers, it is observed that 48 papers discuss the impact of high regulations on different product-recovery options. Figure 21, below, shows the impact of high regulations on different product-recovery choices. It is observed that under high regulations, there are 21 academic papers that discuss remanufacturing as the preferred choice for successful transition to a CLSC model. There are 19 academic papers that discuss recycling as the preferred business model under high regulations. Lastly, there are eight academic papers that discuss both remanufacturing and recycling as the preferred business models in the context of high regulations.

FIGURE 21: HIGH REGULATIONS



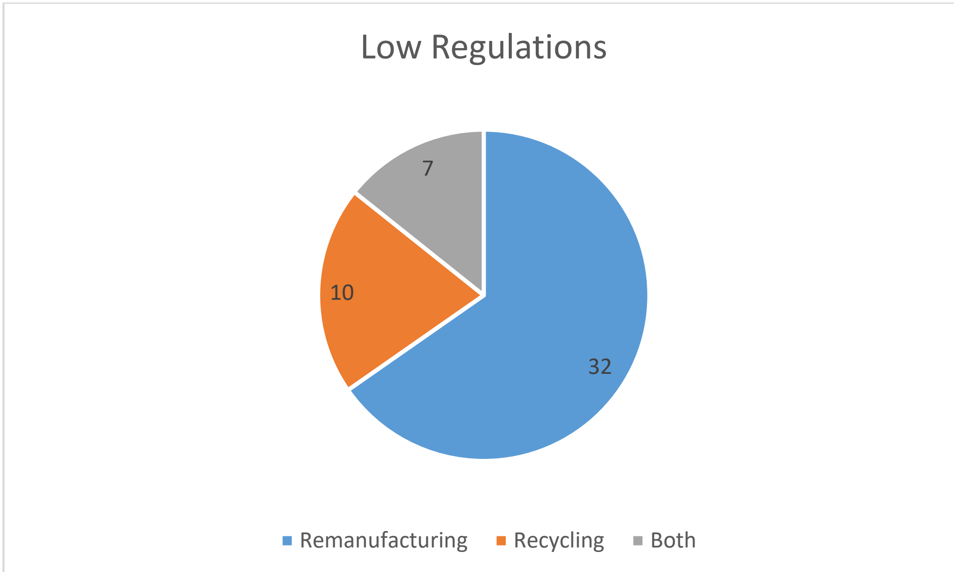
Out of the total sample, it is observed that 35 papers discuss the impact of medium regulations on different product-recovery options. Figure 22, below, shows the impact of medium regulations on different product-recovery choices. It is observed that under medium regulations, there are 15 academic papers that discuss remanufacturing as the preferred choice for their business operation. There are 10 academic papers that discuss recycling as a preferred business model under medium regulations. Also, there are 10 academic papers that discuss both remanufacturing and recycling as the preferred business models in the context of medium regulations.

FIGURE 22: MEDIUM REGULATIONS



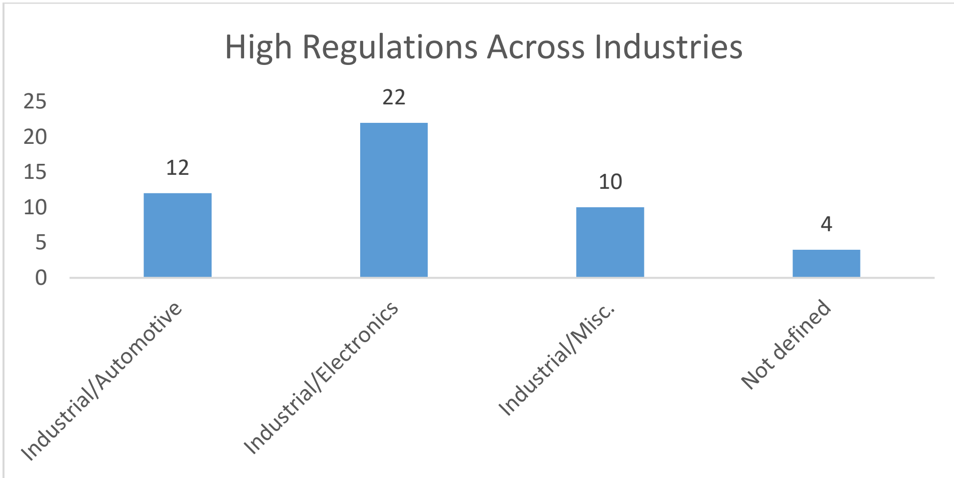
Out of the total sample, it is observed that 49 academic papers discuss the impact of low regulations on different product-recovery options. Figure 23, below, shows the impact of low regulations on different product-recovery choices. It is observed that under low regulations, there are 32 academic papers that discuss remanufacturing as the preferred business model. There are 10 academic papers that discuss recycling as the preferred business model under low regulations. Lastly, there are 7 academic papers that discuss both remanufacturing and recycling as the preferred business models in the context of low regulations.

FIGURE 23: LOW REGULATIONS



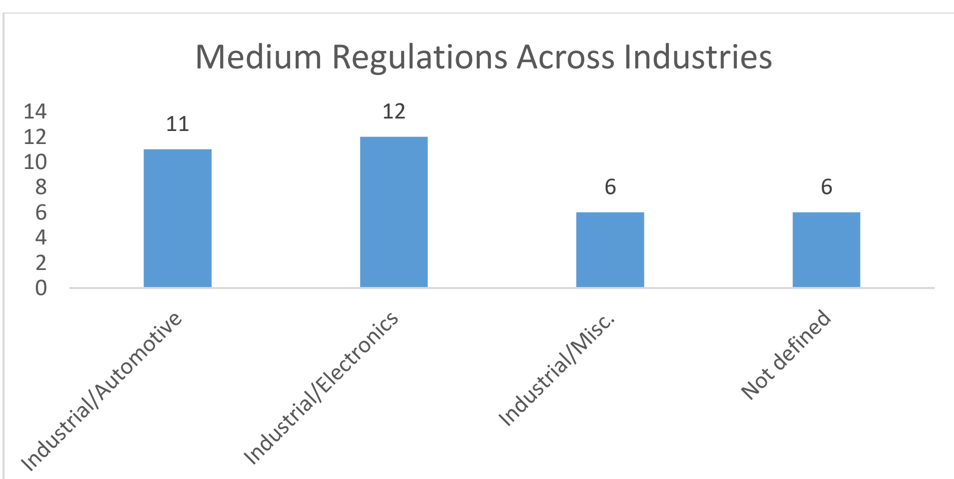
There are 22 academic papers from the sample that address the electronics industry under high regulations and 12 academic papers from the sample that address the automotive industry under high regulations. There are 10 academic papers from the sample that address miscellaneous industry under high regulations, and there are 4 academic papers from the sample that do not define any specific industry under high regulations. Figure 24, below, illustrates the impact of high regulations across industries.

FIGURE 24: HIGH REGULATIONS ACROSS INDUSTRIES



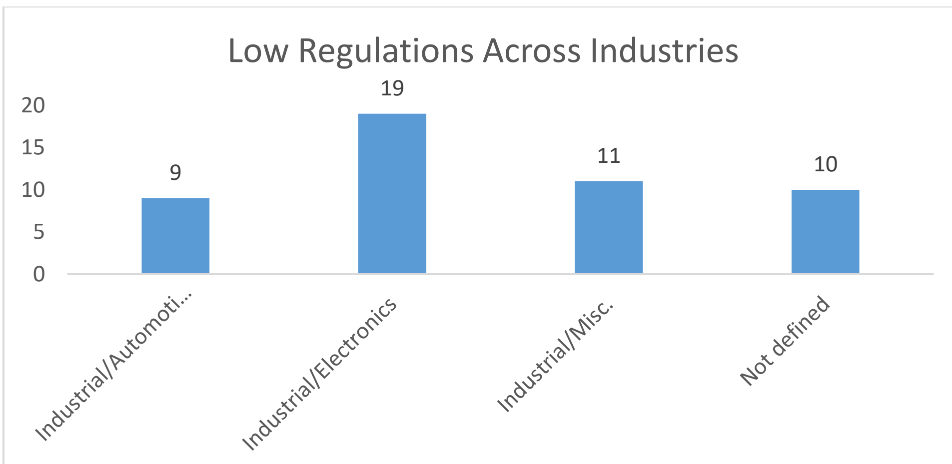
There are 12 academic papers from the sample that address the electronics industry under medium regulations. There are 11 academic papers from the sample that address the automotive industry under medium regulations. There are 6 academic papers from the sample that address miscellaneous industry under medium regulations. Also, there are 6 academic papers from the sample that do not define any specific industry under medium regulations. Figure 25, below, illustrates the impact of medium regulations across industries.

FIGURE 25: MEDIUM REGULATIONS ACROSS INDUSTRIES



There are 19 academic papers from the sample that address the electronics industry under low regulations. There are 11 academic papers from the sample that address miscellaneous industry under low regulations. There are 9 academic papers from the sample that address the automotive industry under low regulations. However, there are 10 academic papers from the sample that are do not define any specific industry under low regulations. Figure 26, below, illustrates the impact of medium regulations across industries.

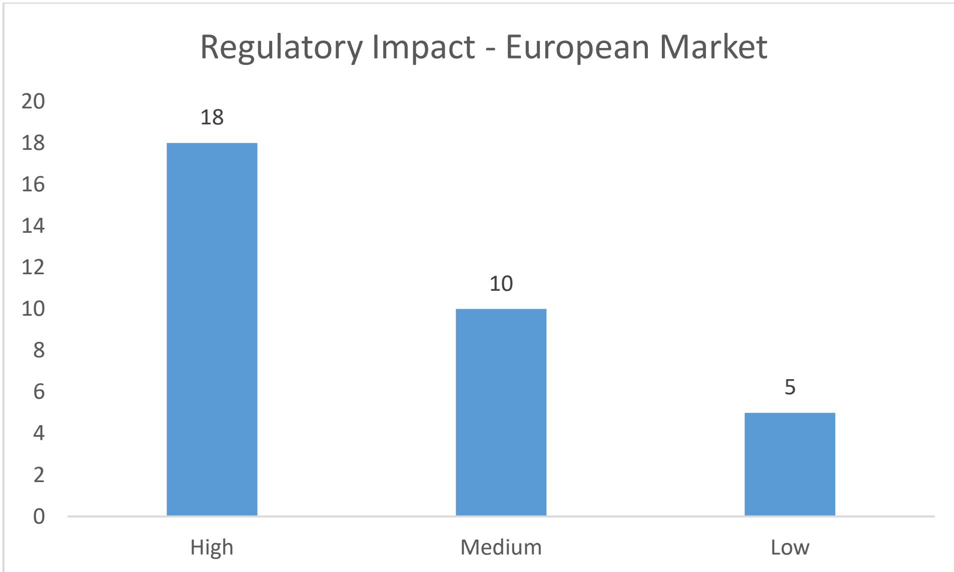
FIGURE 26: LOW REGULATIONS ACROSS INDUSTRIES



4.2.3 GEOGRAPHICAL

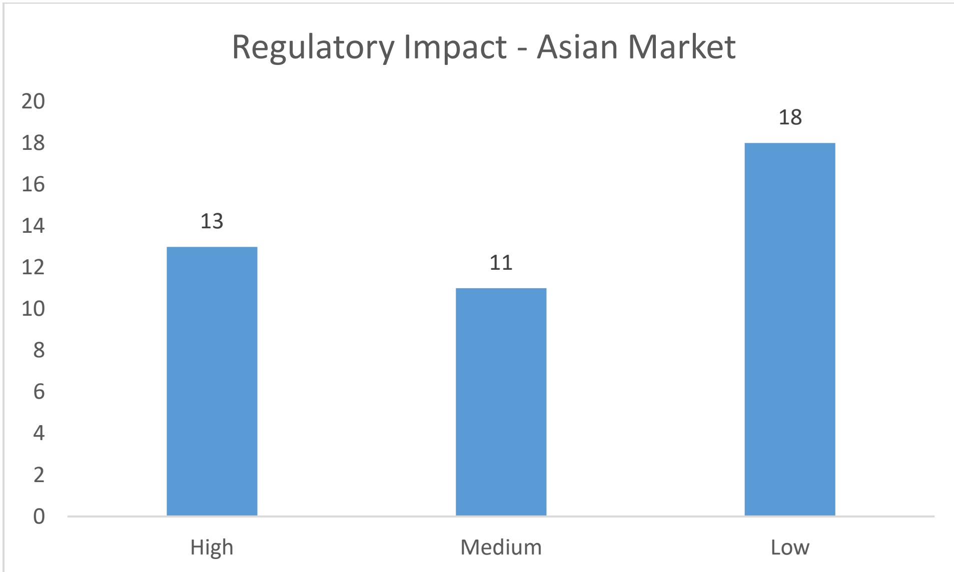
The systematic review of the extant literature helps to understand the impact of regulations on different geographical markets. There are 18 academic papers that discuss a positive correlation between high regulation and CLSC in the context of the European Market. There are 10 academic papers that discuss a positive correlation between medium regulation and CLSC in the context of the European Market. There are 5 academic papers that discuss a positive correlation between low regulation and CLSC in the context of the European Market. Figure 27, below, shows the impact of regulations on the European Market.

FIGURE 27: REGULATORY IMPACT – EUROPEAN MARKET



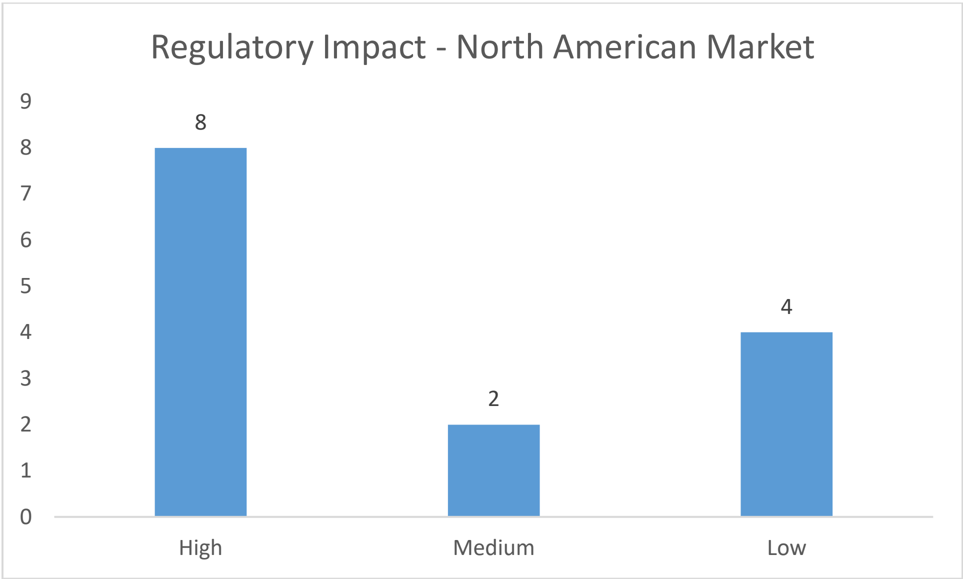
There are 11 academic papers that discuss a positive correlation between high regulation and CLSC in the context of the Asian market. There are 11 academic papers that discuss a positive correlation between medium regulation and CLSC in the context of the Asian market. There are 18 academic papers that discuss a positive correlation between low regulation and CLSC in the context of the Asian market. Figure 28, below, shows the impact of regulations on the Asian market.

FIGURE 28: REGULATORY IMPACT – ASIAN MARKET



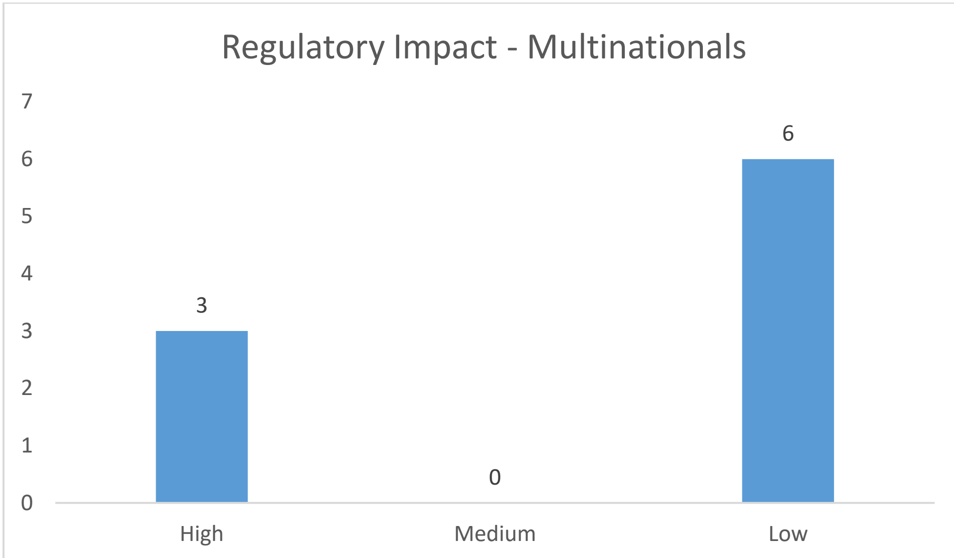
The sample for the North American market is only 14, and hence, any results drawn on the basis of the sample are insufficient. However, based on the existing sample, there are 8 academic papers that discuss a positive correlation between high regulation and CLSC in the context of the North American market. There are 2 academic papers that discuss a positive correlation between medium regulation and CLSC in the context of the North American market. There are 4 academic papers that discuss a positive correlation between low regulation and CLSC in the context of the North American market. Figure 29, below, shows the impact of regulations on the North American market.

FIGURE 29: REGULATORY IMPACT – NORTH AMERICAN MARKET



Similarly, the sample for multinationals is only nine, and hence any results drawn on the basis of the sample are insufficient. However, based on the existing sample, there are 3 academic papers that discuss a positive correlation between high regulation and CLSC in the context of multinationals and 6 academic papers that discuss a positive correlation between low regulation and CLSC in the same context. Figure 30, below, shows the impact of regulations on multinationals.

FIGURE 30: REGULATORY IMPACT - MULTINATIONALS



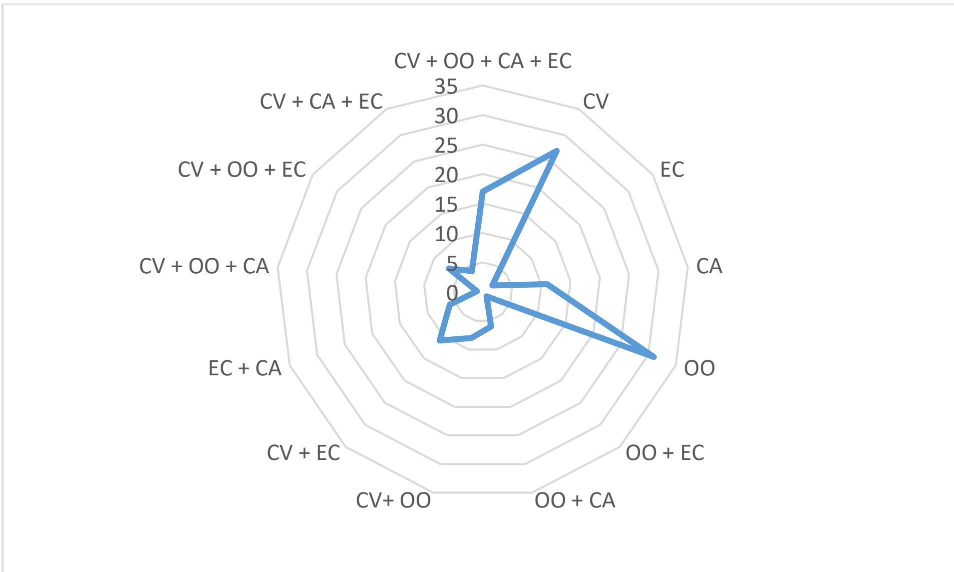
4.3 OBSERVED PATTERNS

This section will discuss the observed patterns across industries in relation to different product-recovery choices (remanufacturing, recycling, and hybrid) in the context of CLSC. First, patterns across industries will be discussed, and then the patterns across industries will be discussed in the context of different levels of take-back legislation.

4.3.1 PATTERNS ACROSS INDUSTRIES – STRATEGIC

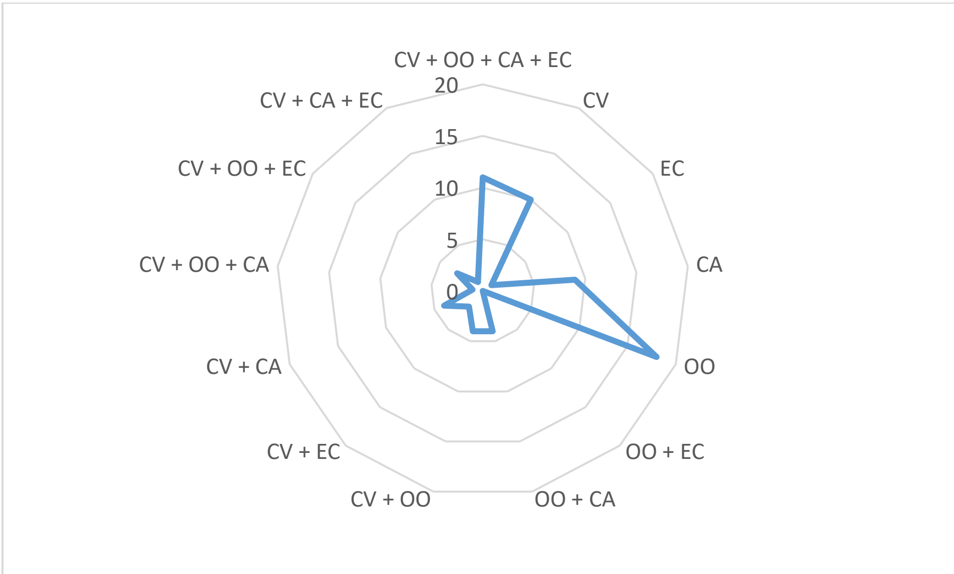
The first pattern reflects the overall impact of CLSC on companies that are involved in any form of product-recovery activity. A radar chart is used to identify patterns in the data, and the overall impact of CLSC is ranked on 14 different categories (OO, CV, EC, CA, OO+CA, CA+CV, CV+EC, OO+EC, OO+CV, CA+OA+EC, OO+CV+CA, OO+EC+CV, CA+CV+EC, OO+CV+CA+EC). This radar chart displays multivariate data in the form of a two-dimensional chart of 14 variables represented on axes starting from the same point. The pattern shows that companies consider OO to be the most favorable factor for adopting a CLSC system. The next factor that is most frequently identified for adopting a CLSC system is CV. The remaining 12 categories are relatively insignificant for companies in adopting a CLSC system. Figure 31, below, illustrates the patterns across industries to study overall CLSC business model.

FIGURE 31: PATTERNS ACROSS INDUSTRIES – CLSC BUSINESS MODEL



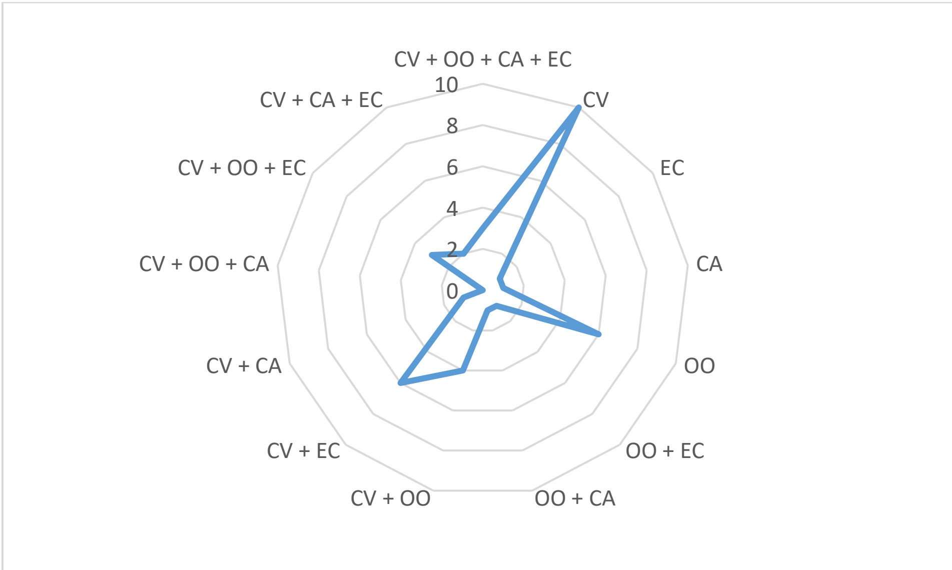
The second pattern reflects the impact of CLSC on companies that are involved only in remanufacturing activities. A radar chart is used to identify patterns in the data, and the overall impact of remanufacturing is ranked on 14 different categories. The pattern shows that companies consider OO to be the most favorable factor for remanufacturing. The remaining 13 categories are relatively insignificant for companies in pursuing remanufacturing activities. Figure 32, below, illustrates these patterns across industries.

FIGURE 32: PATTERNS ACROSS INDUSTRIES – REMANUFACTURING



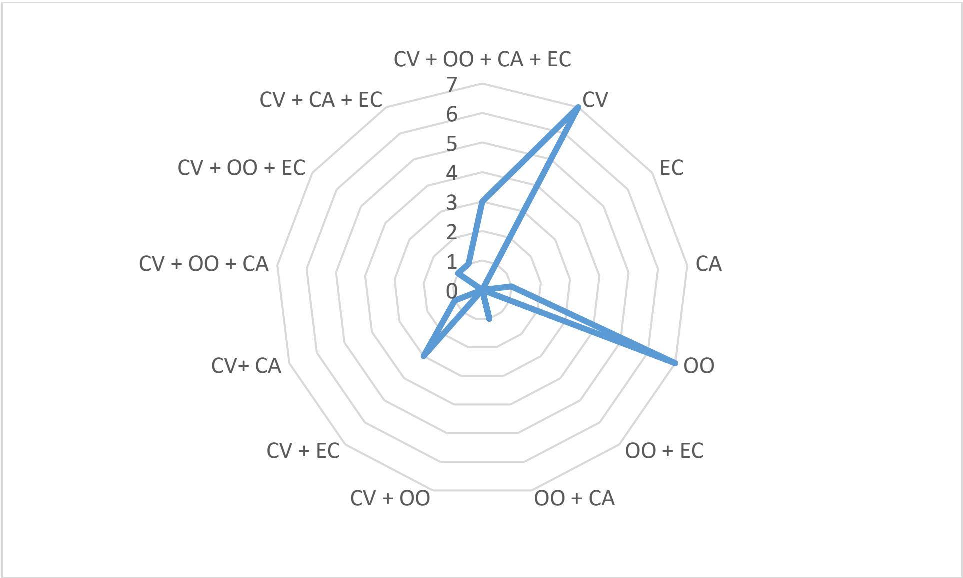
The third pattern reflects the impact of CLSC on companies that are engaged only in recycling activities. A radar chart is used to identify patterns in the data, and the overall impact of recycling is ranked on 14 different categories. The pattern shows that companies consider CV to be the most favorable factor for recycling. The next two factors that are the most frequently identified factors for adopting recycling are OO and CV+EC. The remaining 11 categories are relatively insignificant for companies in pursuing recycling activities. Figure 33, below, illustrates these patterns across industries.

FIGURE 33: PATTERNS ACROSS INDUSTRIES – RECYCLING



The fourth pattern reflects the impact of CLSC on companies that are involved in both remanufacturing and recycling activities simultaneously. The pattern shows that companies consider CV and OO to be the most favorable factors for adopting the hybrid model. The next two factors that are the most frequently identified factors for adopting hybrid model are CV+EC+OO+CA and CV+EC. The remaining 10 categories are relatively insignificant for companies in pursuing recycling activities. Figure 34, below, illustrates these patterns across industries.

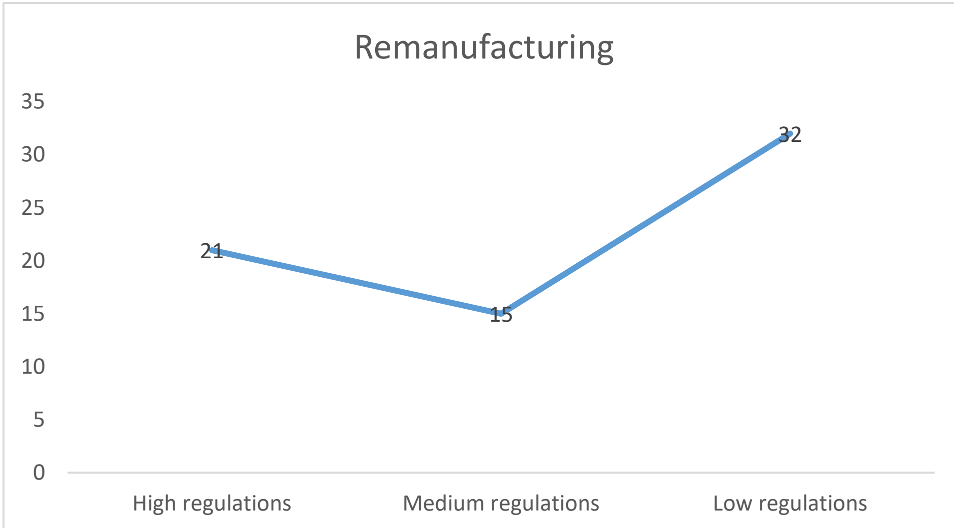
FIGURE 34: PATTERNS ACROSS INDUSTRIES – HYBRID MODEL



4.3.2 PATTERNS ACROSS INDUSTRIES – LEGISLATIVE

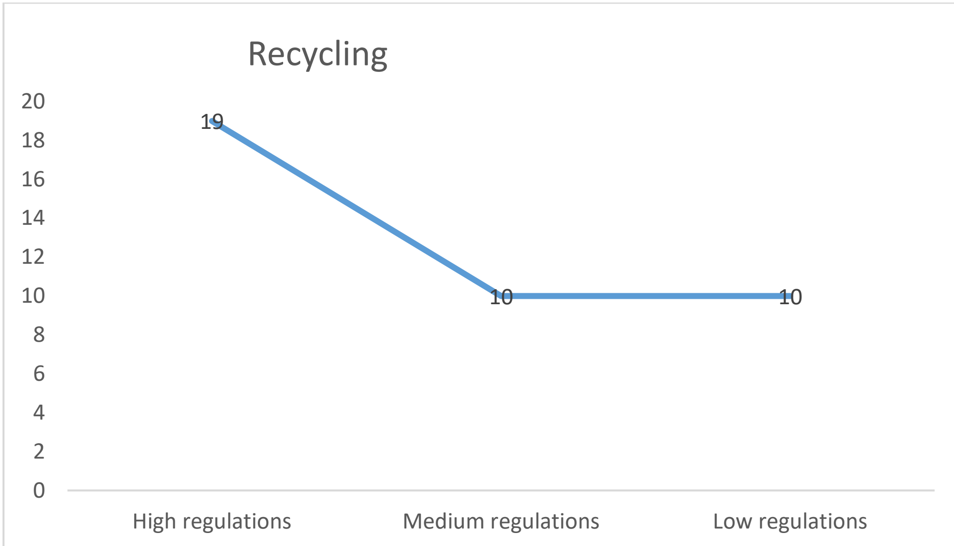
First, the patterns are observed to study the impact of legislative measures on remanufacturing activities. The results from the systematic review of the extant literature show that low regulations are relatively more feasible for remanufacturing activities when compared to high regulations and medium regulations. There are 32 academic papers that discuss remanufacturing under low regulation. There are 21 academic papers that discuss remanufacturing under high regulation, and there are 15 academic papers that discuss remanufacturing under medium regulation. Figure 35, below, illustrates the legislative impact on remanufacturing activities across industries.

FIGURE 35: LEGISLATIVE IMPACT ON REMANUFACTURING



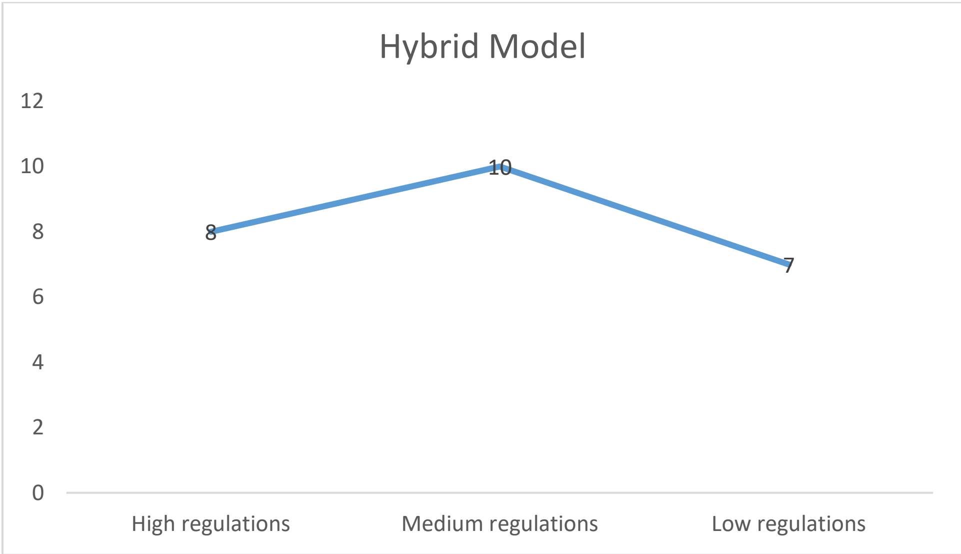
Second, the patterns are observed to study the impact of legislative measures on recycling activities. The results from the systematic review show that high regulations are relatively more feasible for recycling activities when compared to medium regulations and low regulations. There are 19 academic papers that discuss remanufacturing under high regulation, 10 that discuss remanufacturing under medium regulation, and 10 academic papers that discuss remanufacturing under low regulation. Figure 36, below, illustrates the legislative impact on recycling activities across industries.

FIGURE 36: LEGISLATIVE IMPACT ON RECYCLING



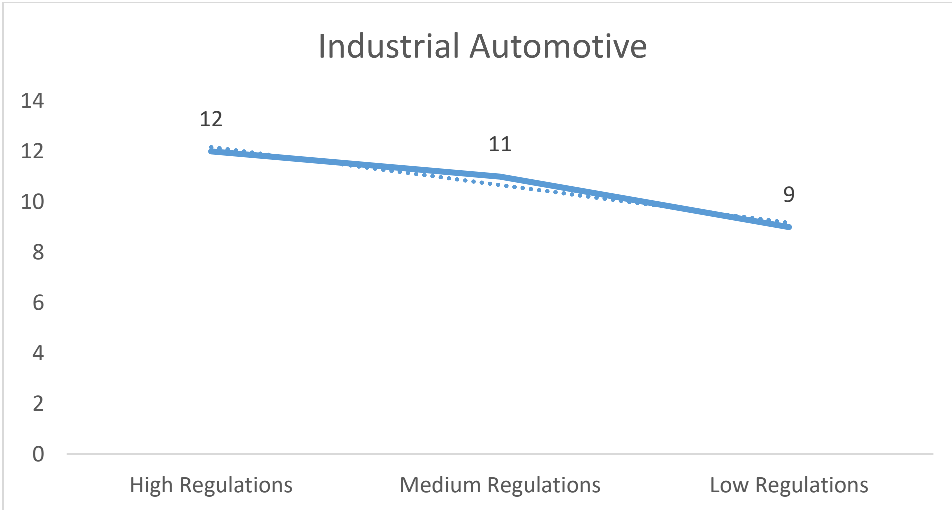
Third, the patterns are observed to study the impact of legislative measures on companies that are involved in remanufacturing and recycling activities simultaneously. The results from the systematic review show that companies in this case are relatively indifferent to the level of take-back regulation imposed. There are 8 academic papers that discuss remanufacturing under high regulation, 10 that discuss remanufacturing under medium regulation, and 7 that discuss remanufacturing under low regulation. Figure 37, below, illustrates the legislative impact on the hybrid model across industries.

FIGURE 37: LEGISLATIVE IMPACT ON THE HYBRID MODEL



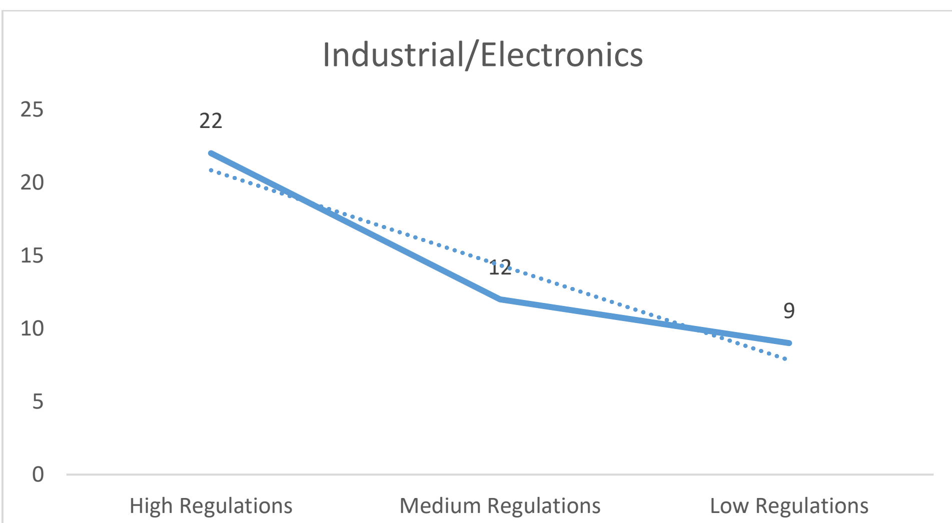
Next, the patterns are observed to study the impact of legislation on the aforementioned two most frequently studied industries, i.e., the automotive and electronics industries. The results from the systematic review of the extant literature show that the automotive sector is relatively indifferent to the level of regulation. Figure 38, below, shows the impact of regulations (high, medium, and low) on the automotive industry.

FIGURE 38: LEGISLATIVE IMPACT ON THE AUTOMOTIVE INDUSTRY



Also, the results from the systematic review show that the electronics industry is positively impacted by the level of regulation, i.e., the higher the take-back regulation, the more electronics companies are inclined to adopt a CLSC system. Figure 39, below, shows the impact of regulations on the electronics industry.

FIGURE 39: LEGISLATIVE IMPACT ON THE ELECTRONICS INDUSTRY



4.4 SUMMARY OF RESULTS

This chapter has provided results by conducting a systematic review of the extant literature on three different product-recovery choices based on the CLSC system. Through the systematic review, four strategic priorities involved in the decision-making process (remanufacturing, recycling, or hybrid) are highlighted. These four strategic priorities (OO, CV, CA, and EC) were created by a coding mechanism during the systematic review. These strategic priorities are mapped across 14 different sub-categories, including OO, CV, EC, CA, OO+CA, CA+CV, CV+EC, OO+EC, OO+CV, CA+OA+EC, OO+CV+CA, OO+EC+CV, CA+CV+EC, OO+CV+CA+EC. The role of each sub-category is conceptualised in achieving optimal results in relation to three product-recovery choices (remanufacturing, recycling, and hybrid). Moreover, the type of regulation is coded as an instrumental variable on a scale from low to high. Overall, some significant details are found from this review. The systematic review identifies patterns across industries in relation to three product-recovery choices. The systematic review has also provided insight on the impact of different levels of regulation on three product-recovery choices.

The next chapter discusses in more depth the patterns across industries, and builds a more informed analysis from the initial interpretation of the results extracted from the systematic review of the extant literature.

5 DISCUSSION

5.1 ANALYSIS THROUGH CONCEPTUAL FRAMEWORK

To initiate a discussion of the findings of the systematic review of the literature, the conceptual framework is first reintroduced. As discussed in Section 2.5.2, the conceptual framework is based on the principles of the CLSC system, in which the forward-loop supply chain is complemented by the reverse supply chain system. The conceptual framework identifies three choices in pursuing the CLSC system. First, companies can adopt the 100% remanufacturing option. In this case, the OEM collects the end-of-life products and remanufactures the returned products. Second, companies can adopt the 100% recycling option, in which the end-of-life products or components are sold in the secondary market for recycling purposes. Third, companies can adopt a hybrid model that is a combination of both remanufacturing and recycling activities. A systematic review of 132 academic papers published between 2000 and 2017 was conducted to identify the various factors involved in the decision-making process (remanufacturing, recycling, and hybrid). Subsequently, the patterns across industries were explored with respect to the three product-recovery choices. Additionally, the impact of take-back legislation across industries, and across geographical locations, was established.

5.2 ANALYSIS OF KEY VARIABLES ASSOCIATED WITH CLSC

The three product-recovery choices (remanufacturing, recycling, and hybrid) were explored through four strategic priorities (OO, CV, CA, and EC), three levels of legislative measures (high, medium, and low), and different geographical locations (Europe, Asia, North America, and multinational). Each of the four strategic priorities was coded based on certain characteristics observed in the systematic review. OO is coded based on three common characteristics (material recovery planning, dismantling process, and design efforts). CV is coded based on four common characteristics (cost of product recovery, return on investment, quality of returned products, and landfill/disposal cost). EC is coded based on two common characteristics (energy consumption, and energy usage). CA is coded based on two common characteristics (return attitude, and perceived risks and benefits). These four strategic priorities (OO, CV, EC, and CA) are then mapped across 14 different sub-categories as detailed above. The three levels of legislative measures (high, medium, and low) are coded against country of origin (country of manufacture, production, or growth). High regulations are categorised in which the country of origin fully implements the take-back legislation. Medium regulations are categorised in which the country of origin partially implements the take-back legislation. Low regulations are categorised in which the country of origin does not institute take-back legislation. Additionally, different geographical locations (Europe, Asia, North America, and multinational) are constituted based on the information collected from the systematic review of the extant literature.

The identified patterns across industries with respect to four strategic priorities mapped across 14 sub-categories brings valuable insight to understanding different product-recovery choices. Without segregating the data into three product-recovery choices, a cumulative analysis of CLSC shows that OO is the most frequent factor for companies that are interested in pursuing reverse logistics in their business model. However, there is a substantial amount of information that states that CV also plays a significant role in pursuing a CLSC model. Hence, the two factors (OO and CV) co-exist closely in the context of CLSC, and both are the most frequently identified factors when a cumulative study on CLSC is performed.

The patterns across industries with respect to remanufacturing show that OO is the most frequently identified factor in pursuing remanufacturing. It is implied from the systematic review that three characteristics (material recovery planning, dismantling process, and design efforts) pertaining to OO need to be aligned for the transition to the remanufacturing process. First, companies need to develop a material recovery planning mechanism that should predict the number of returned products within facilities. This research supports earlier findings regarding the material recovery planning mechanism in conjunction with the remanufacturing model, and suggests that in order to make a product designed for remanufacturing really work, obsolete products need to be consistently returned to the OEM to be remanufactured (Hazen et al., 2016; Hollander et al., 2017). Second, companies need to focus on the dismantling technology that allows them to effectively inspect and test the returned products. This is consistent with past research that emphasizes defining a key metric that can assess the ease of disassembly without destroying the components for the purpose of remanufacturing (Matsumoto et al., 2016; Kalverkamp & Raabe, 2017; Vanegas et al., 2018). Third, companies need to focus on eco-friendly design efforts such that they are able to internalize remanufacturing as part of their regular business operations; this would accompany recent findings on the matter (Kurilova-Palisaitiene & Poksinska, 2018; Lieder & Rashid, 2016). However, there also is an ample amount of evidence through the systematic review of the literature that OO+CV+EC+CA is positively associated with the remanufacturing activity.

The patterns across industries with respect to recycling show that CV is the most frequently identified factor in pursuing the activity. It is implied from the systematic review that four characteristics (cost of product recovery, return on investment, landfill/disposal cost, and quality of returned products) pertaining to CV need to be aligned for the transition to the recycling process. First, the cost of product recovery helps companies to design products that can reclaim maximum value from returned parts. Subsequently, the components are sold in the secondary market with greater profit margins. Incorporating such costs indicates that the effectiveness of recycling would depend on the cost of processing, and significant resources must be devoted when deciding if recycling is financially viable. This has been detailed in the literature (George et al., 2015; Pringle et al., 2016). Second, the resale price needs to be established in such a way that the marginal value of the recycled product is greater than the bid price or buyer's willingness to pay, which is consistent with previous research (Ghisellini et al., 2016; Virtanen et al., 2017). Third, the returned products are able to retain a value that is greater than the disposal or landfill cost. The value retention of recycled products can be achieved by increasing the disposal or landfill cost, and Sultan et al. (2017) have also suggested that legislation on disposal of composites to landfill could also encourage greater recycling. Forth, the quality of the returned products is restored at a reasonable level, such that recycling the parts or components provides a higher margin than dismantling the cores. As Ghisellini et al. (2016) have earlier suggested, if the quality of the product is such that it cannot be recycled, then the industry should not produce such a product and consumers should not buy it. The systematic review of the literature also shows that CV+EC are also frequently identified factors in pursuing the recycling activity. Likewise, OO is also positively associated with recycling.

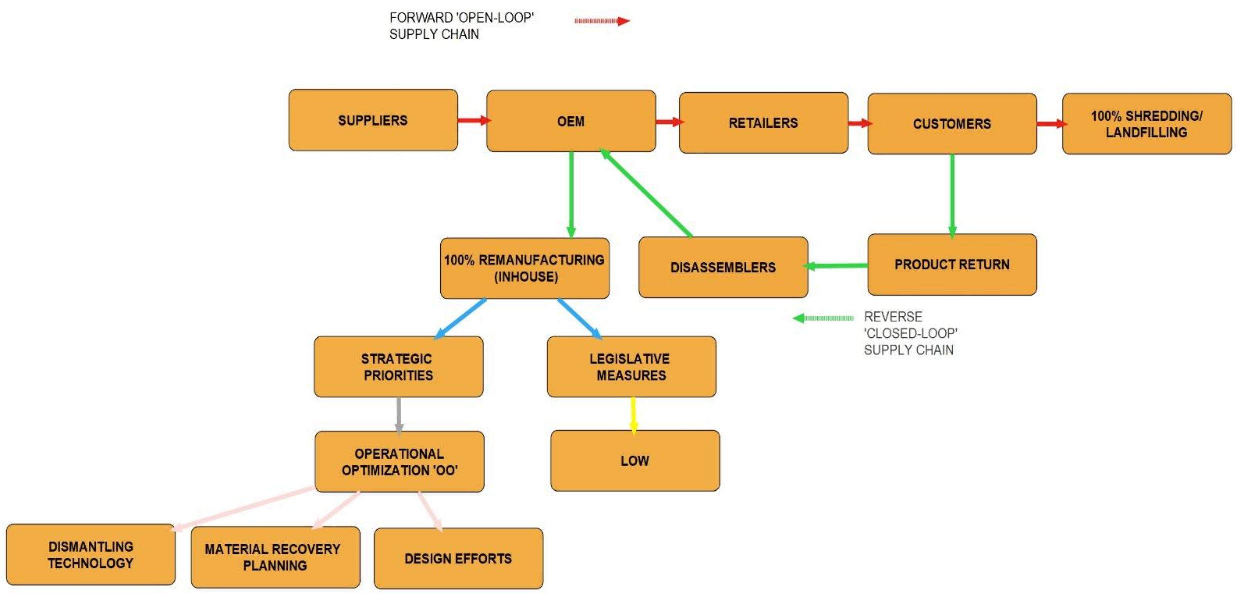
The patterns across industries with respect to the hybrid model shows that both OO and CV are the most frequently identified factors. Since the hybrid model negates the 100% remanufacturing or 100% recycling principle, it is more feasible for companies to focus proportionally on OO and CV. It is implied from the findings of the systematic review that the hybrid model is more feasible for companies that are manufacturing a diverse product range. In such cases, only a few products are disassembled and cycled back into the production cycle for remanufacturing. The remaining products or parts that are not effectively returned to the production cycle are sold in the secondary market. Also, the systematic review of the literature depicts a relatively strong association between CV+ EC and the hybrid model.

The impact of take-back legislation with respect to the three product-recovery choices also provides an interesting insight. The systematic review shows that the remanufacturing activity is strongly associated with a low level of take-back legislation. It can be implied from the findings that internalizing remanufacturing operations requires a huge investment by companies. Any form of take-back legislation brings a negative impact on the efforts to internalize remanufacturing process. Hence, the high level of take-back legislation puts an economic burden on companies, and these companies resist investing in the remanufacturing model. As Atasu and Wassenhove (2011) have remarked, although producers generate one unit of waste, they may have to pay twice for the product take-back cost through waste regulation laws (i.e., selling a product once as new and once as remanufactured may double the product take-back costs these producers incur).

The low level of take-back legislation provides incentives to companies adopting an in-house remanufacturing model. The systematic review of the extant literature shows that the recycling activity is strongly associated with a high level of take-back legislation. It can be implied from the findings that a lot of effort is required to resell parts or components in the secondary market. Companies often assume that the disposal cost or landfill cost is low compared to the efforts required to resell the parts in the secondary market. However, a high level of take-back legislation makes the disposal or landfill cost relatively more expensive. Subsequently, companies become more motivated to restore the value of the returned parts and sell the used parts in the secondary market. Legal requirements such as the WEEE Directive focus on how each product needs to be recycled at the end of its useful life, as detailed in the literature (Neto et al., 2010).

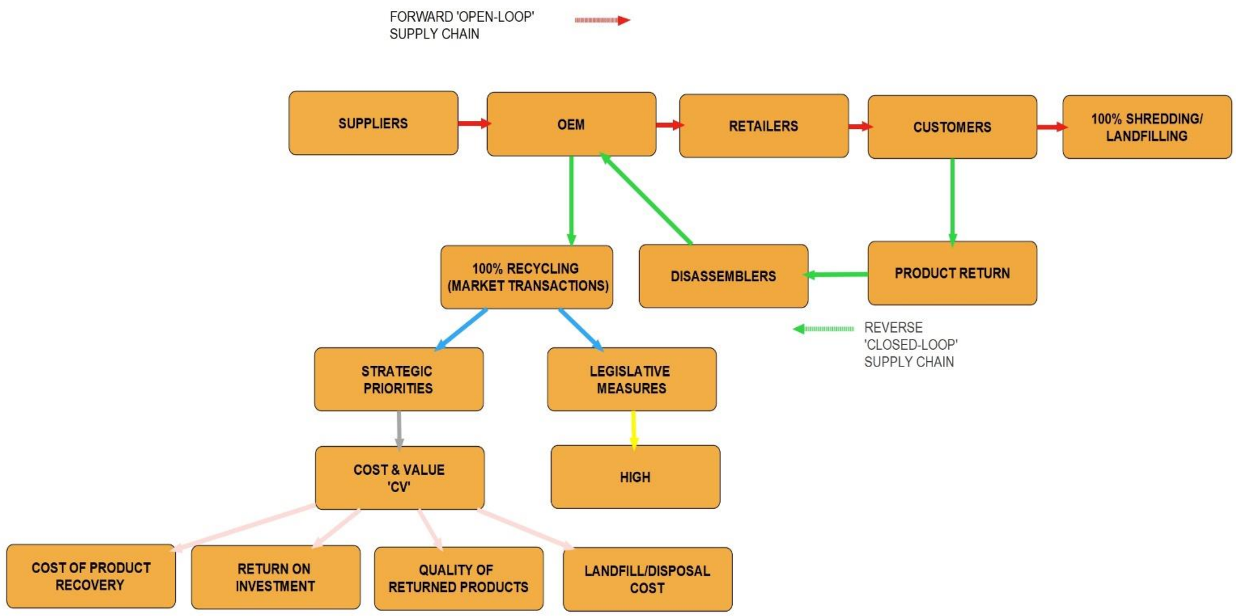
Overall, of the four strategic priorities, OO is considered relatively more feasible for the remanufacturing activity. The other three strategic priorities (CV, EC, and CA) are relatively lower in hierarchy for remanufacturing. Also, it is found from the systematic review that a low level of regulation is considered more reasonable for remanufacturing. Figure 40, below, illustrates the impact of key factors with respect to remanufacturing.

FIGURE 40: IMPACT OF KEY FACTORS ON REMANUFACTURING



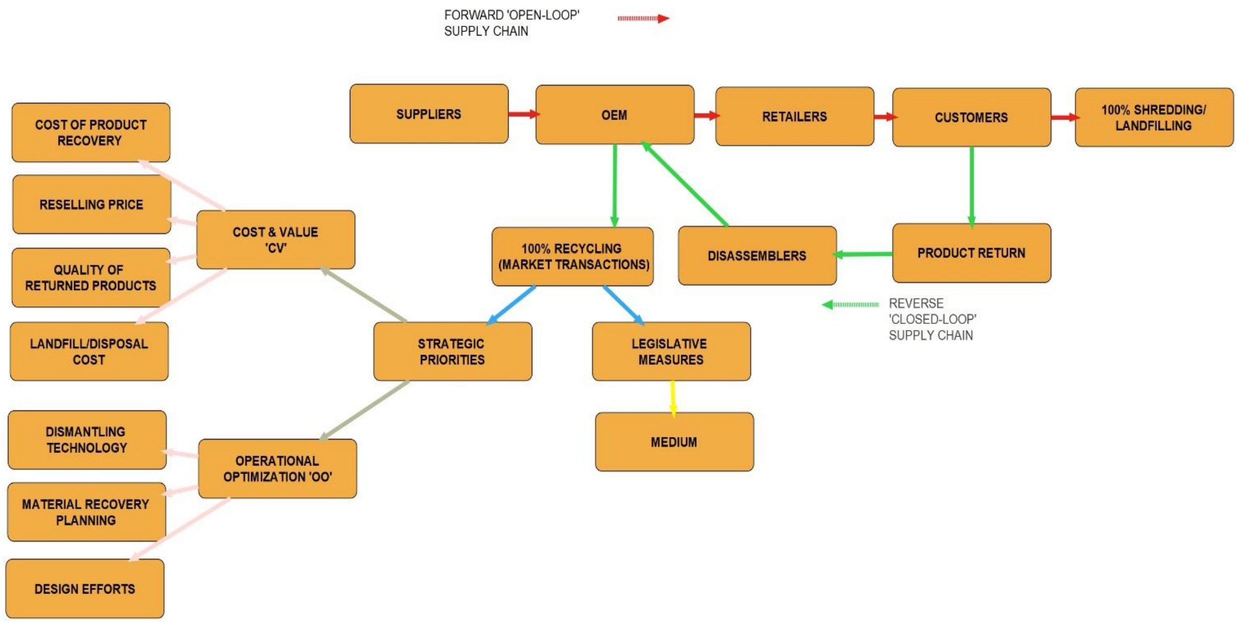
Overall, of the four strategic priorities, CV is considered relatively more feasible for the recycling activity. The other three strategic priorities (OO, EC, and CA) are relatively lower in hierarchy for recycling. Also, it is found from the systematic review that a high level of regulation is considered more reasonable for recycling. Figure 41, below, illustrates the impact of key factors with respect to recycling.

FIGURE 41: IMPACT OF KEY FACTORS ON RECYCLING



Overall, of the four strategic priorities, both OO and CV are equally considered feasible for the hybrid model. The other two strategic priorities (EC and CA) are relatively lower in hierarchy for the hybrid model. Also, it is found from the systematic review that a medium level of regulation is considered more reasonable for the hybrid model. Figure 42, below, illustrates the impact of key factors with respect to the hybrid model through the systematic review of the extant literature.

FIGURE 42: IMPACT OF KEY FACTORS ON THE HYBRID MODEL



The impact of take-back regulations across industries is also considered through the systematic review of the extant literature. The results show that the electronics industry is positively associated with take-back legislation, i.e., the higher the level of take-back regulation, the more electronics companies are inclined towards pursuing a CLSC model. The increase in the magnitude and growth of take-back legislation over the last decade could be the reason that electronics companies have started to adopt CLSC systems. However, the systematic review does not show a definite relationship between the automotive industry and the level of regulation. It may be inferred that the full and effective implementation of take-back legislation in the context of the automotive sector is still lacking, and needs further attention by policymakers.

Additionally, the impact of take-back regulations across geographical locations provides a valuable insight about different markets. The systematic review of the literature shows that the European Market is highly regulated across all industrial sectors. This is consistent with past research, as Sthiannopkao and Wong (2013) have described the European Union as a leader in formulating and implementing e-waste regulation. However, the systematic review of the literature indicates that the Asian market is relatively less regulated across all industrial sectors. This may be because certain societal, political, and economic issues exist in many Asian countries that are major hindrances towards an effective implementation of a take-back policy. As Zhang et al. (2011) have commented, the OEMs in China have little enthusiasm to participate in the remanufacturing industry because of a lack of effective economic policies, tax policies, and extended-producer-responsibility regulation. The samples of the North American market and multinationals were not sufficient, and hence, the impact of take-back regulations on these two markets could not be ascertained through the systematic review of the extant literature.

The next section will discuss the utility of TCE in remanufacturing versus recycling decision-making in the context of CLSC.

5.3 REMANUFACTURING VERSUS RECYCLING DECISION-MAKING THROUGH THE LENS OF TCE

The theoretical lens of TCE provides an operational landscape in which to weigh the benefits of internal production against those of outsourcing. As discussed in section 2.4.2, three transaction attributes (asset specificity, uncertainty, and frequency of transactions) of TCE are considered significant to analyze the make-or-buy decision, and these attributes have the capacity to be interpreted in various other fields and applications. Hence, the basic inquiry of TCE with respect to whether a transaction is more efficiently performed within a firm (internal) or outside (market) can be extended to remanufacturing (in-house) or recycling (secondary market).

Of the three transaction attributes of TCE, asset specificity is based on the core competencies of the organization, and it is considered relevant to the scope of this research. The other two transaction attributes (i.e., uncertainty and frequency of transactions) are considered to have non-material impact on product-recovery choices, and hence, these attributes are considered to be outside of the scope of this paper. Under asset specificity, high asset specificity is positively associated with the core competency of the organization, and hence, companies with high asset specificity are inclined towards the in-house production model. Of the four strategic priorities (OO, CV, EC, CA), OO is coded on three key characteristics, of which design efforts (one of the three characteristics) are made to enhance the core competency of the organization. Subsequently, the products made are highly asset specific because of the design solution, and these products are generally difficult to replicate by competitors. For example, Apple's core competency is its design solution. Apple's design solution is highly asset specific, and hence its products are difficult to replicate by competitors. Design efforts enhance the asset specificity of the product, and ultimately improve the OO. Hence, a positive association between high asset specificity and OO is developed through this analysis. Companies that improve their OO become highly asset specific, and it is more feasible for them to engage in remanufacturing activities, as has been detailed in the literature (Martin et al., 2010; Mcnally & Griffin, 2004). This is in agreement with the findings of the systematic review, which suggest that OO is considered relatively more feasible for the remanufacturing activity.

Low asset specificity is negatively associated with the core competency of the organization, and hence, companies with low asset specificity are inclined towards the outsourcing model. Similarly, the theoretical lens of TCE suggests that the products with low asset specificity are easy to replicate. Since little information is needed to exchange low-specificity products with the transaction partner, such products are in higher demand in the secondary market. Additionally, economies of scale can be exploited by trading low-specificity products in the secondary market. Of the four strategic priorities (OO, CV, EC, CA), CV is coded on four characteristics, of which return on investment (one of the four characteristics) is primarily focused on ‘rate of return’ versus ‘demand rate.’ Hence, the return on investment is positively associated with the demand for the product in the market. Since products with low asset specificity have higher demand in the secondary market, there is a positive association developed between low asset specificity and CV. Hence, companies that are concerned about their CV are generally more focussed on low-specificity products. Subsequently, it is more feasible for such companies to engage in recycling activities, as has been detailed in the literature (Martin et al., 2010; McNally & Griffin, 2004). This is in agreement with the findings of the systematic review, which suggest that CV is considered relatively more feasible for the recycling activity.

5.4 FINAL OBSERVATIONS

A CLSC system is an effective way to reduce the amount of waste transferring to landfill through remanufacturing and recycling activities. However, companies need to consider a number of key factors in transitioning to a CLSC system. For example, an investment that supersedes the marginal benefits of a CLSC system brings diminishing returns to the business; hence, the CV of CLSC is a critical factor in deciding different product-recovery choices. Similarly, if the cost of implementing CLSC is relatively higher than the existing forward-loop system, OO is a necessary factor to bring down the overall implementation cost of CLSC. This paper discusses three choices only, i.e., 100% remanufacturing, 100% recycling, and the hybrid model. One of the limitations of this paper is that it does not discuss the appropriate weightages with respect to remanufacturing and recycling in the context of the hybrid model. Companies can make better decisions if appropriate weightages are known with respect to remanufacturing and recycling in the context of the hybrid model. Also, governments need to implement take-back legislation in the context of the given market situation. For example, what incentives are beneficial when investing in a CLSC system, and what barriers are required to counter low disposal or landfill costs?

6 CONCLUSION

6.1 INTRODUCTION

The general purpose of this thesis was to better understand what patterns across industries exist for companies with respect to different product-recovery choices. By understanding these patterns across industries, companies can better prepare themselves to generate optimal rates of remanufacturing and/or recycling. Companies can further curb the inefficient flow of single-use products to landfill by leveraging the patterns identified through this systematic review of the literature. The results from the systematic review show that companies consider a number of strategic priorities (OO, CV, EC, and CA) in order to achieve better results from different product-recovery choices. Besides these four strategic priorities, there is a significant impact of take-back legislation on product-recovery choices, and also the level of take-back legislation is varied for different geographical locations. While EC and CA may reduce the inefficient flow of single-use products to landfill, the results of this paper show how optimization in production operation (i.e., OO) and forming a more economically viable CLSC system (i.e., CV) can positively impact sustainable production practices, as has also been detailed in the literature (Brandenburg et al., 2014; Genovese et al., 2017; Tseng et al., 2015). Further, this study gives unique insight into how companies are constrained by different levels of regulation in selecting whether to choose in-house remanufacturing, to recycle through the secondary market, or to adopt a hybrid model. Additionally, this paper used the theoretical lens of TCE to weigh the benefits of remanufacturing and recycling activities from the perspective of companies. This paper attempts to expand the basic inquiry of TCE (whether a transaction is more efficiently performed within a firm or outside) to remanufacturing (in-house) and recycling (secondary market).

Overall, this paper implies that all relevant intra- and inter-organizational production processes must be channelled to improve the effectiveness and efficiency of CLSC systems. This is an area for further examination as suggested in other studies (Kuik et al., 2011). The creation of a win-win situation through a CLSC system assures increased competitiveness and profitability for every stakeholder.

6.2 CONTRIBUTIONS OF THE RESEARCH

One of the most significant contributions of this paper was the identification of how intra- and inter-company information and material processes can be coordinated to improve the overall effectiveness and efficiency of a CLSC system. In the context of this paper, intra-company production practices relate to various remanufacturing activities, which allow for utilization of used products in the existing manufacturing system of the OEM. Similarly, inter-company production practices relate to various recycling activities via which waste generated by one company can be used as a valuable resource by another company through the recycling process. Additionally, this paper discusses a hybrid model, in which inter-company and intra-company sustainable practices are combined based on product specificity. The impact of key factors (strategic, legislative, and geographical) on three different product-recovery choices (remanufacturing, recycling, and hybrid) brings a better insight on both intra- and inter-company production practices in the context of a CLSC system.

In terms of its academic contribution, this thesis aims to promote knowledge about CE and CLSC systems based on three different product-recovery choices (remanufacturing, recycling, and hybrid). This research is relevant because there are still a limited number of companies that have adopted a CLSC system, and a majority of companies are inclined towards forward or open-loop supply systems, which generate waste. By enhancing the knowledge around CLSC systems, it is desired that companies will feel encouraged to implement the most-efficient product-recovery system in their production system. This thesis helps to identify various patterns across various industries, and across different geographical locations, in the context of three different product-recovery choices; hence, it provides a better overall understanding of CLSC.

With respect to the study of CLSC systems, the major contribution of this paper is that it closes the literature gap in empirical studies from the companies' perspective. The existing literature on CLSC is focused on either explaining cases of choosing a specific product-recovery option or choosing between different product-recovery options at a given point in time. Most studies, including Matsumoto and Umeda (2011), Agrawal et al. (2016), and Barkmeyer et al. (2017), to name a few, have focused on individual analyses, but have not looked at the patterns from the companies' perspective. This study broadens the literature by exploring different patterns across industries, and across geographical locations that can help to identify the criteria with which to evaluate what factors are crucial in adopting each product-recovery option.

6.3 CONTRIBUTIONS TO PRACTICE

There are two managerial insights that can be drawn out by analyzing various key factors in relation to implementing a CLSC system.

Insight 1: When the overall implementation cost of a CLSC system is equal to or greater than the cost of a forward-loop supply system, reducing the implementation cost of the CLSC system increases the capacity of companies to either remanufacture or/and recycle the existing products. Reducing the implementation cost of the CLSC system does not increase the cost of the forward-loop supply system, but could generate some other benefits through an efficient product-recovery system, such as lower inventory cost of returned products relative to landfill/disposal cost.

Insight 2: When the overall implementation cost of a CLSC system is less than the cost of a forward-loop supply system, further reducing the implementation cost of a CLSC system, such as by investing in a recovery-planning system (i.e., OO) or increasing the quality of returned products (i.e., CV), may lead to a higher re-sale price that is not desirable for company performance and societal needs.

Hence, it is very critical that companies precisely identify the implementation cost of the CLSC system with respect to their product requirements, and this is consistent with past research (Ghisellini et al., 2016). Optimally identifying the implementation cost of CLSC will help companies to compare the cost of the CLSC system with their existing production system (i.e., forward-loop supply system).

6.4 LIMITATIONS

While the best effort has been made to ensure that the most accurate results are presented, there are still some limitations in this research.

One major limitation is the availability of data. As explained in Section 3.2.7, the inclusion and exclusion criteria used in the systematic literature review does not assure that all relevant case studies pertaining to remanufacturing and recycling decisions are included and synthesized. Despite the fact that the most relevant data is used through the systematic review, for data imputation, the results are still based on a few probable factors. It is not a true display of the reality, but rather it is the closest presentation. Moreover, for this paper, the replicability of the results can be challenged, since some researchers may interpret the results of the systematic review differently.

Although CLSC is a good indicator of how much product recovery a company is doing, it is valuable to understand the most accurate percentage of remanufacturing and/or recycling. For this paper, the product-recovery choices are considered as a categorical variable (all remanufacturing, all recycling, or hybrid). In reality, the product-recovery choices are captured in a spectrum, i.e., a range of percentages rather than an absolute choice (i.e., 100% remanufacturing, or 100% recycling, or hybrid). This range of percentages in product-recovery choices is likely to have some influence on the outcome of the study, though the influence is expected to be minimal.

The last limitation is the implication of the study. This research primarily explores the patterns in relation to remanufacturing and/or recycling across the electronics and automotive sectors, but may not be directly applicable to other markets. Moreover, take-back legislation is a unique regulatory system that has varied monitoring criteria for different countries. For example, the European market enforces stringent take-back criteria for most of its consumer products. This regulatory structure is very different from those in other regions.

6.5 RECOMMENDATIONS FOR FUTURE RESEARCH

This thesis organized the body of knowledge about CE and CLSC by conceptualizing patterns across industries with respect to three different product-recovery choices and their elements, contributing toward sustainable production system and expanding the theoretical knowledge about the theme. The diverse and critical elements of this study are consolidated and organized, enabling a better understanding of patterns across industries in relation to different product-recovery choices. This facilitates the work of future studies as well as of companies that are restructuring their remanufacturing or/and recycling operations, or at least intend to start them.

Future studies on the topic of different product-recovery choices can be pursued in various ways. As mentioned in the last section, one of the limitations of this study is the lack of data. It would be interesting to study the patterns again when more relevant CLSC data is available. In addition, finding significant outcomes with respect to other industries not covered in this paper will produce even more convincing results. Doing a study of other industries may be useful in finding out whether various factors (strategic, legislative, and geographical) identified in the context of CLSC are also applicable to other markets. Lastly, another opportunity for future research is to revisit take-back legislation analysis for underutilized markets where product recovery is not happening. Currently, there is no study that attempts to value the presence of take-back legislation in underutilized markets. If the WEEE Directive is proven to be the driving force of CLSC activities in Europe's electronics market, then adapting a perfected WEEE model across underutilized markets can quickly solve the problem of waste going to landfill.

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APPENDIX A

LIST OF PAPERS USED FOR THE SYSTEMATIC REVIEW

	Year	Journal	Strategic Priorities	Sub-factors
Westkamper	2003	Institute of Industrial Manufacturing and Management	OO	Material recovery planning, dismantling process, design efforts
Hatcher et al.	2014	Journal of Cleaner Production	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Subulan et al.	2012	Journal of Intelligent & Fuzzy Systems	OO	Material recovery planning, dismantling process, design efforts
Govindan et al.	2012	International Journal of Production Economics	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Leigh & Li	2014	Journal of Cleaner Production	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Diener & Tillman	2015	Resources, Conservation and Recycling	OO	Material recovery planning, dismantling process, design efforts
Clottey et al.	2012	Decision Sciences	CA	Return benefits, perceived risks and benefits
Jim enez-Parra et al.	2014	Journal of Cleaner Production	CA	Return benefits, perceived risks and benefits

Jayant et al.	2014	Procedia	OO	Material recovery planning, dismantling process, design efforts
Liu et al.	2017	Journal of Cleaner Production	EC	Energy consumption, energy usage
Reigado et al.	2017	Procedia	OO	Material recovery planning, dismantling process, design efforts
Barkmeyer et al.	2017	Procedia	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Miao et al.	2017	Waste Management & Research	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Veleva et al.	2017	Journal of Cleaner Production	CA	Return benefits, perceived risks and benefits
Aras et al.	2003	ITE Transactions	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Sasikumar & Kannan	2008	International Journal of Sustainable Engineering	OO	Material recovery planning, dismantling process, design efforts
Chung & Wee	2010	International Journal of Computer Integrated Manufacturing	OO	Material recovery planning, dismantling process, design efforts

Subulan & Tasan	2013	International Journal of Advanced Manufacturing Technology	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Atasu et al.	2008	Institute for Operations Research and the Management Sciences	CA	Return benefits, perceived risks and benefits
Guide et al.	2000	Institute for Operations Research and the Management Sciences	OO	Material recovery planning, dismantling process, design efforts
Jayaraman & Luo	2007	Academy of Management	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Bayindir et al.	2005	The Journal of the Operational Research Society	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Dowlatshahi	2000	Institute for Operations Research and the Management Sciences	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
DeCroix	2005	The Journal of the Operational Research Society	OO	Material recovery planning, dismantling process, design efforts
Chen & Chang	2012	The Journal of the Operational Research Society	CV+CA	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Return benefits,

				perceived risks and benefits
Lee & Shih	2012	The Journal of the Operational Research Society	CV+OO+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Material recovery planning, dismantling process, design efforts + Energy consumption, energy usage
Aidonis et al.	2013	The Journal of the Operational Research Society	CV+OO+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Material recovery planning, dismantling process, design efforts + Energy consumption, energy usage
Guide et al.	2009	Institute for Operations Research and the Management Sciences	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Noman & Amin	2017	Journal of Remanufacturing	CA	Return benefits, perceived risks and benefits

Karvonen et al.	2017	Journal of Remanufacturing	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits
Anthony & Cheung	2017	Journal of Remanufacturing	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Mukherjee et al.	2017	Journal of Remanufacturing	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits
Vogtlander et al.	2017	Journal of Remanufacturing	CA	Return benefits, perceived risks and benefits
Priyono	2017	Journal of Industrial Engineering and Management	OO	Material recovery planning, dismantling process, design efforts

Chen et al.	2014	International Journal of Logistics Management	CV+OO	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Material recovery planning, dismantling process, design efforts
Xu & Yeh	2016	Annals of Operations Research	CV+OO	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Material recovery planning, dismantling process, design efforts
Tepprasit & Paopan	2016	International Journal of Business and Information	OO	Material recovery planning, dismantling process, design efforts
Peniciuc et al.	2016	Artificial Intelligence for Engineering Design, Analysis and Manufacturing	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Xin	2016	Grey Systems: Theory and Application	CV+OO+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Material recovery planning, dismantling process, design efforts + Energy consumption, energy usage

Hameed et al.	2016	Technical Journal, UET Pakistan	CV+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, Energy usage
O'Reilly & Kumar	2015	International Journal of Logistics Management	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits
Agrawal et al.	2015	Competitiveness Review	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Choi & Hwang	2015	Operations Management Resource	CV+OO	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Material recovery planning, dismantling process, design efforts
Priyono et al.	2015	Journal of Remanufacturing	OO	Material recovery planning, dismantling process, design efforts

Capraz et al.	2015	Flexible Services and Manufacturing Journal	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Luminita & Vasile	2015	Applied Mathematics and Materials	OO	Material recovery planning, dismantling process, design efforts
Xie & Breen	2014	Supply Chain Management	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits
Migliano et al.	2014	Journal of Operations and Supply Chain Management	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Neto et al.	2014	not available	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Romani & Zhang	2013	Clean Technologies and Environmental Policy	CV	Cost of product recovery, return on investment, quality of returned products,

				landfill/disposal cost
Wang & Chan	2013	Journal of Remanufacturing	OO	Material recovery planning, dismantling process, design efforts
Gupta et al.	2013	Journal of Operations Management	CV+OO+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Material recovery planning, dismantling process, design efforts + Energy consumption, energy usage
Cojocariu	2013	Revista de Management Comparat International	CV+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, Energy usage
Schau et al.	2012	Journal of Remanufacturing	CV+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, Energy usage
Stagner et al.	2012	Journal of Polymers and the Environment	OO	Material recovery planning, dismantling process, design efforts
Wang et al.	2012	Applied Mechanics and Materials	OO	Material recovery planning,

				dismantling process, design efforts
Salhofer et al.	2012	Waste and Resource Management	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Quariguasi-Frota-Neto & Bloemhof	2012	Production and Operations Management	CV+OO+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Material recovery planning, dismantling process, design efforts + Energy consumption, energy usage
Freiberger et al.	2011	Journal of Remanufacturing	OO	Material recovery planning, dismantling process, design efforts
Mitsutaka & Yasushi	2011	Journal of Remanufacturing	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits
Hernández et al.	2011	Group Decision and Negotiation	OO	Material recovery planning,

				dismantling process, design efforts
Kapetanopoulou & Tagaras	2010	International Journal of Operations & Production Management	CV+CA+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Return benefits, perceived risks and benefits + Energy consumption, energy usage
Yang et al.	2011	Contemporary Logistics	OO	Material recovery planning, dismantling process, design efforts
Abraham	2011	Journal of Fashion Marketing and Management	CV+CA	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Return benefits, perceived risks and benefits
Bernon et al.	2010	International Journal of Physical Distribution & Logistics Management	OO	Material recovery planning, dismantling process, design efforts
Grant & Banomyong	2009	Asia Pacific Journal of Marketing and Logistics	OO	Material recovery planning, dismantling process, design efforts
Krikke	2010	The International Journal of Life Cycle Assessment	CV+CA+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Return benefits,

				perceived risks and benefits + Energy consumption, energy usage
King & Gu	2010	Waste and Resource Management	CV+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, Energy usage
Ordoobadi	2009	Management Research News	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Defee et al.	2009	Supply Chain Management	CV+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, Energy usage
Li & Olorunniwo	2009	Supply Chain Management	CV+OO	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Material recovery planning, dismantling process, design efforts
Srivastava	2009	International Journal of Physical Distribution & Logistics Management	CV	Cost of product recovery, return on investment, quality of returned products,

				landfill/disposal cost
Hanafi et al.	2008	International Journal of Logistics Management	CV+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, Energy usage
Wikner & Tang	2008	International Journal of Logistics Management	OO	Material recovery planning, dismantling process, design efforts
Wikner & Tang	2008	International Journal of Logistics Management	OO	Material recovery planning, dismantling process, design efforts
Georgiadis et al.	2006	Production and Operations Management	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Seitz & Wells	2006	Business Process Management Journal	CV+OO	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Material recovery planning, dismantling process, design efforts
Tan & Kumar	2006	International Journal of Logistics Management	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost

Srivastava & Srivastava	2006	International Journal of Physical Distribution & Logistics Management	OO	Material recovery planning, dismantling process, design efforts
King & Burgess	2005	Journal of Engineering Manufacture	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits
Walther & Spengler	2005	International Journal of Physical Distribution & Logistics Management	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits
Talbot et al.	2007	Journal of Manufacturing Technology Management	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products,

				landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits
Lieder et al.	2017	International Journal of Advanced Manufacturing Technology	OO	Material recovery planning, dismantling process, design efforts
Masoudipour et al.	2017	Journal of Cleaner Production	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Agrawal et al.	2016	Journal of Cleaner Production	CV+CA+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Return benefits, perceived risks and benefits + Energy consumption, energy usage
Agrawal et al.	2015	Journal of Modelling in Management	CV+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, Energy usage
Chen et al.	2015	European Journal of Operational Research	CV+CA	Cost of product recovery, return on investment, quality of returned products, landfill/disposal

				cost + Return benefits, perceived risks and benefits
Sundin et al.	2012	Assembly Automation	OO+CA	Material recovery planning, dismantling process, design efforts + Return benefits, perceived risks and benefits
Matsumoto & Umeda	2011	Journal of Remanufacturing	OO+CA	Material recovery planning, dismantling process, design efforts + Return benefits, perceived risks and benefits
Matsumoto & Umeda	2011	Journal of Remanufacturing	OO+CA	Material recovery planning, dismantling process, design efforts + Return benefits, perceived risks and benefits
Cao et al.	2011	Production Planning & Control	OO	Material recovery planning, dismantling process, design efforts
Dowlatshahi	2010	International Journal of Production Research	CV+CA	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Return benefits, perceived risks and benefits
Dowlatshahi	2010	International Journal of Production Research	CV	Cost of product recovery, return on investment, quality of returned

				products, landfill/disposal cost
Lieder et al.	2017	Journal of Cleaner Production	CA	Return benefits, perceived risks and benefits
Kalverkamp et al.	2017	Sustainability	CV+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, Energy usage
Germani et al.	2016	International Journal of Sustainable Engineering	OO	Material recovery planning, dismantling process, design efforts
Khor et al.	2016	International Journal of Production Economics	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits
Ziout et al.	2013	Journal of Cleaner Production	CV+OO+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Material recovery planning, dismantling process, design efforts +

				Energy consumption, energy usage
Seitz	2007	Journal of Cleaner Production	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits
Dowlatshahi	2005	International Journal of Production Research	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits

Dowlatshahi	2005	International Journal of Production Research	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits
Chen et al.	2016	Journal of Cleaner Production	OO+CA	Material recovery planning, dismantling process, design efforts + Return benefits, perceived risks and benefits
Tseng et al.	2017	Journal of Cleaner Production	CA	Return benefits, perceived risks and benefits
Forcellini et al.	2013	Journal of Cleaner Production	OO+CA	Material recovery planning, dismantling process, design efforts + Return benefits, perceived risks and benefits
Forcellini et al.	2013	Journal of Cleaner Production	OO+CA	Material recovery planning, dismantling process, design efforts + Return benefits, perceived risks and benefits

Chinnam et al.	2010	Journal of Cleaner Production	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits
Sharma et al.	2014	Journal of Cleaner Production	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits
Chakrabarty et al.	2011	Journal of Cleaner Production	CA	Return benefits, perceived risks and benefits
Li et al.	2017	Journal of Cleaner Production	CV+OO+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Material recovery planning, dismantling process, design efforts + Energy

				consumption, energy usage
Lanham et al.	2014	Journal of Cleaner Production	CV+OO	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Material recovery planning, dismantling process, design efforts
Almeida et al.	2012	Journal of Cleaner Production	CV+OO	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Material recovery planning, dismantling process, design efforts
Soebarto et al.	2014	Journal of Cleaner Production	CV+OO	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Material recovery planning, dismantling process, design efforts
Fujii et al.	2012	Journal of Cleaner Production	OO+EC	Material recovery planning, dismantling process, design efforts + Energy

				consumption, energy usage
Sarmah and Jena	2015	Journal of Cleaner Production	CA	Return benefits, perceived risks and benefits
Dalhammar	2015	Journal of Cleaner Production	OO	Material recovery planning, dismantling process, design efforts
Canning et al.	2016	Journal of Cleaner Production	OO	Material recovery planning, dismantling process, design efforts
Wu et al.	2010	Journal of Cleaner Production	CV+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, Energy usage
Konnola et al.	2010	Journal of Cleaner Production	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits

Konnola et al.	2010	Journal of Cleaner Production	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits
Russo et al.	2010	Journal of Operations Management	CA	Return benefits, perceived risks and benefits
Giovanni and Ramani	2017	European Journal of Operational Research	CV+CA	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Return benefits, perceived risks and benefits
Vladimir et al.	2015	Journal of Manufacturing Systems	CV+OO+CA	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Material recovery planning, dismantling process, design efforts + Return benefits, perceived risks and benefits
Kaur and Bhattacharya	2015	Journal of Manufacturing Systems	CV	Cost of product recovery, return on investment, quality of returned products,

				landfill/disposal cost
Chen	2013	Journal of Manufacturing Systems	CV+CA	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Return benefits, perceived risks and benefits
Barua and Prakash	2015	Journal of Manufacturing Systems	OO+CV+EC+CA	Material recovery planning, dismantling process, design efforts + Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, energy usage + Return benefits, perceived risks and benefits
Pishvaee et al.	2015	Journal of Manufacturing Systems	CV	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost
Shimura et al.	2017	Resources, Conservation and Recycling	CV+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, Energy usage
Tillman and Diener	2016	Resources, Conservation and Recycling	OO	Material recovery planning,

				dismantling process, design efforts
Williams and Kahhat	2012	Resources, Conservation and Recycling	CV+CA+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Return benefits, perceived risks and benefits + Energy consumption, energy usage
Krikke	2011	Resources, Conservation and Recycling	EC	Energy consumption, energy usage
Aydın et al.	2015	Resources, Conservation and Recycling	CV+EC	Cost of product recovery, return on investment, quality of returned products, landfill/disposal cost + Energy consumption, Energy usage
Barua and Prakash	2016	Resources, Conservation and Recycling	OO	Material recovery planning, dismantling process, design efforts