Linnæus University
Sweden

Master's Degree Project

Sustainability of Construction & Demolition Waste:

A Closed-loop Supply Chain for Flat Glass

Author: Dahl, Thor Lobekk; Lu, Yichang; Thill, Sidney C.
Supervisor: Helena Forslund
Examiner: Helena Forslund
Co-Examiner: Peter Berling

Term: VT21
Subject: Business Process Control & Supply Chain Management
Level: Master's Level
Course code: 5FE04E

Linnæus University
Sweden

Abstract

Purpose: This thesis' purpose is to identify a CLSC model of flat glass, including actors, waste sources, and what can be done with recycled flat glass. In addition, this research aims to propose a cost structure of a flat glass CLSC. Thus, this thesis' research questions (RQ) are: *RQ1: How can closed-loop supply chains (CLSC) for the purpose of flat glass look like? RQ1.A: What actors are a part of a flat glass CLSC? RQ1.B: What are the waste sources of flat glass in a flat glass CLSC? RQ1.C: What are the uses of flat glass as secondary material? RQ2: How can a cost structure for a closed-loop supply chain (CLSC) for the purpose of flat glass look like?*

Method: For this purpose of this thesis the researchers chose to employ a pragmatist research philosophy. The thesis is an exploratory qualitative study using an abductive approach. A case study strategy was used, and data was collected through semi-structured interviews and a literature review. Seven interviews were conducted with the six case companies.

Findings: A flat glass CLSC consists of three phases: manufacture, use, and secondary (raw) material. The main actors are float glass manufacturer, flat glass processor/refiner, flat glass distributor, construction and demolition company, flat glass recycler, and freight hauler. Sub-actors of a flat glass CLSC are raw materials supplier, government, third-party contractors, container glass manufacturer, and glass wool manufacturer. Secondary material occurs during flat glass manufacturing, distribution/transport, construction, and demolition. It can be divided into three types, i.e., pure, high quality cut-offs, contaminated flat glass, and end-of-use flat glass. The possible uses of flat glass as secondary material are float glass, container glass, and glass wool manufacturing. The cost structure for a flat glass CLSC divides cost elements into the three phases of a flat glass CLSC and six supply chain cost categories, which include manufacturing cost, distribution cost, warehousing cost, administration cost, capital cost, and installation cost.

Theoretical Implications: This master's thesis helps in adding to two research areas: flat glass and CLSC. By reviewing existing literature and conducting the case studies in China, Germany, and Norway, the researchers can reflect the current practices of flat glass CLSCs in different countries, thereby adding to existing scientific research to close the research gap of flat glass CLSCs.

Practical Implications: This master's thesis contributes to practice by providing a flat glass CLSC model and cost structure which can be used as a starting point of developing a flat glass CLSC and its cost structure. In addition, this thesis is connected to another bigger research project in collaboration with the Linnaeus University and the city of Växjö, the findings from this thesis are beneficial for improving the situation of flat glass in Sweden.

Societal Implications: By researching circularity in CDW, this master's thesis helps not only the city of Växjö but also other Swedish cities to improve the situation of flat glass and strive towards a full circular economy, further contributing to an increase in sustainability in Sweden.

Key Words: Closed-loop Supply Chain – Circular Economy – Flat Glass – Construction and Demolition Waste – Secondary Material – Costs

Acknowledgements

This master's thesis represents our final work for our program Business Process Control and Supply Chain Management at Linnaeus University.

The idea to this topic was born through a bigger research project in collaboration with the Linnaeus University and the city of Växjö.

This body of work was supported by many, and we would like to thank and express our gratitude towards everyone who has been a part of this experience.

Special thanks go to our tutor and supervisor Helena Forslund who has guided us through this process and provided us with tremendous support. We would like to further express our gratitude to our seminar group who despite the length of this thesis have taken the time to read and provide us with valuable feedback. Without our interviewees we would not have gotten to this point. Thank you for sharing your extensive knowledge with us. We would like to further express our gratitude to our families and friends who despite being located in different countries always supported us.

Lastly, we would like to thank each other for the constant support, interesting discussions, and an unforgettable experience. Writing a master's thesis during a global pandemic is hard but we together we pulled through and are proud of each other.

Monday, 31 May 2021

We, that are Dahl, Thor Lobekk; Lu, Yichang; and Thill, Sidney C.

Table of Contents

List of Figures

List of Tables

Appendices

List of Abbreviations

C&D	Construction and Demolition
CDW	Construction and Demolition Waste
CE	Circular Economy
CSF	Critical Success Factor
CLSC	Closed-loop Supply Chain
EU	European Union
EOL	End-of-life
EOW	End-of-waste
FL	Forward Logistics
GDPR	General Data Protection Regulation
GHG	Greenhouse Gas
PCB	Polychlorinated Byphenyl
RL	Reverse Logistics
RQ	Research Question
R&D	Research and Development
SC	Supply Chain
SCC	Supply Chain Cost
SCM	Supply Chain Management
SR	Social Responsibility

1 Introduction

This chapter introduces the research background and then highlights the research gaps in the problem discussion. Further, two research problems are formulated with the indication of the research purpose. The disposition of this paper is presented at the end.

1.1 Background

Over the past few decades, consequences of climate change such as extreme weather events, global warming, sea level rise and ocean acidification have caused major impacts on society and the natural ecosystem (Hodgkinson and Smith, 2018). To mitigate climate change, sustainability has become one of the most important topics of contemporary society (Esposito et al., 2018). Recycling promotes environmental sustainability because it saves not only space in landfill, but also energy and raw materials. From the long-term aspect, recycling can reduce consumption and pollution substantially, along with innumerable other benefits (Panda et al., 2017). In many countries, the government is directly involved in developing recycling systems (Ferronato et al., 2019). Recycling in the European Union (EU) has achieved remarkable results, the recycling rate of municipal waste has steadily increased from 38.0% in 2010 to 47.6% in 2019 (Eurostat, 2020).

As one of the heaviest and most voluminous waste streams, the construction and demolition (C&D) segment dominated the waste recycling services market in Europe in 2019 (Recycling Magazine, 2020). In the Nordic countries, substantial amounts of construction and demolition waste (CDW) are recycled for construction purposes (Hjelmar et al., 2016). If a CDW aggregate obtains end-of-waste (EOW) criteria and ceases to be waste, it is possible to be used as a replacement of virgin materials in construction (Ibid). In CDW, glass is a 100% recyclable material, most end-of-life (EOL) architectural glass/flat glass/float glass, such as windows, transparent walls and glass doors, could be dismantled and recycled in glass furnaces with no technical issues (Geboes, 2020). Despite its recyclability, a large part of the flat glass waste in the building industry will not be recycled into new glass products but will instead be crushed together with the other building materials and put into landfills or downcycled together with other CDW (Ibid.). For instance, Sweden has built up a very dense recycling system for container glass with a recycling rate of over 95% in recent years. About 2/3 of the recovered glass is processed for the production of new glass bottles (Recovery, 2018). However, the flat glass from CDW is still in a dead-end recycle path and not used in the new production of flat glass, because the requirements placed on flat glass from glass recycling systems are far higher than they are in the case of container glass (Ibid.). Flat glass is predestined for closed-loop recycling, because recycling flat glass from CDW not only conserves non-renewable natural material resources, but also reduces the melting energy required, and thus, decreases the CO2 emissions (Rose et al., 2019). Furthermore, the closed-loop recycling of flat glass is an important breakthrough for changing the situation that new EU regulations (Waste Framework Directive 2008/98/EC) stipulate an increase in recycling of demolition materials to 70%, while flat glass accounts for less than 1% of such demolition materials (Recovery, 2018).

Today, the majority supply chain (SC) processes of flat glass are still the traditional forward flows that focus on producing and distributing products to end customers, the recovery value of flat glass is not fully utilized (Kazemi et al., 2019). By collecting and remanufacturing used flat glass, the SC processes can be reversed back to manufacturers, thereby forming a closed-loop supply chain (CLSC) to maximize values of flat glasses. CLSC is defined as a system which has both forward and reverse logistics (RL) to dynamically generate and recover value over the entire life cycle of a product (Govindan et al., 2015). CLSC integrates concepts of sustainable manufacturing, green supply chain and circular economy (CE) and directly reduces the waste from landfill, it has been recognized as a significant innovation for manufacturing industry and environmental protection (He et al., 2019). CLSC have been successfully implemented in some organizations, for instance, the H&M group has moved viscose and modal producers towards a closed-loop manufacturing system, by 2025, “H&M group will only use viscose and other man-made cellulosic fibre producers with good environmental practices” (H&M Group, 2018, 40). Undoubtedly, CLSC is one of the main drivers of sustainability, existing CLSCs of other products can provide practical insights and solutions to design, control and operate CLSC of flat glass.

While implementing CLSC, costs play a decisive role for flat glass manufacturing companies. Generally, if the remanufacturing cost of used products is less than the manufacturing cost of new products, it would encourage companies to adopt remanufacturing processes therefore move towards a CLSC (Taleizadeh et al., 2020). Evaluating the cost for CLSC of flat glass is not a simple task, many factors such as time value, and social responsibility (SR) could be considered in modeling the cost structure of a CLSC (Kadambala et al, 2017). However, once the cost model for a CLSC of flat glass is drawn, it can aid the participating actors in making the decision to go from a traditional SC towards closing the loop.

1.2 Problem Discussion

1.2.1 General

In the last five years scholars have conducted extensive research in the field of CLSCs, CE, reverse logistics, and recycling within several different industries. For example, in her article "Developing closed loop supply chains for environmental sustainability" (Ashby, 2018, p. 699) Ashby looks at how CLSCs "can be successfully developed to address environmental sustainability" (Ibid.) by conducting a case study within the UK fashion industry. The case study's findings highlight the interplay of companies and their suppliers. "Strategic resources and shared vision and principles" (Ibid.) are of utmost significance. The author expresses the need for an extension of the current UK fashion CLSC which includes a new function and a new actor, i.e., design and the end customer (Ibid.).

In contrast, the authors Govindan et al. (2015) have written an extensive literature review of papers concerning CLSCs and reverse logistics. They have established a general basis of existing scientific research and determined research gaps to be closed in the future. The authors mention fields of RL and CLSC, specifically the connection of green SC and sustainability, and the identification of new parameters that are considered uncertain, to be research gaps, amongst others concerning more the type of analysis method than topic (Ibid.).

The authors Amin et al. (2018, p. 153) have investigated "the reverse logistics of plastic pallets in Canada". They provide a literature review concentrating on pallets. The authors, then, present a case company and discuss problems related to the Canadian pallet industry, typical features of and the forward SC of pallets made of plastic. Amin et al. (2018) also give insights into reverse SC. In addition, the authors utilize a SWOT analysis to determine "the company's potential establishment of a recovery system for plastic pallets" (Ibid., p. 171) and subsequently "an optimization model to configure a pallet CLSC network" (Ibid.) is presented.

In their article Moktadir et al. (2020) conduct their research within the leather industry. They identify and classify "critical success factors (CSFs) needed in the business strategy development of CE practices as well as to minimize environmental pollution" (Moktadir et al., 2020, p. 3611). According to them the most significant CSF of CE is "leadership and top management commitment" (Ibid.). The authors Martínez Leal et al. (2020) propose a circular eco-design for recycling and demonstrate their approach on the basis of recycling of smartphones. They point out that while the proposed approach is based on smartphones, it can be transferred onto different products (Ibid.).

While the articles mentioned previously highlight important aspects of CLSCs, CE, RL, and recycling, they do not relate to either flat glass or CDW. Aspects may be derived from these articles, however, they are not directly applicable and need to be transferred and adjusted onto the CDW industry, specifically flat glass, considering its different characteristics compared to, for example, the fashion industry or plastic pallets.

1.2.2 RQ 1 – Closed-loop Supply Chains of Flat Glass

In the previous mentioned research fields fewer scientific articles can be found that concentrate on CDW. For instance, the authors Vefago and Avellaneda (2013) propose concepts for CDW materials, end-of-life building materials, and recyclability assessment of these. These concepts "propose a more realistic view about the future life cycles for building construction materials" (Ibid., p. 135) and are concerned with a multitude of types of CDW materials, such as "recycled, infracycled, reused and infraused materials" (Ibid., p. 127). The authors' findings demonstrate the concepts' suitability towards the current environmental situation (Ibid.). In contrast to Vefago and Avellaneda's research, Beldek et al. (2016, p. 771) examine the cost and social consequences of green SCM methods which are used in Turkey. They develop a CLSC model for the Turkish C&D industry which decreases CDW by utilizing "recycle, repair and remanufacture" (Ibid., p. 778).

The authors Ginga et al. (2020, p.1) review literature about CE and CDW, focusing on "material recovery and production". They present CE frameworks and discuss these with an emphasis on waste recycling and reusing of waste. The authors present several research gaps and suggestions for future research. According to them, future research is to be conducted into "measures for effective reuse of construction materials" (Ibid., p.16), "effective proportioning of recycled materials, natural materials, and other materials"

(Ibid.), “methods that promote waste-free recycling” (Ibid.), and risk assessment of CDW use instead of non-waste material.

One can recognize that from the scientific articles about CDW, CLSC, and recycling that do exist, a substantial amount focusses on China as the country in case studies, for example, “A cost compensation model for construction and demolition waste disposal in South China” (Liu et al., 2019, p. 13773), and “Investigating the determinants of contractor’s construction and demolition waste management behavior in Mainland China” (Wu et al., 2017, p. 290).

In their paper, Liu et al. (2019, p. 13773) calculate the cost of four ways of CDW disposal, including “illegal dumping, controlled dumping (landfill), centralized recycling, and on-site recycling”. They also propose a model for cost compensation to find out how much of the disposal costs should be contributed by the Chinese government. This paper’s findings suggest that recycling of CDW on-site will be the method of choice in the future of the disposal of CDW. While the dumping of CDW illegally seems to be more profitable compared to recycling the waste on-site taking only direct costs into consideration, the latter is cheaper in total costs than the former (Ibid.).

In their article, Wu et al. (2017) look at the factors that contribute to a contractor’s behavior in CDW management. Their findings demonstrate “economic viability” (Ibid., p. 290) and “governmental supervision” (Ibid.) to be the most crucial factors behind a contractor’s behavior. According to the authors, the Chinese government plays a pivotal role in improved CDW management (Ibid.).

On the contrary, the field of flat glass and CLSCs significantly lacks scientific literature. In their report, the authors DeBrincat and Babic (2018, p. 9) investigate “the economic, technical, environmental and logistical viability of post-consumer construction flat glass closed-loop recycling” in the UK. Their findings suggest several benefits, barriers, and opportunities. The benefits are mainly environmentally oriented: significant reduction of amount of raw material used and connected processes to acquire and transport raw material, decrease in energy usage if more cullets are used, decrease in CO_2 emissions, and decrease of glass ending up in landfills. DeBrincat and Babic (2018) see the low taxes on landfills to be barriers, higher taxes would pose as incentives towards more recycling. Further barriers are lack of availability of high quality cullets, legislations are not good enough to promote CLSCs, current demolition practices make recycling difficult, and the recycling costs vary. The authors mention the following opportunities for CLSCs of flat glass: “change to existing processes” (Ibid., p. 44), building of a sustainable network, emergence of “sustainable business practices” (Ibid., p. 47), and change in design towards more circularity.

The book by Hillebrandt et al. (2019, p. 1) looks at “buildings as sources of materials” amongst other things flat glass with the help of successful case studies. Furthermore, Rose et al. (2019) go into more detail by investigating Germany’s up-to-date flat glass recycling habits to propose an improved CLSC. Like DeBrincat and Babic, Rose et al. (2019) point out that the use of cullets enables the use of less raw material, decrease in energy usage, and CO2 emissions decrease significantly. The authors present a CLSC which “contains both the mass flows of production and sales in Germany as well as the amounts of flat glass waste from the pre- and post-consumer sector” (Ibid., p. 6).

Lastly, Geboes’ (2020, p. 87) research aims to close the loop on flat glass by presenting the reader with hurdles, such as “inflexible standards, technical and economic feasibility”, that prevent turning the SC of flat glass into a CLSC. The author also proposes various options that navigate the process to a flat glass CLSC.

The Swedish industry revenue of flat glass production is showing a negative trend (Statista, 2019) whereas the revenue of “shaping and processing of flat glass” (Statista, 2020) is showing a positive trend (Ibid.). The former aggregated to 3.8 million US dollars in 2016 which is a decrease of 1.07 million US dollars since 2011. Further reductions are anticipated; it is predicted to drop to 2.44 million US dollars in 2023 (Statista, 2019). The latter totaled at 246.1 million US dollars in 2016 and is projected to increase by 16.23 million US dollars in 2024 (262.33 million US dollars) (Statista, 2020).

Globally, CDW makes up about 30% of all waste, of which about 924.000.000 tonnes were contributed in 2016 by countries in the European Union (Ginga et al., 2020). Sweden produces a yearly estimate of 1.312.000 tonnes of CDW; of which 4.850 tonnes (0,37%) are contributed by flat glass (Youhanan et al., 2016). Figure 1 shows a comparison of flat glass’ contribution to CDW compared to plastic, plaster and other types of CDW. Today, Sweden recycles about 45% (2.200 tonnes) of flat glass waste. Nevertheless, the difficulty of flat glass recycling lies in the type of the material that is contained in flat glass and in the overall expensive recycling process of the contaminated flat glass. This particular flat glass still ends up at landfills (Ibid.). Another challenge is the lack of a clear cost model, as today it is often not clear who should bear the costs related to dismantling, transportation, and recycling of the flat glass (Dubois et al., 2013 as cited in Geboes, 2020, p. 68).

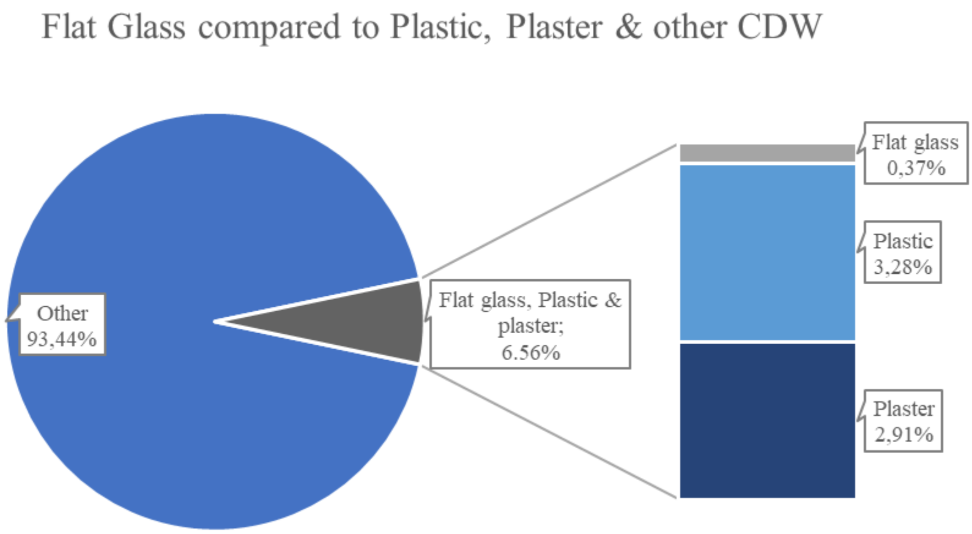


Figure 1: Flat Glass Waste compared to Plastic, Plaster and other CDW (Youhanan et al., 2016).

All articles mentioned previously are concerned with CLSCs, CE, RL, and recycling in the C&D industry, however, very few researchers investigated flat glass. This, besides the economic waste situation, indicates a need for further research into this topic. In addition to a lack of scientific research about flat glass CLSCs, there exists a lack of scientific research about cost aspects of such a CLSC. The authors Beldek et al. and Liu et al. have included cost aspects of C&D CLSCs into their research.

1.2.3 RQ 2 – Cost Structure of Closed-loop Supply Chains of Flat Glass

As previously stated, the field of flat glass CLSC significantly lacks scientific literature. This is no different with the cost structure of flat glass CLSCs. However, there is scientific literature on cost structures, cost aspects, or cost strategies available. In their article, Zou et al. (2018, p. 13) analyze a CLSC consisting "of one risk-averse manufacturer and two risk-averse retailers who compete in terms of both retail price and recycle price" and propose "a CLSC contract coordination model" (Ibid., p. 2). Their findings suggest that a centralized approach for making decisions is favorable to a decentralized one. By determining "the optimal revenue-sharing ratio" (Ibid., p. 1) the contract model proposed by Zou et al. grows the SC members' profits.

The authors Ke and Cai (2019, p. 75) investigate "pricing decisions" of a CLSC. Similar to the CLSC looked at by Zou et al., this paper's CLSC consists of "a manufacturer, two retailers and the end costumer" (Ibid.). Its aim is to examine "the performance of the CLSC participants under the collection's effectiveness on demand expansion and the impacts of the retailer's collecting decision on the supply chain" (Ibid., p. 76). The authors' finding suggest "that there will be a higher wholesale price when the collection's effectiveness on demand expansion is significant and the manufacturer sets transfer price higher than cost savings to motivate the collector, or a lower wholesale price otherwise" (Ibid., p. 86).

In contrast, Meng et al. (2020, p. 17) research governments' policies, i.e., the ideal "consumption subsidy policy" and two manufacturers' ideal decisions for assessing financial value. They found out that it might not be ideal as the government to present such a subsidy; actors of such a CLSC may not profit from it; and the policy increases demand of goods that are remanufactured while simultaneously decreasing it for newly manufactured goods.

The authors Taleizadeh et al. (2020, p. 1195) investigate "pricing and reverse channel selection decisions" of a CLSC. Four slightly varying CLSCs with different approaches to decision making, i.e. centralized and decentralized, are considered. Their findings show similarities to the results of Zou et al.; a centralized approach is favorable to a decentralized one because the former surpasses the latter "in achieving the highest total expected profit, attaining highest demand by setting lowest selling price, and also by considering the environmental viewpoint and resource usage" (Ibid.).

1.2.4 Research Project

As pointed out before, the lack of scientific literature and the economic situation of flat glass in Sweden actively demonstrate a need for more research within this specific topic. In addition, current research projects also accentuate the importance for the shift of focus in research. Such a current research project is the project this master's thesis is connected to. The research project, in collaboration with the city of Växjö and Linnaeus University, is concerned with the circularity of flat glass and increasing its recyclability by closing the loop. Its aim is to develop and visualize a CLSC for flat glass, contributing towards an increase in sustainability.

1.3 Research Purpose and Research Questions

While the economic situation of flat glass in Sweden indicates a potential and need for improvement in flat glass recycling, the lack of research on the topic of CLSC and the cost aspects connected to it, is limiting its potential. To enable the potential further research is needed.

Therefore, this thesis' purpose is to identify a CLSC model of flat glass, including actors, waste sources, and what can be done with recycled flat glass through an exploratory study by conducting case studies in China, Germany, and Norway. In addition, this research aims to propose a cost structure of a flat glass CLSC. Thus, this thesis' research questions (RQ) are:

RQ1: How can closed-loop supply chains (CLSC) for the purpose of flat glass look like?

RQ1.A: What actors are a part of a flat glass CLSC?

RQ1.B: What are the waste sources of flat glass in a flat glass CLSC?

RQ1.C: What are the uses of flat glass as secondary material?

RQ2: How can a cost structure for a closed-loop supply chain (CLSC) for the purpose of flat glass look like?

1.4 Disposition

The paper's structure is presented in the following figure 2.

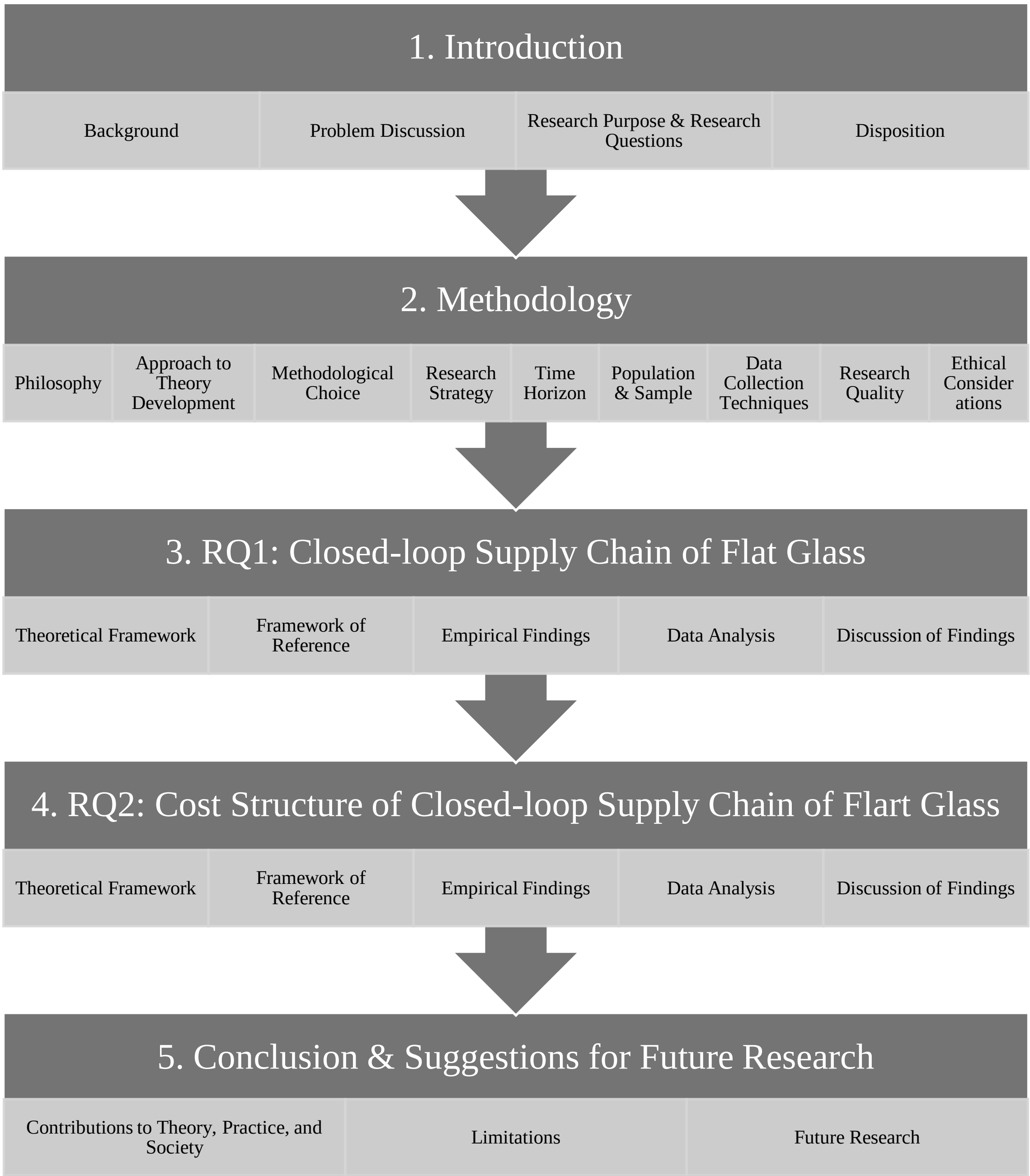


Figure 2: Disposition.

2 Methodology

The methodology chapter follows the research onion to discuss the research methodology and highlights the choices of approach made by the researchers. Furthermore, this chapter includes research quality and ethical considerations. In the end the methodological choices are summarized.

2.1 Research Methodology

A research philosophy is a set of beliefs and assumptions about how we develop knowledge. Whether consciously or not, a researcher will throughout their research make assumptions regarding ontology, epistemology, and axiology in relation to their research. These assumptions will in turn affect the understanding of the research question, which methods will be used and how the information gathered will be interpreted (Crotty, 1998 as cited in Saunders et al., 2019). By evaluating and deciding on a consistent set of assumptions, the researcher can attain a credible research philosophy. This philosophy will subsequently guide and support the researcher's choice of methodology, research strategy and data collection and analysis techniques. The result of this process will be a common thread through the research project (Saunders et al, 2019).

Ontological assumptions reflect on the nature of reality. The researcher's ontological assumption affects how he views and studies the research objects. These objects can be an organization or the systems, individuals, and events in it. The researcher's ontological perspective will therefore influence what his research topic is (Saunders, 2019). Epistemology is the theory of knowledge. It includes assumptions about what knowledge is, what should be seen as acceptable, valid and legitimate knowledge as well as theories of how knowledge can be communicated to others (Burrell and Morgan 2016 as cited in Saunders et al., 2019). As a result of business and managements multidisciplinary origin, a multitude of different types of information can be considered as legitimate knowledge. The researcher's epistemological assumptions will therefore directly affect his choice of methods and consequently the results achieved from the research (Saunders et al., 2019). Axiology concerns the place of ethics and value in research. When conducting research, it is important that the researcher is aware of his own value position, as it is inevitable that these values will be incorporated and affect the research conducted. Consequently, it is important that the researcher reflects over whether this impact should be viewed as a positive influence and thereby welcomed or not (Ibid.).

This decision is in many ways a choice between embracing objectivism or subjectivism. If the researcher takes an objectivist stance, he will embrace the view of natural sciences proclaiming that the social reality which is being researched exists external to the actors in it. Objectivism takes the ontological lens of realism. In its most extreme form realism argues that social entities possess the same characteristics as physical entities of the natural world. Thus, they exist independently of our perception or even awareness of them. This extreme form of realism asserts that there only exists one true social reality, and the perceptions and actions of the actors cannot influence it. This conviction leads to an epistemological stance where the researcher strives towards factual statements of observable phenomena to achieve generalizable results. It also leads to an axiological position where the researchers try to detach themselves from the project and minimize the effects their own values have on it (Saunders et al., 2019).

On the other side of the spectrum is the position of subjectivism. Subjectivism instead adopts its assumptions from the arts and humanities and takes the ontological standpoint of nominalism. In its most extreme form, nominalism claims that the social phenomena researcher's study is constructed by the social actors in it. Thus, nominalists are convinced that there does not exist an underlying true social reality, but rather that the social actors through their experiences and perceptions create their own reality. Since social phenomenons are constructed by interaction between the social actors, their significance is dependent on the historical, geographical, and cultural context of the actors in it. It is consequently important for a subjectivist researcher to study the context of the phenomena to understand its true meaning and purpose. This means that a subjectivist researcher is not interested in finding generalizable laws that govern our social behavior but is instead looking for different opinions and narratives that can contribute to understanding the different social realities of actors. Subjectivist researchers also hold the belief that they cannot completely detach themselves from the project, so instead of minimizing the effects of their own values they instead acknowledge the effect and actively reflect on the consequences of it (Saunders et al., 2019).

On the spectrum of extreme objectivism to extreme subjectivism there exists a multitude of different research philosophies. So, to help guide us through the methodological choice for this thesis the researchers have determined to use Saunders et al. (2019) research onion. This framework consists of six decisions the researchers need to take to generate a consistent methodology. These six choices are related to, research philosophy, approach to theory development, methodological choice, research strategy, time horizon, and techniques and procedures.

2.2 Research Philosophy

Saunders et al. (2019) proposes five major research philosophies for the field of business and management: positivism, critical realism, interpretivism, postmodernism and pragmatism.

2.2.1 Positivism

The positivistic research philosophy is derived from the philosophical stance held by natural scientists and focuses on the observable social reality, which is studied to produce “law-like generalizations” (Saunders et al., 2019, p. 144). These generalizations are in turn used to predict and explain the behavior of organizations and the events that occur in them. Fundamental to the positivist philosophy is the strive towards for results that are not influenced by human bias and can therefore be viewed as pure. A positivist researcher would therefore try to detach himself as much as possible from the research to remain as neutral as possible to avoid tainting the result. As a result, positivist researchers emphasize quantifiable data and statistical analysis. They also depend on a highly structured methodology which enables replication to easily control for any bias in their results (Ibid.).

2.2.2 Critical Realism

Critical realism can be considered as the middle ground between positivism and postmodernism. Critical realist researchers apply epistemological relativism. Epistemological relativism is a subjectivist approach to knowledge in which knowledge is dependent on and changes with its time. They also hold that social facts are a social construction that is dependent on the consensus of people, instead of being independent of it. Reality is the focal point of critical realist research. While reality is external and independent, a critical realist acknowledges that reality might not always be accessible through observations and instead tries to explain it by analyzing the underlying structures that affect the events we observe. To explain these structures, critical realist researchers often utilize in-depth historical analysis to analyze how both social and organizational structures have developed over time. A critical realist researcher does not try to detach himself as much as possible from the research, but instead strives towards understanding and remaining aware of how one's socio-cultural background and experiences influences both how the research is conducted and interpreted and tries to minimize these influences as much as possible to remain objective (Saunders et al., 2019).

2.2.3 Interpretivism

Interpretivism originated as a critique of positivism. Central to the philosophy is the subjectivist view that humans differ from physical phenomena, as they create meaning and consequently the social sciences should not try to replicate natural science. Interpretivist researchers fear that important aspects of humanity will be lost that way and instead hold the subjectivist conviction that people experience different social realities, affected by their culture, time and circumstances. By investigating these different social realities, interpretivist researchers hope to uncover new facets of the social world and its phenomena. From a business and management perspective, this leads to a focus on different groups of people and how their experiences of events are shaped by their background and position. Interpretivists also acknowledge that their interpretation of data is a crucial part of the research process and that their values and beliefs in turn will affect the results (Saunders et al., 2019).

2.2.4 Postmodernism

Postmodernism takes an even more critical stance against positivism and objectivism than interpretivism. It rejects the realist ontology proposed by objectivism and instead holds the extreme nominalist position that there does not exist any order and structure in the social phenomena outside that created by the social actors. Social actors construct order through the use of language with the categories and classifications it contains. Central to the postmodernist position is the acknowledgement that while language contributes to order it will always be partial and inadequate. As a consequence, it will marginalize certain aspects of what it is describing, while privileging others. Since the only order found in the social world is contributed by its actors through the use of language, postmodernists believe that there is no way of determining an absolute right or true way of describing it. Instead, what we generally believe to be true is collectively decided by the actors. This dynamic leads certain aspects or actors to be marginalized while others are privileged as these collective choices are formed by the ideologies that dominate the specific contexts. Postmodernists believe that the suppressed aspects of social reality can hold valuable information that if explored can improve what we view as the truth today. By deconstructing the dominant realities postmodernists aim to radically challenge the established way of thinking by emphasizing marginalized perspectives (Saunders et al., 2019).

2.2.5 Pragmatism

The last research philosophy proposed by Saunders et al. (2019) is pragmatism. Pragmatism relates to the question of ontology, epistemology, and axiology in a different way than the four previous philosophies. Instead of taking a definite stance on the topics it proposes that it should be adapted to best answer the question at hand. For a pragmatist what determines the choice of research design and strategy is most importantly the research problem that is being solved. Research design and strategy are chosen with the goal of contributing practical solutions that can be used to enhance future practice. Consequently, how subjectivist or objectivist a pragmatic researcher is largely depends on his interpretation of the problem at hand. Pragmatists acknowledge that people can interpret the world in a vast amount of different ways and that no single research strategy can ever offer the whole solution. Thus, they are open to using multiple methods in situations where it will enable them to gather more credible, reliable, and relevant data (Ibid.).

2.2.6 Our Choice of Approach

Pragmatism is the philosophy that best reflects the position held by this paper and its authors. The research arose as a response to gaps in the knowledge about the recycling of flat glass and the possibility of creating a CLSC. Thus, at the center of this study are the research questions and the research design and strategy should be adapted as to best answer them. As a pragmatic philosophy encourages the use of diverse data collection methods, we feel it best enables us to analyze and answer the problems at hand.

2.3 Approach to Theory Development

The next step in the framework provided by Saunders et al. (2019) is the choice of approach to theory development. Saunders et al. (2019) proposes that there are three different approaches available to the researcher: deductive, inductive, and abductive.

2.3.1 Deductive

Deduction is the most common research approach used in the natural sciences and it is applied when the conclusion is logically derived from a series of theory-built premises. The deductive approach seeks to explain causal relationships between concepts and variables and aims to achieve this by developing a theory, which in turn is tested by the use of a set of propositions. Deductive research employs a highly structured methodology to ensure the possibility of replication and thus increasing its reliability. This is also achieved through a thorough operationalization and use of reductionism to ensure that the topic can be measured in a factual way. The approach strives toward achieving generalizable results and it is therefore important to establish an accurate sample, which is of ample size (Saunders et al., 2019).

Blaikie (2010, as cited in Saunders et al., 2019) proposes six steps that make up the deductive process. First, one or multiple hypotheses is proposed to form a theory. Then, testable propositions are put forward by examining existing literature. The third step is to examine the propositions to see if the premises can offer any new insights. If they can, the research should move on to testing the premises. To do this the researcher collects and analyzes data that can be used to measure the concepts central to the theory. The result of the analysis can either be consistent or not with the premises put forth. If the result is not consistent, then the test has failed, and the theory must either be rejected or modified. If on the other hand the results are consistent with the premises the research has corroborated the theory.

2.3.2 Inductive

The inductive approach starts at the opposite end compared to the deductive approach; here the theory follows the data (Bell et al., 2019; Saunders et al., 2019). With the inductive approach the theory is the outcome of the research rather than the basis of it. The goal is to draw generalizable conclusions from the observations gathered in the research, often in the form of conceptual frameworks (Ibid). One of the main strengths of the inductive approach is the possibility to gain a better understanding of how social actors interpret the social world. This is often achieved by studying a smaller sample to gain a better insight into the context in which events take place. The qualitative methods used enable inductive research to establish different perspectives of phenomenons (Saunders et al., 2019).

2.3.3 Abductive

The last approach proposed by Saunders et al. (2019) is abductive. Abduction approaches the topic differently than the two others. Instead of using theory to produce data (deductive approach) or data to produce theory (Inductive approach), the abductive approach combines the two. Abductive reasoning is commonly used in business and management research as it enables the researcher to overcome some of the shortcomings of the previous two. Namely deductive reasoning's reliance on its "strict logic of theory-testing and falsifying hypothesis" (Bell et al., 2019, p.24) without a clear way of knowing how to decide which theories should be tested and inductive reasoning's dilemma that no amount of empirical data gather can guarantee the possibility of theory-building (Ibid.). The abductive approach begins with a puzzle, a fact, or an observation that theory cannot account for, and then tries to explain it. Abduction uses the logic of deduction and induction to test plausible theories that can help unfold the puzzle.

2.3.4 Our Choice of Approach

For this research, an abductive approach is employed. By first analyzing existing theoretical knowledge the researchers identified gaps in the existing literature. Empirical data will then be collected and used to substantiate the relevancy of the gaps found. Additionally, more empirical data will be collected to establish the situation of flat glass recycling and the opportunities and obstacles for the introduction of a CLSC. Finally, theory related to CLSC, RL and cost models will be applied to the established situation of flat glass to generate a proposal of the actors, waste sources and the possible uses of flat glass as secondary material in a CLSC, as well as the costs connected to it.

2.4 Methodological Choice

2.4.1 Quantitative, Qualitative, and mixed Method Research

The methodological choice of a research project can in simple terms be viewed as a choice between quantitative and qualitative research. Quantitative research is often described as data collection techniques or analysis procedures that enable the researchers to produce numerical data. On the other hand, Qualitative research is also described as techniques and analysis procedures, but which produce non-numerical data. However, Saunders et al. (2019) claims that this oversimplification can be problematic as much of the research conducted in business and management uses designs that enable them to combine the use of both.

2.4.1.1 Quantitative Research

While quantitative research is most commonly associated with the philosophy of positivism, it is also used to varying degrees in the interpretivist, realist and pragmatist philosophies. It is often used in a deductive approach where the quantitative data collected is analyzed to test theories. Although not as frequent, it can also be employed in combination with an inductive approach, where the data collected is used to develop theory. Quantitative research uses statistical and graphical techniques to analyze numerical variables to investigate the relationship between them. Central to the quantitative method is validity of data and generalizability. Validity is ensured by incorporating controls, while generalizability is often ensured through the use of probability sampling techniques. The approach is usually associated with experimental and survey research strategies (Saunders et al. 2019).

2.4.1.2 Qualitative Research

Qualitative research is often used in combination with an inductive approach where the goal is to build theory or enrich already existing theoretical perspectives. Though in some cases a deductive approach is used, here the objective is to test an existing theory by utilizing qualitative procedures. A subjectivist approach is common in qualitative research and different measures can be used to address bias. The unstructured and semi-structured techniques used produce non-standardized data that the research needs to classify into categories. Qualitative research is diverse and can be used with a variety of research strategies, such as case study, ethnography, and grounded theory (Saunders et al. 2019).

2.4.1.3 Mixed Method

Mixed method research design is as the name indicates a combination of the previous mentioned. It is often associated with the two research philosophies pragmatism and critical realism and necessitates that the researcher has a pluralist view of research methodology. Mixed method design can use a deductive, inductive, and abductive approach, depending on the needs of the research project. The research can be concurrent, meaning that both methods are used simultaneously, sequentially, where one follows the other, or multi-phase sequential, where there are multiple phases of data collection that switches between the two possibilities. Thus, how integrated the mixed method design is can vary a lot between projects. As both methodologies are used the design and techniques employed are numerous (Saunders et al. 2019).

2.4.1.4 Our Choice of Approach

For pragmatist research, the nature of the research question, the context in which it is being conducted and the likely consequences of the project should be the determining factors for the choice of appropriate method. Pragmatists can justifiably use all the three designs previously mentioned (Saunders et al. 2019), but for the purpose of this research the researchers find a qualitative method to be most fitting, as it enables the collection of real-world contexts to the topic studied. Qualitative methods diversity can provide the researcher with a rich and broad understanding of the opportunities and obstacles that a CLSC of flat glass brings with it.

2.4.2 Purpose

Another important choice the researchers need to consider before creating their research questions is the purpose of the study. The researcher should consider which type of purpose is most appropriate to the nature of their study. Saunders et al. (2019) suggest that the purpose of a research can be either fully exploratory, descriptive, explanatory, or evaluative, or a combination of them and highlights that the purpose of a study may change over time. Exploratory studies can be a useful way of gaining a better understanding of an issue or phenomenon that is unclear to the researcher and is mostly used to answer research questions that begin with "what" or "how". Descriptive research aims at providing an accurate representation of events, persons, or situations. Here the research questions can be a bit more varied, but usually includes words like, "when", "where", "who", "what" or "how". Explanatory studies are used to establish causal relationships between different variables and are used to answer questions that include words like "why" or "how". The last type of purpose proposed by Saunders et al. (2019) is evaluative. Evaluative research is done to assess how well something works and is used to answer questions that include words like "how", "what" or "to what extent" (Ibid.). Since the aim of the study is to examine a phenomenon that has received limited attention in research before, the researchers consider the purpose of the study to be exploratory.

The purpose is to provide a clearer understanding of the possibility for CLSC for flat glass and the cost associated with it.

2.5 Research Strategy

A research strategy should explain how the researchers are planning on answering their research questions. The choice of strategy should be coherent with the research design and enable the researcher to meet their objective. While certain strategies historically have been associated with particular philosophies or approaches, the business and management field has shown large flexibility with a multitude of combinations. When picking a research strategy, it is important to take a holistic view of the project. While it is crucial that the strategy permits the researchers to explain the research questions and objects and that it offers coherence with the choice of philosophy, approach, and purpose, more pragmatic concerns need to be addressed as well. The amount of existing knowledge of the subject, the time available to the researchers and resources at disposal, also needs to be taken into consideration (Saunders et al., 2019).

Saunders et al. (2019) explains that business and management research diverse traditions make a wide range of strategies available to the researchers, but for the purpose of their research onion they highlight eight. The first strategy is experiment and is usually associated with quantitative research. Experiments are used to investigate how a change in an independent variable can cause a change in a dependent variable. The second strategy, survey, is also mostly used in combination with a quantitative strategy. Surveys are often associated with questionnaires and allow the researcher to collect large amounts of data that can be analyzed quantitatively with the use of descriptive and inferential statistics. The next strategy proposed is archival and documentary research and can be used in both quantitative and qualitative research. This strategy employs analyses of documents to gain insights into the phenomenon studied. Case studies are another strategy that can be used in both quantitative and qualitative research. Here an in-depth inquiry is carried out with the aim of studying the phenomenon in its real-life setting. The four last strategies highlighted are all most common in qualitative strategy. Ethnography is a strategy where the researcher explores the phenomenon from the perspective of the subjects of the study, often by the use of participant observation. Action research is a participative and collaborative approach created to develop new solutions to real problems organizations face. The use of grounded theory can offer the researcher "theoretical explanations of social interactions and processes" (Saunders et al., 2019, p. 205). The last strategy is narrative inquiry. Researchers use narrative inquiry when they believe that the experiences of the study subject can best be understood when collected and analyzed in its entirety. Here the subject is invited to provide a complete version of their experience, instead of through multiple questions which would divide up their data (Ibid.).

2.5.1 Our Choice of Approach

For the purpose of this research the researchers found that a multiple case studies strategy would best enable us to answer the research questions. A case study offers the possibility to study the subject of flat glass recycling and CLSC in-depth and in a real-life setting. The authors will conduct multiple case studies with the aim of achieving theoretical replication. By studying the context of the current flat glass recycling in the countries China, Germany and Norway, the researchers aim to assess the opportunities and obstacles for a CLSC of flat glass.

2.6 Time Horizon

The last layer of Saunders et al. (2019) research onion is the time horizon of the project. A short time horizon, also called cross-sectional studies, is the most common among student projects as academic courses have inherent time constraints. Cross-sectional studies are used in both quantitative and qualitative studies and offer the researchers a snapshot of the phenomena they are studying. While more costly in time and resources, a longer time horizon, called longitudinal studies, offers the researcher the possibility to study the change and development of a phenomena over time (Ibid.).

2.6.1 Our Choice of Approach

As the purpose of this study is to analyze the state of flat glass recycling today with the purpose of developing a possible CLSC a cross-sectional study will be employed. While the development and change of the glass recycling process offers an intriguing study, it is not relevant for the purpose of this study.

2.7 Population and Sample Size

Bell et al. (2019, p.594) defines population as "The universe of units from which a sample is to be selected", a population can be a group of people, but also companies, countries, and other entities (Ibid.). As it is impracticable in most research to collect a census of the entire research population a sample is needed. Different sampling techniques enable the researchers to reduce the amount of data needed for the research by considering data from a subgroup, rather than the population as a whole. The sample of a study should be taken in such a way that it represents the population examined in a meaningful way, but it must also enable the researchers to answer the purpose of the study (Saunders et al, 2019). Saunders et al. (2019) provides two main categories of sampling techniques: Probability sampling and non-probability sampling. Probability sampling is most commonly associated with research strategies which employ statistical methods to draw generalizable conclusions about a population. In these techniques the probability of each case in the target population being selected is known in advance and it is usually equal across all cases. In research using a non-probability sampling technique, the likelihood of each case being selected is not known and should therefore not be used to make statistical inferences about a population's characteristics (Ibid.).

For this research, a non-probability sampling is most appropriate. As no statistical inferences of the population will be drawn in this study, the non-probability sample enables the researchers to more selectively choose the sample that will best enable them to answer the research question. There exists a wide range of alternative non-probability sampling methods that can be employed to select a sample that will provide the researcher with the information needed to explore their research question and gain new theoretical insights. Saunders et al. (2019) mentions four different subgroups of non-probability sampling techniques. Quota techniques try to ensure the representativeness of the population through the use of quota variables. The purpose is to ensure that the variation in the variables for the sample is the same as in the population as a whole as the sample will be picked with that in mind. In volunteer sampling methods the participants volunteer to be a part of the study rather than being chosen by the researchers. This method is most commonly employed in research where there are difficulties in identifying members of the target population. In Haphazard sampling there is no obvious principle used in the selection of a sample. The most common form is convenience sampling where the sample is selected because of their availability. The last subgroup of sampling techniques is purposive sampling. Purposive sampling techniques work well with the small sample sizes of case studies as it relies on the judgment of the researchers to select the cases that enables them to optimally answer the research questions. There exist multiple techniques that guide the researcher on which basis the sample should be picked (Saunders et al., 2019).

In extreme case sampling, cases that are unusual or special are chosen on the basis that they will offer insights that will best enable the researchers to answer the RQ. With a heterogeneous sampling technique, the researchers aim to pick cases with sufficiently diverse characteristics as the varied data collected will enable them to find common themes across them. A Homogenous sampling technique is the opposite of the heterogeneous. Here researchers will pick cases that have characteristics that are as similar as possible. This will enable the researchers to explore the cases in greater depth and minor differences in the sample will be more noticeable and easier to study. Typical case sampling is often used by researchers to provide an example of what is usual in their subject matter. This can be fitting when the reader is unfamiliar with the topic at hand. The opposite technique is called critical case sampling. When applied, the researchers pick cases because of their individual importance. Opportunistic sampling techniques are applied when unforeseen opportunities, such as new potential research participants, occur and are taken advantage of by the researchers. When applying a theoretical sampling technique, sampling is an ongoing process. Here participants are chosen as they are needed on the basis of the emerging theory of the research (Saunders et al., 2019).

2.7.1 Our Choice of Approach

For this research paper a multi-stage sampling process was needed. First the country of origin of the flat glass supply chain had to be selected. Since the researchers did not have any theoretical foundation for the selection of countries, a convenience sample was chosen. The three national counties of the researchers, China, Germany, and Norway were chosen to enhance the data gathering process. This enables interviews to be held in the native language of the interviewees, which can make the interviews more detailed and increases the likelihood of gaining access.

The second stage of the sampling process was the selection of companies to interview. For this a purposive sampling was first applied to identify case companies that are a part of the current flat glass supply chain in the countries. Initially the plan was to select cases based on the generic flat glass CLSC covered in 3.1.3 in which at least one actor in each phase would be interviewed in each case country. The researchers were also open to using snowball sampling after initial contact, by allowing the already contacted companies to connect the researchers with other important actors in their supply chain. By using a purposive sampling technique, the researchers are able to pick case companies that have active and important roles in the current flat glass supply chain. The snowball sampling technique enabled the researchers to get case companies with established relationships that better showcased the current supply chain and the possibilities in it.

As the sampling process went on, gaining access to companies was proven to be difficult. For example, only one company in Germany agreed to participate in the study. Consequently, the cases are not equally detailed, reducing the quality of a cross-case analysis. While it has affected the analytical outcome of the thesis, the researchers still feel that valuable insights can be derived from it. Table 1 shows an overview of the interviewees.

Table 1: Interviewee Overview.

Case	Respondent	Company	Interview Method	Date
CHIMA1	Production Manager	Manufacturer	Voice Call	10.05.2021
CHIMA2	Director of Float Glass Production Workshop		Voice Call	18.5.2021
	Deputy Minister of Equipment Management		Voice Call	19.5.2021
GERRE	Product Management in R&D	Recycler	Video Call	11.05.2021
NORIWA	Technical Manager	Interest & Employer Association	Video Call	10.05.2021
NORRE	High Level Manager	Recycler	Video Call	10.05.2021
NORNG	Production Manager, Head of Glass		Voice Call	20.05.2021

Even though the researchers did not achieve the desired sample size, the sample size is still sufficient according to Saunders et al. (2019). It is also important to note that the current Covid-19 situation limited the mobility of the researchers. This made techniques such as on-site visits and in-person interviews unavailable to the researchers, further complicating the sampling process.

2.8 Data Collection Techniques

2.8.1 Literature Review

The process of critically reviewing literature on a certain topic is often called a literature review. There are three types of literature reviews. The first one is conducted to build a theoretical foundation for a research proposal. The second, often called a critical review, is the one that will be conducted in this paper. A critical review is conducted to provide theoretical context and framework for the research being conducted. The last type is conducted for the discussion part of a paper and is used to position a research within the wider knowledge on the topic (Saunders et al., 2019).

While it is common to start the process of producing a critical review early in a project it is usually necessary to continue refining it throughout the project. The review enables the researcher to synthesize the current body of knowledge found in literature, where it is lacking and how the research conducted first into it. While there are multiple forms of a critical review, the one conducted in this project will be theoretical. A theoretical review investigates the theoretical implications accumulated in literature in relation to a phenomenon. It establishes which theories are currently relevant and how they relate to each other. It also enables the researcher to discover areas of the phenomenon that the current theories do not adequately cover and thus, use this as a basis for developing new theory (Saunders et al., 2019).

2.8.1.1 Our Choice of Approach

The literature search was conducted within mainly with the database OneSearch, but Google Scholar was used for certain snowballed articles, and resulted in mainly secondary literature such as academic journals and books. The search was structured in several steps to ensure a thorough search. These Steps are explained in the following two figures (figure 3 and 4). In addition, References found with the use of the snowball method were then added. A list of all the references found for problem discussion and theoretical framework can be found in the appendix (Appendix 1 – Table of Scientific Literature).

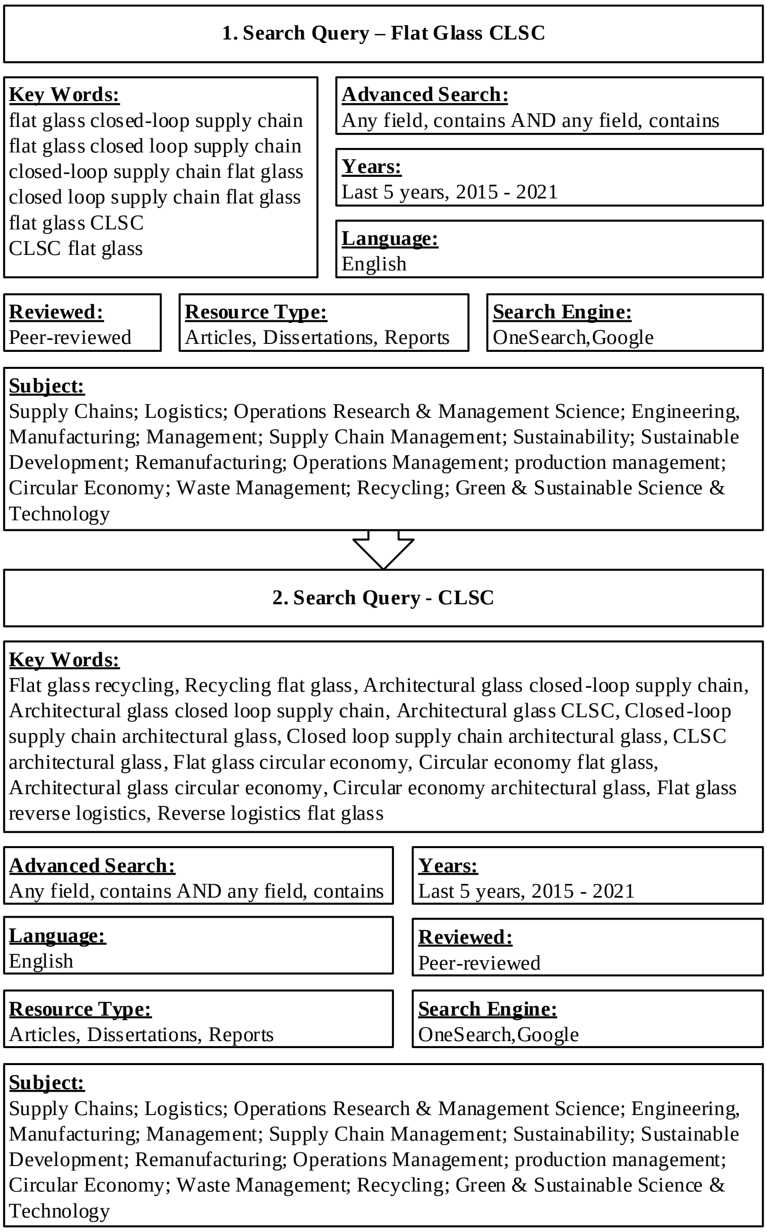


Figure 3: Literature Search 1.

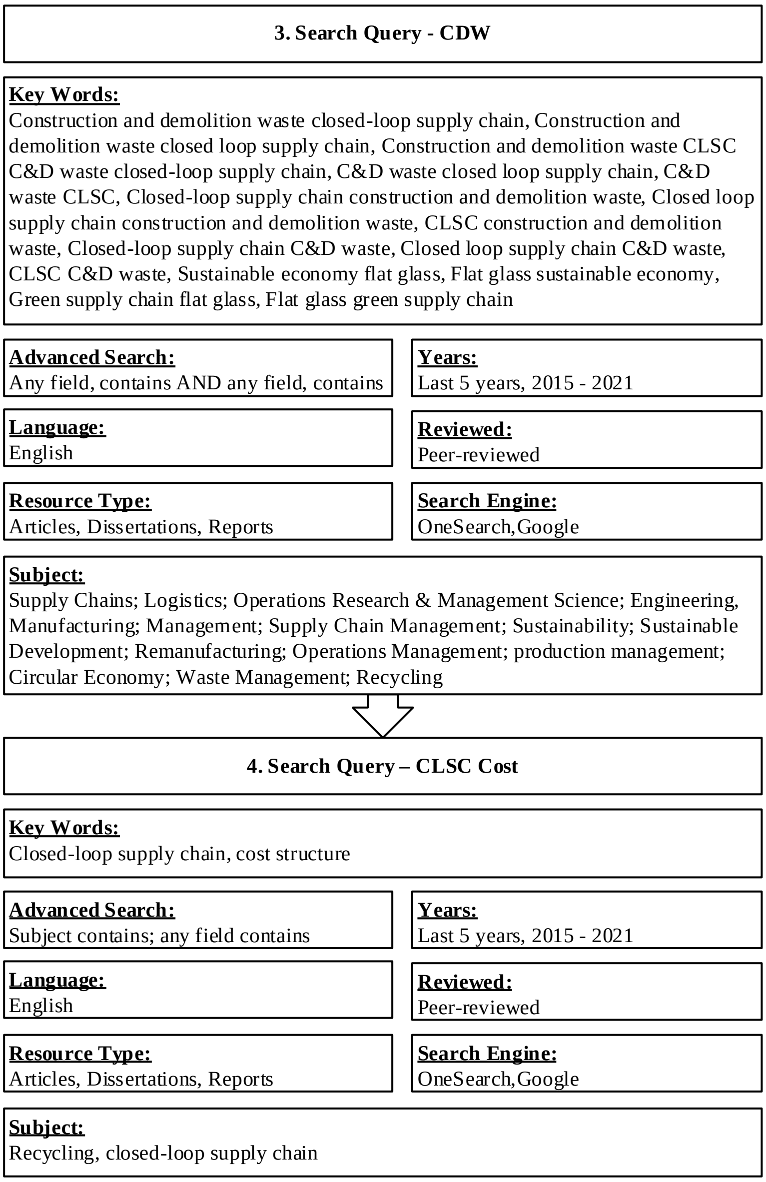


Figure 4: Literature Search 2.

2.8.2 Semi-structured Interviews

Semi-structured interviews, also referred to as qualitative research interviews, are non-standardized interviews. When conducting a semi-structured interview with an interpretivist approach the interviewer uses predetermined themes and questions to guide the process, but the process itself will be flexible and contingent on the answers of the subject. An example of this flexibility is that the order of which questions will be asked depends on the flow of the conversation with the subject and the data being shared with you. Depending on the answer provided the researcher might omit or modify the questions of certain themes during the interview (Saunders et al., 2019). For case studies interviews are one of the most important sources of information, as it enables the researcher to find explanations for events and insights into participant's perspectives and beliefs (Yin, 2018).

2.8.2.1 Our Choice of Approach

In preparation for the interviews the researchers constructed interview guides. Different versions were crafted for different types of companies to ensure that the guide contained as relevant questions as possible. The interview guides were provided to the supervisor which provided feedback. After the interview guides had been adjusted test interviews were conducted. As each of the researchers would be conducting interviews, multiple test interviews were done to ensure that researchers were prepared. The semi structured interviews were conducted in the native language of those interviewed. This was done to ensure precise information. The recordings of the interviews were then transcribed and translated.

2.9 Data Analysis Techniques

Yin (2018, p. 239) proposes that there is no right way of analyzing data in a case study, but rather that the researchers need to rely on their own "style of rigorous empirical thinking", their ability to gather sufficient data, and willingness to consider alternative interpretations, to get the best analytical results. To assist in this process Yin (2018) puts forth five analytical techniques for use in case studies: pattern matching, explanation building, time-series, logic model, and cross-case synthesis. Pattern matching is one of the techniques most suitable for case studies. It compares the patterns found in the case studies, with that of a prediction made by the researchers before the case study. If the empirical patterns collected match those predicted beforehand, the cases can be used to strengthen the internal validity of the case study. Explanation building is a specific type of pattern matching that analyses the empirical data of the case study by constructing an explanation of the case itself. The technique is mostly used in explanatory case studies. Time-series analysis is a technique that observes a phenomenon over time to investigate the effects an external variable has on it over time. The aim is to investigate whether a match can be found between the empirical trend observed and a theoretical trend predicted. Logic models are practical to evaluate case studies. Their purpose is to operationalize complex strings of events over time as a means to explain how they take place. Cross-case synthesis is only applicable to multiple-case studies. Cross-case synthesis is a case-based approach that enables the researchers to retain the integrity of the entire case rather than reducing it into a number of variables. The cases are then used to synthesize any pattern found across the cases (Yin, 2018).

2.9.1 Our Choice of Approach

For this thesis a cross-case synthesis technique will be applied to the cases of China, Germany, and Norway to answer the research questions of the thesis. In combination with the homogenous sampling process, cross-case synthesis will enable the researchers to look for patterns within the three flat glass markets and highlight minor differences that can affect the structure of the CLSC of flat glass and the costs associated with it.

2.10 Research Quality

In any type of research, it is impossible to know for certain that representation of the phenomenon and conclusion drawn are 100 percent factually true. Instead, what the researcher can do is to reduce the likelihood of making mistakes. Thus, it is important that the researcher has tools to assess the quality of their own and others research. Historically the two main criteria to assess the quality of research have been validity and reliability. Validity is a criterion for the integrity of the conclusions drawn. It covers the appropriateness of the measurements used, the accurateness of the analysis conducted are and how generalizable the findings are. Reliability is a criterion of the replicability of the results of the study. If the research is conducted again under the same circumstances the result should be the same (Bell et al., 2019; Saunders et al., 2019). While validity and reliability have attributes that make them appropriate to assess the quality of quantitative studies, the same is not necessarily the case for qualitative studies. Saunders et al. (2019) describe that interpretivist researchers seek to either adapt the tools before use, or they outright reject them as they often consider them as philosophically and technically inappropriate for qualitative studies (Ibid.).

Lincoln and Guba (1985 as cited in Saunders et al., 2019, pp. 216-217), Guba and Lincoln (1989 as cited in Ibid.) and Lincoln et al. (2011 as cited in Ibid.) developed alternative tools to reliability and validity for use in qualitative research. Lincoln and Guba developed dependability as an alternative for reliability, credibility for internal validity, and transferability for external validity. Since interpretivist research has a tendency of shifting focus as the research progresses, the researcher should aim to record all these changes to ensure a dependable account that can be evaluated by others.

Credibility is a criterion for how well the research's portrayal of a participant's realities accurately reflects their intention. There are many techniques available to ensure this. Initially it is important that the researcher spends sufficient time with the participant to build trust and collect adequate data. After finishing collecting data, the researcher can allow the participant to check the data collected, analysis conducted, and the interpretations made. This can help clear up any misunderstandings. During the research it is also important to be aware of one's own expectation of the research, to make sure that these views are not privileged at the expense of different views the participants might hold. The possibility of transferability is ensured by providing full descriptions of the research process. This enables the reader of the study to judge whether or not the study is transferable onto a different setting. Guba and Lincoln (1989 as cited in Saunders et al., 2019, p. 217) and Lincoln et al. (2011 as cited in Ibid.) developed the criterion authenticity criteria as an alternative to validity. These criteria were specifically designed for interpretivist research and encourages the researcher to be fair in their research process (Saunders et al., 2019).

2.11 Ethical Considerations

In recent years, ethics have developed into a topic that needs to be thoroughly reflected over to realize a successful research project. How the researcher can gain access to the data needed and possible ethical concerns that can arise during the project are important subjects for the researcher to address before conducting any research. In a research setting ethics can be defined as a standard of behavior that steers a researcher's behavior in relation to the subjects of his work. What constitutes the standard of behavior is affected by the broader social norms present in society. Ethical concerns can arise at any stage of the research, from choice of research topic to the presentation of the finished thesis (Saunders et al., 2019), but for this research the researchers have identified problems in relation to gaining access, the privacy of subjects, and the legal concerns regarding data protection and management as the most relevant to address.

For the success of this research gaining access to companies in both the flat glass production industry and construction industry, will be essential. This will enable the researchers to view the opportunities and obstacles of a flat glass CLSC from both a manufacturer and consumer viewpoint. Given the travel restrictions of the ongoing Covid-19 pandemic, the researchers will make use of internet-mediated access. Internet-mediated access involves the use of technological aids to gain virtual access to the interviewees. The semi structured interviews will be conducted through the use of zoom, Microsoft teams and a skype. Since the research requires interviews from multiple companies a multi-organizational access is needed. As a consequence of the researchers being external to the organizations they will approach, they will have to rely on their Goodwill. It is therefore important for gaining access that the researchers are able to demonstrate their own competence and integrity as well as describe the research project and its purpose clearly to the subjects (Saunders et al., 2019).

The next two ethical concerns arise when access has been given. When conducting interviews, the interviewees should have the option of maintaining their anonymity and the privacy of the information they provide (Saunders et al., 2019). Anonymity will be maintained by using fictional names for both the people and companies interviewed in this research. The privacy of the data collected will be upheld by not altering the information gathered and allowing the interviewee access to it to clear up any misconceptions or unclarities. Saunders et al. (2019) also highlights the importance of complying with data protection regulations. For counties in the EU, such as Sweden, the main regulation that must be followed is the data protection ordinance (GDPR).

2.11.1 GDPR

The general data protection regulation (GDPR) was enacted on the 25th of May 2018 and concerns the gathering, processing, and storage of personal data. The ordinance defines personal data as information that can be used to directly or indirectly identify a living person. The GDPR states that all personal data collected must meet certain fundamental principles: (Linnaeus University, 2021)

- Justified cause for collecting data.
- Subjects consent to the collection of data.
- Only necessary data is collected, processed, and stored.
- Data is not stored longer than needed.
- Data is stored in a secure way.

To address these principles the researchers have followed seven steps suggested by Linnaeus University (2021):

1. Identify if personal data is needed.
2. Define which data is needed and which purpose it has.
3. Register the processing of personal data at Linnaeus University.
4. Decide on a secure place to store personal information.
5. Decide how long the data is needed and when it can be deleted.
6. Inform the interviewee of the purpose of the data collection and obtain consent and collect data.
7. Process the collected personal data.

For this thesis, some personal information must be collected. Personal data such as name, place of work, and work title will be collected to extinguish between the respondents. Before the data collection process began the researchers registered the process at the university and decided on a secure store solution. All personal information gathered will be deleted once the thesis has been graded and uploaded to DiVA. Before any personal information was gathered the interviewee was informed about what data would be collected, What the information would be used for, who would have access to it, their right to take part in the collected data and withdraw their consent at any time, and that any complaints can be directed to the Linnaeus University and/or the Swedish data protection authority. After the interviewee was informed, consent was obtained, and the data collection began.

2.11.2 Individual Contributions

This research into CLSC of flat glass was conducted during the spring semester 2021 at Linnaeus University by the three researchers: Thor Lobekk Dahl, Yichang Lu, and Sidney Carina Thill. The decision to accept the offer to be a part of the flat glass research project was made unanimously, as every member of the group viewed it as an interesting and highly relevant topic. The methodological choices were investigated, debated, and decided on as a group, where every member got to front their point of view. To produce the thesis within the timeframe certain aspects of the thesis have been divided and worked on individually at times. These parts were then later evaluated and approved by the other members. Consequently, communication and planning have been two important aspects of this work. Even though members at times have worked individually, the authors of this thesis met either in person or through Zoom multiple times a week to discuss, evaluate and adjust the texts written.

During the five months of writing the thesis, multiple seminars were attended. In preparation for these all members read the opposition's text and provided questions and feedback for the seminar. Every seminar was attended by each of the members, who all contributed to defend the paper and offer feedback to the opposition.

In preparation for the interviews, the three members crafted interview guides and conducted test interviews together. But as the interviews were conducted in native languages, the different members conducted, transcribed, and translated an unequal number of interviews. The results of the interviews were analyzed in group and discussions of the results were a vital aspect of the work. Even though the members of the research team at times have worked on different aspects of the assignment, it is nonetheless the opinion of the group that every member has contributed equally to the finished product.

All members of the research team have been presented with the above statement in relation to individual contribution and agree with its conclusions.

2.12 Summarized Methodological Choices

Table 2 summarizes the methodological choices that have been made for this thesis.

Table 2: Summarized Methodological Choices.

Methodology	
Research Philosophy	Pragmatism
Approach to Theory Development	Abductive
Methodological Choice	Exploratory Qualitative
Research Strategy	Multiple Case Study
Time Horizon	Cross-sectional
Sampling	Purposive & Snowball
Data Collection Techniques	Literature Review & Semi-structured Interviews
Data Analysis Techniques	Cross-case Synthesis
Research Quality	Dependability, Credibility, Transferability
Ethical Considerations and GDPR	

3 RQ1: Closed-loop Supply Chain of Flat Glass

This chapter provides the theoretical framework necessary to build the framework of reference and provide a basis for the analysis. It includes a framework of reference, followed by the empirical findings and lastly, the analysis and discussion of the findings related to RQ1.

3.1 Theoretical Framework

In the following subchapters a theoretical framework will be established. This framework includes theory about flat glass as well as closed-loop supply chains. This knowledge will then be utilized to build a flat glass closed-loop supply chain (see figure 5).

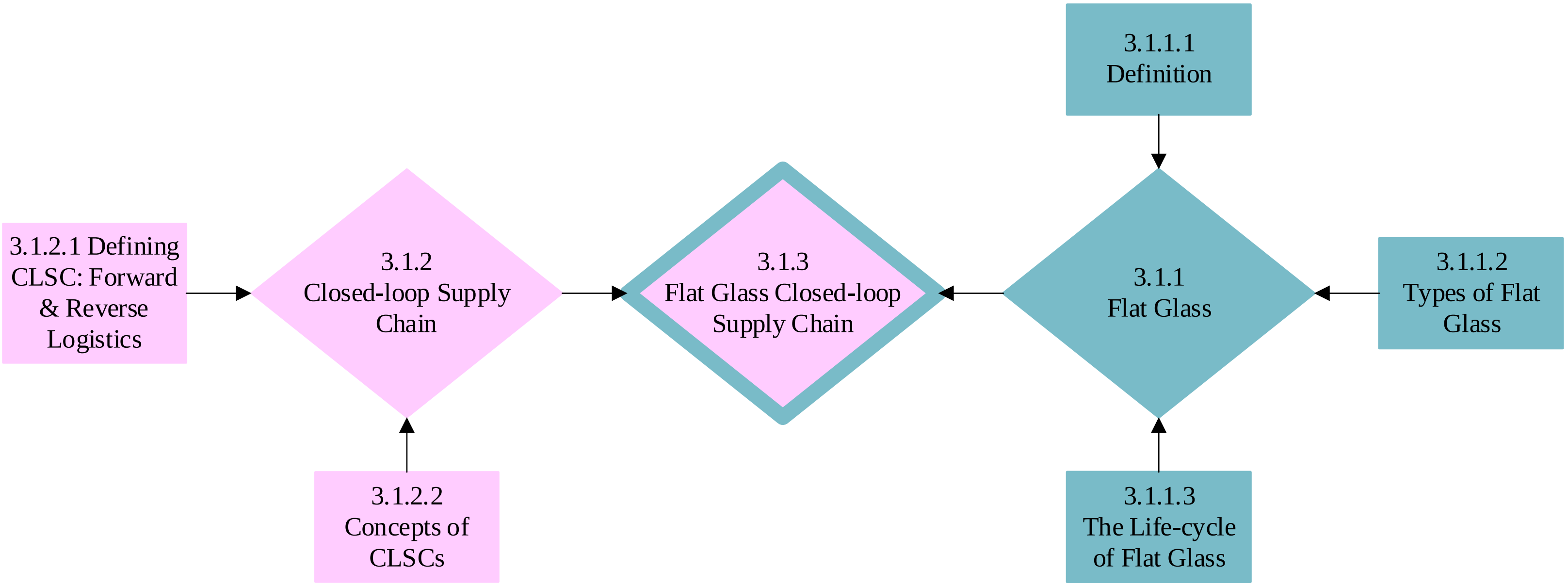


Figure 5: Theoretical Framework RQ1.

3.1.1 Flat Glass

This subchapter establishes a theoretical basis for flat glass (see figure 6). This includes defining what flat glass is, describing the types of flat glass, and illustrating the life-cycle of flat glass.

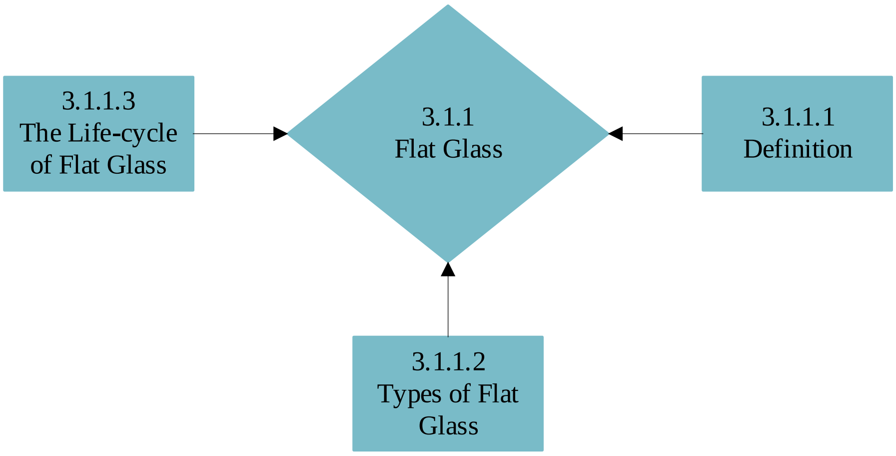


Figure 6: Theoretical Framework Flat Glass.

3.1.1.1 Definition

Flat glass is widely researched in the field of materials science. From a chemical view, Hess (2004) points out that flat glass is an amorphous material which is neither a solid nor a liquid, and it is made by fusing silica with a basic oxide. Geboes (2020) further elaborate raw materials of flat glass are silica sand, lime and soda. There are two significant characteristics of flat glass: transparency and durability. Compared with other transparent materials, such as plastics, flat glass is a desirable material because of its high temperature and corrosion resistance (Hess, 2004).

3.1.1.2 Types of Flat Glass

According to Market Research Future's (2021) report about the flat glass market, flat glass can be classified as annealed glass, tempered glass, insulated glass, coated glass, laminated glass, and others. Different types of flat glass have different characteristics (see table 3).

Table 3: Characteristics of Different Flat Glass Types.

Flat Glass Types	Characteristics	Reference
Annealed Glass	• High optical quality • Sensitive mechanical properties	Navarrete et al., 2017
Tempered Glass	• High stress resistance • Spontaneous breakage because of impurity particles expansion	Kua and Lu, 2016
Insulated Glass	• Excellent thermal insulation properties	Wüest and Luible, 2016
Coated Glass	• Self-cleaning • Anti-reflection • Heat preservation	Coherent Market Insights, 2020
Laminated Glass	• Excellent projectile protection properties	Hess, 2004

Annealed glass is the clear float glass from the float line without any treatment (Geboes, 2020). Navarrete et al. (2017) point out annealed glass has high optical quality, but its mechanical properties are sensitive to external factors (e.g., stress rate and environmental conditions). Vedrtnam and Pawar (2017, p. 317) highlight that annealed glass is “an initial material for producing superior products", such as tempered glass, coated glass and laminated glass.

Tempered glass is a type of safety glass with high stress resistance, usually stronger than normal annealed glass, i.e., four to five times. However, sometimes tempered glass may have spontaneous breakage because of impurity particles expansion (Kua and Lu, 2016).

Insulated glass typically consists of two or three layers of glass and hermetically-sealed gas cavity between layers. It has excellent thermal insulation properties (Wüest and Luible, 2016).

Coated flat glass has various properties compared with other types of flat glass, such as self-cleaning, anti-reflection and heat preservation (Coherent Market Insights, 2020).

Laminated glass is another type of safety glass with the multilayer combination of annealed float glass or tempered glass. It has excellent projectile protection properties and can even resist high-velocity projectiles (Hess, 2004).

3.1.1.3 *The Life-cycle of Flat Glass*

The life-cycle of flat glass mainly contains three phases: manufacture phase, use phase and waste management phase. The input of each of the phases is transformed into output and transported to the next phase. For instance, raw materials are transported to the manufacturing plant and transformed into flat glass product. Flat glass product is transported to the use phase and transformed into flat glass waste which is then transported to the waste management phase and transformed into end-of-waste (Geboes, 2020). According to Commission Regulation (EU) 1179/2012 (2012), end-of-waste is the certain type of waste which is no longer waste but becomes a product or a secondary material. Since the waste of flat glass is almost never recycled into new flat glass products, the life-cycle of flat glass is linear (Geboes, 2020). The simplified model for the life-cycle of flat glass is shown as figure 7.

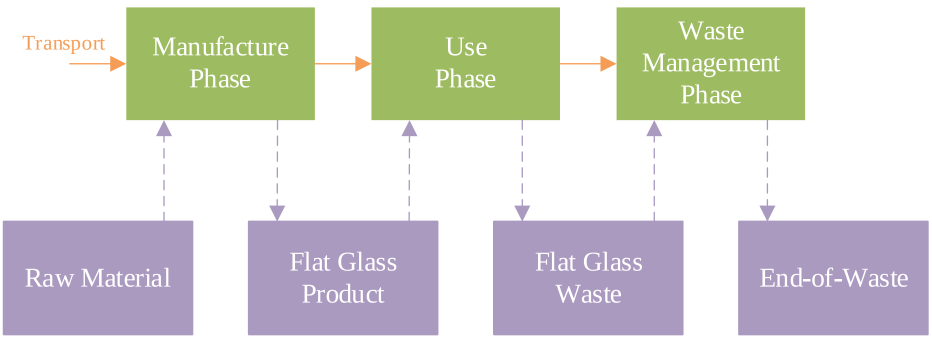


Figure 7: The simplified Model for the Life-cycle of Flat Glass (Geboes, 2020).

Flat Glass Manufacture

Flat glass has been produced by humans hundreds of years ago. According to Hess (2004), casting, blowing, and spinning were common manufacturing processes of flat glass in the early stages. Nascimento (2014, p.50) highlights that “the very first flat glass process was patented in March 22nd, 1848 by the English engineer Henry Bessemer”. Bessemer attempted to form a continuous ribbon of flat glass between rollers, however, it was not completely successful (Nascimento, 2014). In the early 1900’s, the manufacturing process of flat glass was improved in Belgium and the USA. “The molten glass was drawn vertically through rollers and then cooled” (Hess, 2004, p. 76). Since then, flat glass has better quality and various thicknesses, however, some problems such as “distortions, irregularities and inhomogeneities” (Nascimento, 2014, p. 50) still cannot be avoided during the manufacturing process.

Alastair Pilkington innovatively introduced the float process into flat glass manufacture, which has become an important technique widely used in the modern world. Therefore, modern flat glass is also called float glass (Li et al., 2017). Na et al. (2013) describe float glass manufacturing as “a continuous process whereby a ribbon of molten glass is produced in a furnace and then cooled on a bath of molten tin to ensure flatness” (Ibid., 2013, p. 561). Nascimento (2014) explains why molten tin is used in flat glass manufacturing. It is used because the surface of molten tin is flat, and its density of tin is greater than the density of glass. This ensures glass can float above the molten tin and cool to a flat state. Geboes (2020) points out that controlling temperature plays a significant role in the float process: melting raw materials with temperature up to 1500°C at first, then gradually cooling them down to 1100°C and keeping this temperature for several hours, so that the remaining air bubbles can be completely removed from the molten glass.

The float glass has an important place in the history of flat glass manufacture. From a historical point of view, the float process is a revolutionized start of mass production of flat glass (Nascimento, 2014). From a contemporary point of view, the integration of new technologies in the float process has increased the level of automation in the manufacture of flat glass (Na et al., 2013).

Uses of Flat Glass

Nowadays, there is a great demand for flat glass in different industries. According to Market Research Future (2021), flat glass products are commonly used in four industries: building and construction industry, automotive industry, consumer electronic industry, and solar industry. Correspondingly, flat glass products range from “window, automotive glazing, electronic display and solar energy panel” (Li et al., 2017, p. 46).

Among all the above-mentioned industries, the building and construction industry has the largest market share of flat glass, as shown in figure 8 (Market Research Future, 2021). Geboes (2020) specifies that the application of flat glass in the construction industry covers windows, transparent walls, and glass doors.

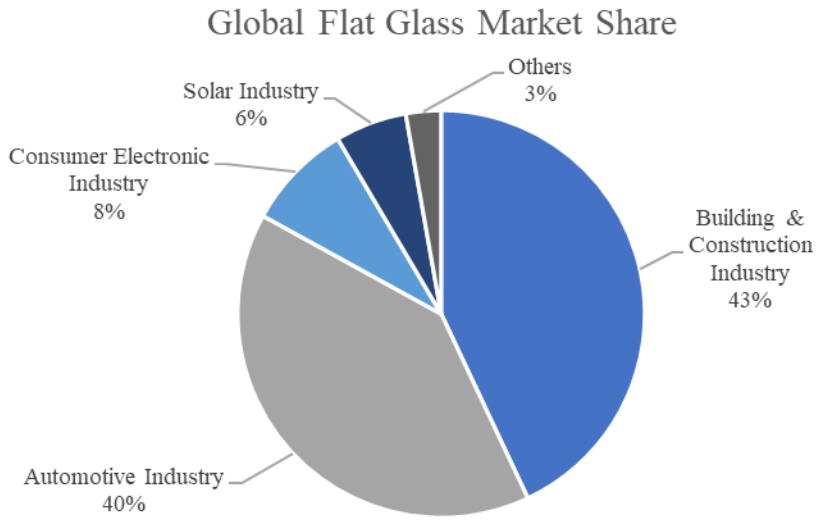


Figure 8: Global Flat Glass Market Share (Market Research Future, 2021).

Based on the characteristics of flat glass, different types of flat glass are widely used for construction products. Navarrete et al. (2017) mention that architects use annealed float glass to create "stairs, roofs, floors, frames and curtain walls" (Ibid., p. 417) due to its high optical quality. Kua and Lu (2016) point out that tempered glass, the safety glass with high stress resistance, is an ideal material for making building envelopes and interior systems of buildings. Bedon and Amadio (2018) state that many modern office buildings have glass facades made by high-performance insulated glass in order to prevent overheating in summer. Coherent Market Insights (2020) points out that coated flat glass can improve solar gain by preserving heating inside buildings, therefore, it is extensively used for windows, facades, and verandas. For buildings with high safety requirements, laminated glass can play an important role, because it has well-known "stiffness, impact strength, fracture pattern, and the load-bearing capacity" (Vedrtnam and Pawar, 2017, p. 317).

Flat Glass Waste Management

Flat glass might become waste in every life-cycle phase, Geboes (2020) classifies flat glass waste as "pre-consumer and post-consumer flat glass waste" (Ibid., p. 20). As one important part of CDW, flat glass waste from the EU is required to be managed under the Waste Framework Directive (Hillebrandt, 2019).

Flat glass has good recyclability potential. According to Commission Regulation (EU) 1179/2012 (2012), flat glass waste can be used as input for recovery operation. Geboes (2020) point out that flat glass waste can be recycled into secondary raw materials for new glass products, such as container glass and technical glass. According to Saint-Gobain (2014), flat glass cullet can be reused to manufacture new flat glass products, container glass and glass-wool. In addition to recycling flat glass waste to manufacture new glass products, some scholars have also evaluated the possibility of recycling flat glass waste together with other waste. For example, Rodrigues et al. (2021, p.1) highlight the innovation of using "solid waste from kraft pulp mill and flat glass cutting waste" in red ceramic products.

The importance of flat glass waste management has been increasingly adopted by academics. Although scholars have provided many available waste management solutions, the current recycle rate of flat glass is still low. Topateş (2020, p.555) states that "the rate of flat glass (construction, windows and vehicle glass) is 42% of the entire glass products, but the recycling rate of flat glass is only 11%". Geboes (2020) explains the low recycle rate of flat glass is due to the fact that landfills are still the mainstream of flat glass waste management. Saint-Gobain (2014) defines embankment, as "material recovery rather than recycling" (Ibid., p. 15), because it is the last resort for flat glass waste which cannot be secondary materials for manufacturing any new glass product.

Saint-Gobain (2014) points out that although flat glass cullet can be reused to manufacture any other glass products, new flat glass products can only accept flat glass waste which meets special requirements of color, purity, and quality. Strict requirements for flat glass products have become a main obstacle hindering the application of a circular life-cycle, which calls the urge to design a CLSC for flat glass.

3.1.2 Closed-loop Supply Chain

This subchapter establishes a theoretical basis for closed-loop supply chains (see figure 9). This includes defining forward and reverse supply chains, introducing the concept of circularity as well as the concepts of closed-loop supply chains.

Figure 9: Theoretical Framework Closed-loop Supply Chain.

3.1.2.1 Defining CLSC: Forward and Reverse Logistics

A traditional supply chain is solely concerned with a sequence of processes, such as the manufacturing of products and the distribution of these to the end customer (Kazemi et al., 2019). The distribution of the products from manufacturer to end customer is called forward logistics (FL) (Lippman, 2001 as cited in Ashby, 2018, p. 703). Actors in a traditional SC, also forward SC, include "suppliers, manufacturers, transporters, warehouses, retailers, and customers" (Chopra and Meindl, 2010 as cited in Govindan et al., 2015, p. 603).

As a result of an increased interest in sustainability and environmental matters, manufacturing companies have shifted their view of SCs from only consisting of forward streams to also including reverse streams (Kazemi et al., 2019). Rogers and Tibben-Lembke (1998, p. 2) define reverse logistics as

> "*the process of planning, implementing and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal."*

RL is what makes it possible to close the loop of a SC, making it a CLSC (Ashby, 2018). It consists of several activities which are needed to recover products that were returned. These activities may vary depending on the industry but can include the collection of used or EOL products, "product disposition, repair or remanufacturing, remarketing, and recycling" (Amin et al., 2018, p. 154). Actors of a reverse supply chain may include customers, collectors or collection facilities, disassemblers or disassembly facilities, recovery and recycling facilities, disposal facilities and landfills, and manufacturers (Ibid.). By combining RL with FL into a CLSC companies can reclaim value of an EOL product and create value while minimizing waste and generating business for material recovery (Kazemi et al., 2019). In short RL enables to use EOL products to the maximum and it enables "the implementation of the environment-focused activities of recycling, reuse, remanufacturing and repair" (Ashby, 2018, p. 703).

Closed-loop supply chains were developed as a result of disruption of traditional SCs by CE (Holgado and Aminoff, 2019). Circular economy is understood as

> *"an industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shifts toward the use of renewable energy, eliminates the use of toxic chemicals impairing reuse, and aims at eliminating waste through the superior design of materials, products, systems, and business models" (Ellen MacArthur Foundation, 2016 as cited in Mahpour, 2018, p. 216).*

Figure 10 shows a basic CLSC including forward and reverse flows (differentiated in green and blue in the figure), and typical CLSC tasks which are included in each of the flows. Figure 11 shows common CLSC actors within the forward and reverse SC. Another example of a generic CLSC can be found in Govindan et al. (2015).

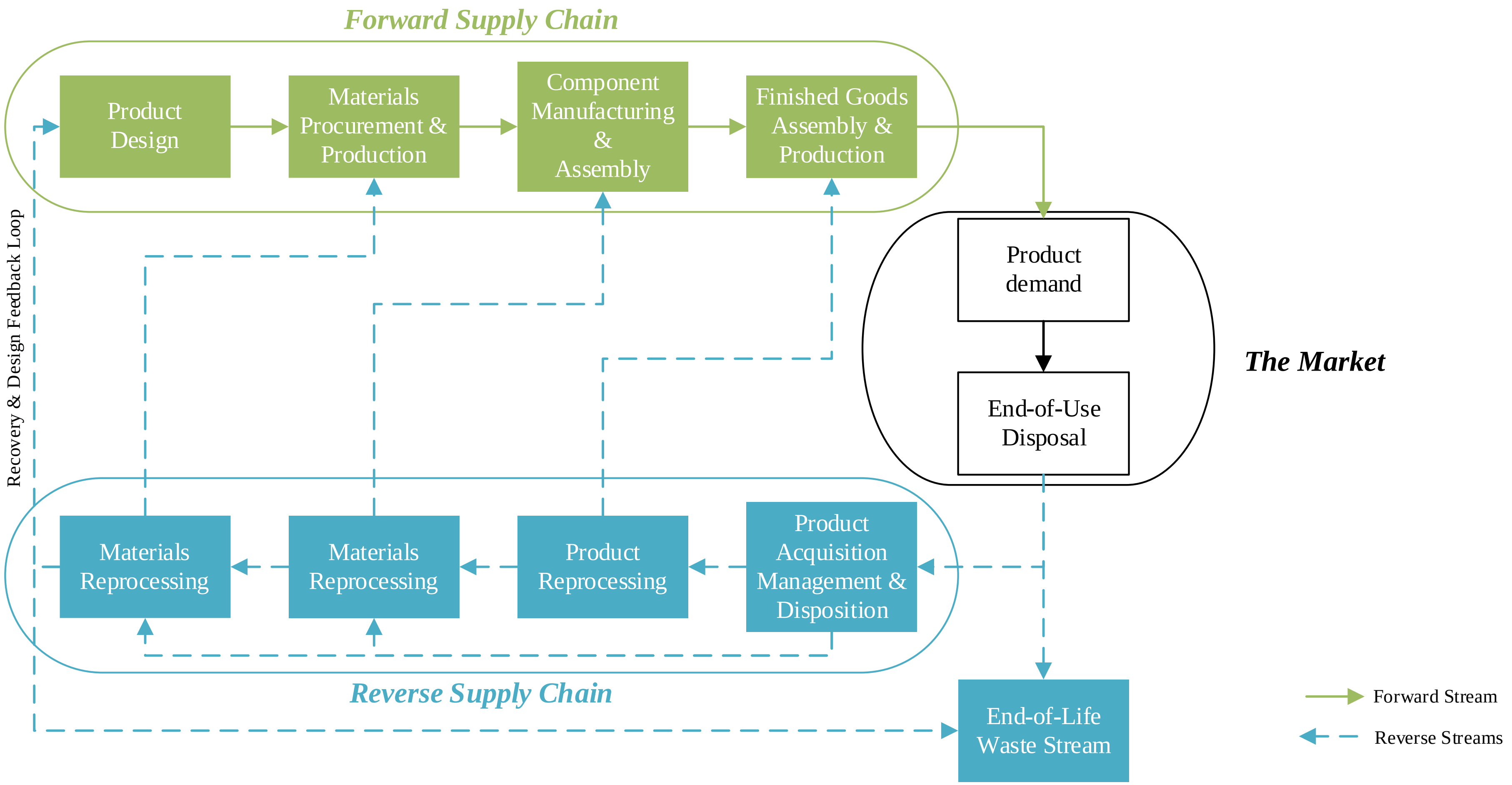


Figure 10: Common CLSC Processes (Abbey and Guide, 2017 as cited in Kazemi et al., 2019, p. 4938).

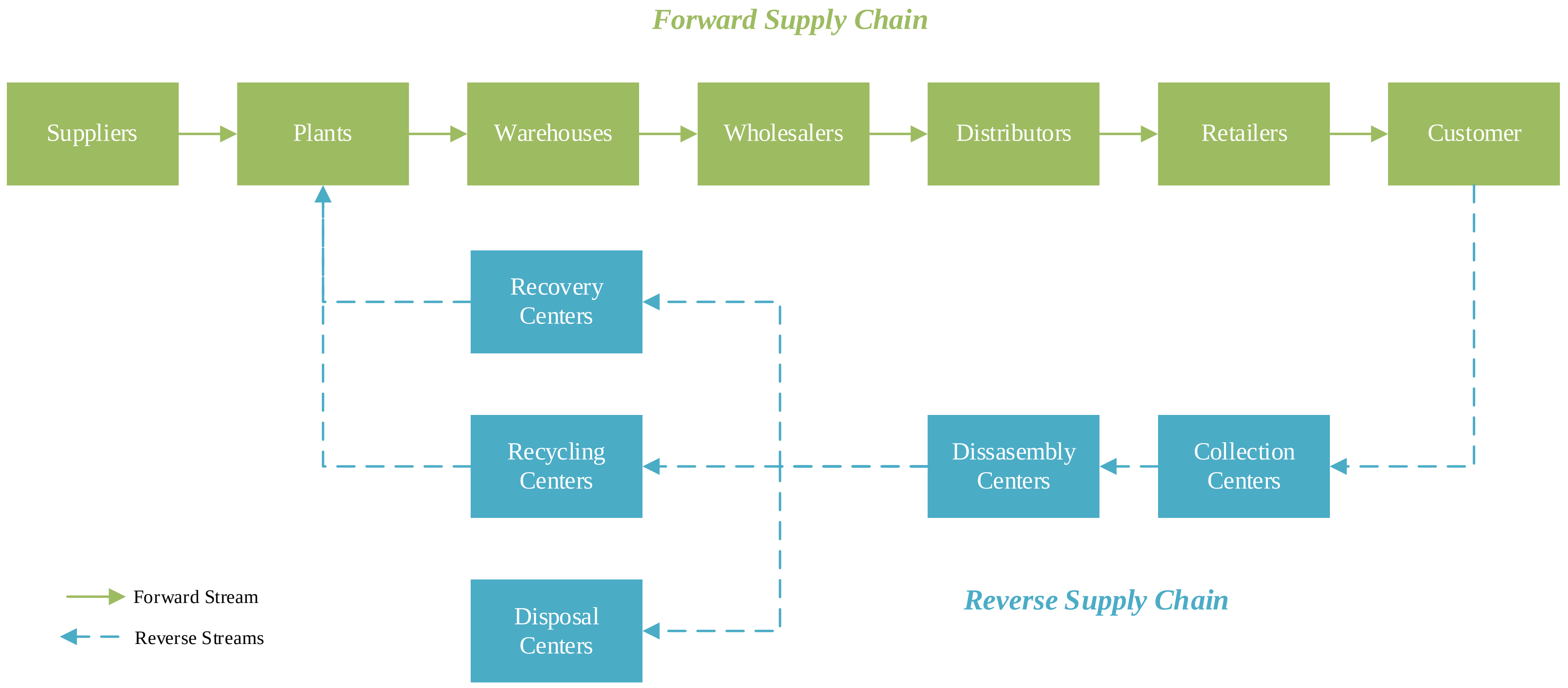


Figure 11: Common CLSC Actors (Amin et al., 2018, p. 154).

3.1.2.2 Concepts of CLSCs

Closed-loop supply chains are considered to be "one of the main drivers of sustainability, and […] one of the primary factors in achieving sustainable operations" (Kleindorfer, Singhal, and Wassenhove, 2005 as cited in Kazemi et al., 2019, p. 4938), lowering the environmental consequences resulting from manufacturing processes (Ibid.). As mentioned in the previous chapter, CLSCs consist of FL and RL, with RL making it possible to close the loop. RL is also the place where the concepts of CLSCs and its activities are applied (Ashby, 2018).

The concepts of CLSCs are the Rs of reverse logistics. Researchers are discordant when it comes to what the Rs are or how many should be considered and are relevant. Commonly mentioned Rs in the context of CDW are the 3Rs "reduce, reuse and recycle" (Peng et al., 1997 as cited in Huang et al., 2018, p. 36). Ashby (2018) also mentions remanufacturing and repair.

To reduce means to decrease the amount of something specifically in order to reduce waste. Yang et al. (2017, p. 395) mention the reduction of "hazardous or toxic materials" from CDW and the use of up-to-date technology to be ways of reducing CDW (Ibid.). When designing a plan which manages CDW, the principle of reduce should be taken into consideration first, because "waste reduction is the optimal management measure due to having the lowest adverse impacts on the environment" (Huang et al., 2018, p. 40).

Another R is reuse. To reuse means to utilize materials again after their initial use. The material can only be reused if it is in the condition to be used for the same initial purpose or if it is eligible for a different purpose. The latter is also called repurposing (Huang et al., 2018). Reuse utilizes the used components promoting waste reductions as well as a better handling of available resources (Ashby, 2018).

Recycling is the method of transforming a product or material into a different product (Yang et al., 2017). The product is disassembled into parts which can then be utilized in new products (Huang et al., 2018). Field and Sroufe (2007 as cited in Ashby, 2018, p. 703) mention the following about the recycling process: "recycling requires disassembly of the waste or returned product, separation of parts and material reprocessing, and denotes material recovery without conserving any of the original product's features." To recycle is about recovering material (Kenne et al., 2012 as cited in Ashby, 2018, p. 703) which in general saves costs and has lower effects on the environment (Field and Sroufe, 2007 as cited in Ashby, 2018, p. 703).

To remanufacture a used product means to rebuild it by using a combination of parts. Used products are returned to the manufacturer for remanufacturing. The process consists of "sorting, inspection, disassembly, cleaning, reprocessing and reassembly, and replacement of parts which cannot be brought back to original quality" (Hatcher et al., 2009 as cited in Ashby, 2018, p. 703). Contrary to recycling, remanufacturing is about recovering value (Kenne et al., 2012 as cited in Ashby, 2018, p. 703). However, just like recycling it saves costs as well as lowers environmental effects (Field and Srouffe, 2007 as cited in Ashby, 2018, p. 703). In addition, remanufacturing a product prolongs the life of that product and used parts do not end up in landfills instead are reverted back into manufacturing (Ashby, 2018).

To repair a product means to restore its parts to working condition (Kumar and Putnam, 2008 as cited in Ashby, 2018, p. 704). The manufacturer repairs the customer's product (Kusumastuti et al., 2008 as cited in Ashby, 2018, p. 704) until the products becomes an EOL-product which decreases unnecessary waste disposal and increases a products lifespan (Ashby, 2018).

The following table lists the challenges that each of the R principles are faced with.

Table 4: Challenges of the Rs.

R	Challenge
Reduce	"lack of building design standard for reducing CDW, low cost for CDW disposal and inappropriate urban planning" (Huang et al., 2018, p. 36)
Reuse	"lack of guidance for effective CDW collection and sorting, lack of knowledge and standard for reused CDW, and an under-developed market for reused CDW" (Huang et al., 2018, p. 36)
Recycle	"ineffective management system, immature recycling technology, under-developed market for recycled CDW products and immature recycling market operation" (Huang et al., 2018, p. 36)
Remanufacture	"inflexible standards, technical and economic feasibility" (Geboes, 2020, p. 87)
Repair	

3.1.3 Flat Glass Closed-loop Supply Chain

Based on the theory provided in the previous chapters (3.1.1 Flat Glass and 3.1.2 Closed-loop Supply Chain) a generic flat glass CLSC is built in three steps:

1. Life-cycle of Flat Glass
2. Add a Reverse Supply Chain
3. Build a Generic Flat Glass Closed-loop Supply Chain

The life-cycle of flat glass, which can be found in chapter 3.1.1.3 The Life-cycle of Flat Glass, is the starting point of the generic CLSC model. Due to the linearity of the life-cycle a reverse SC needs to be added to it (see figure 12) as the second step. Lastly, the figure is adjusted based on the theory from the previous chapters. Figure 13 shows the simple generic flat glass CLSC. The generic flat glass CLSC only depicts the general process steps not the actors. Based on the life-cycle phases of flat glass and possible CLSC actors mentioned previously, the actors in the process steps are manufacturer, construction and demolition companies, and recyclers.

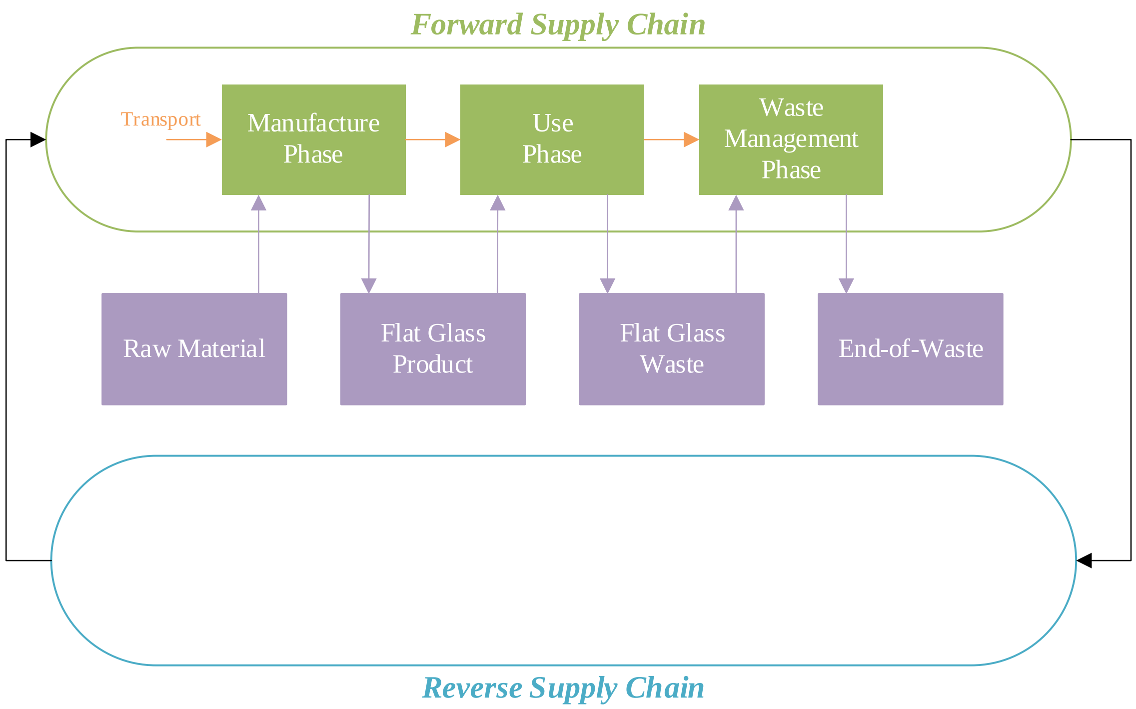


Figure 12: Life-cycle Flat Glass with added Reverse Supply Chain (Abbey and Guide, 2017 as cited in Kazemi et al., 2019, p. 4938; Geboes, 2020).

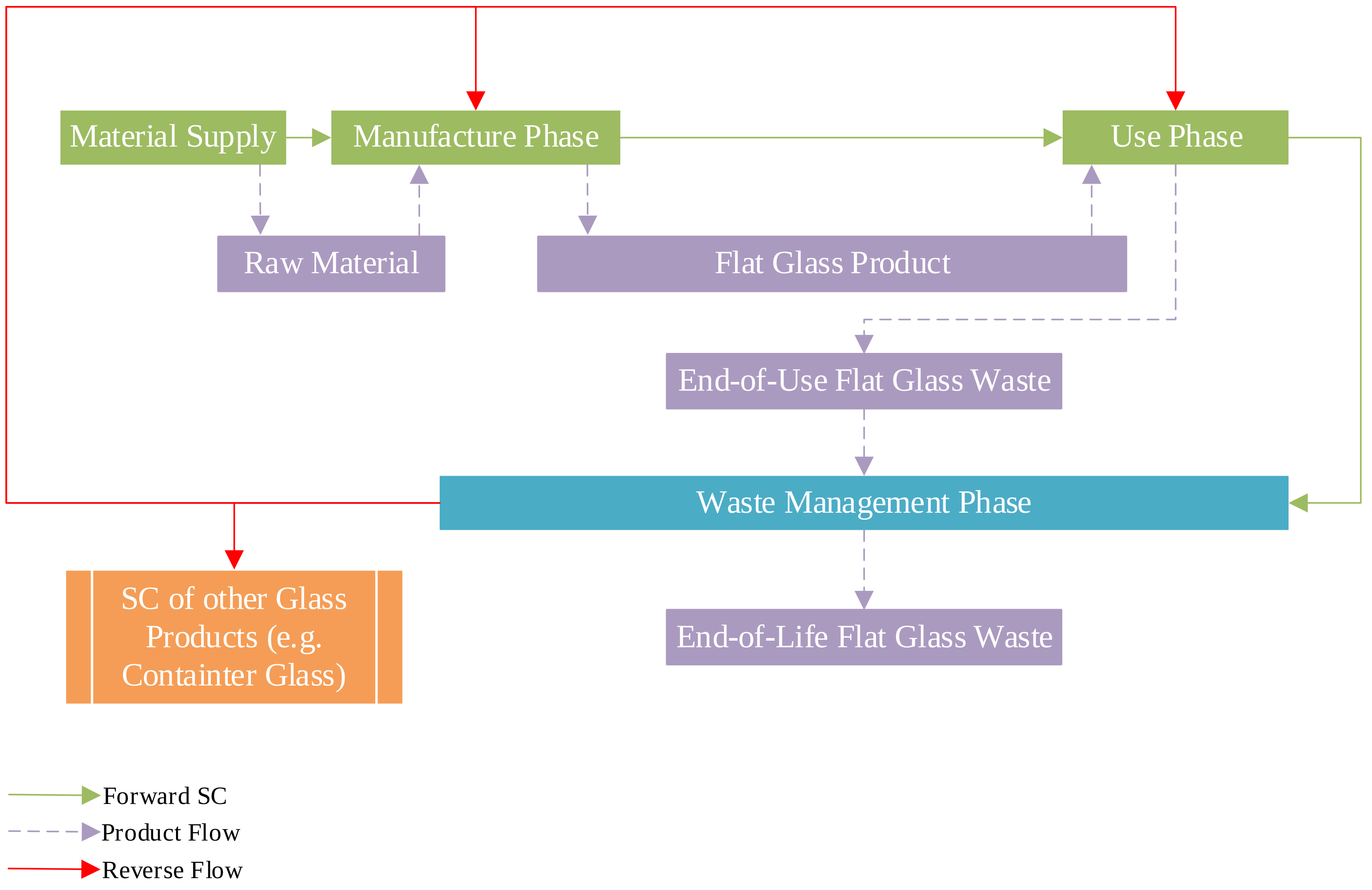


Figure 13: Generic Flat Glass Closed-loop Supply Chain (Geboes, 2020).

3.2 Framework of Reference

This chapter presents the research model and operationalization model for RQ1 and its sub-questions. In the end, the concepts described in theory are summarized.

3.2.1 Research Model

The research model for RQ1 and its sub-questions is visualized in figure 14. In short, the analysis is based on empirical data which is based on theory. A generic flat glass CLSC was developed by combining flat glass and CLSC theory. The theory will pose as the foundation for the interviews. The findings of the empiry part of the research model will then be analyzed and used to build a flat glass CLSC model. The question marks visualize the parts of the generic flat glass CLSC model that are unknown. The interview guides that were used to gather empirical data can be found in the appendices.

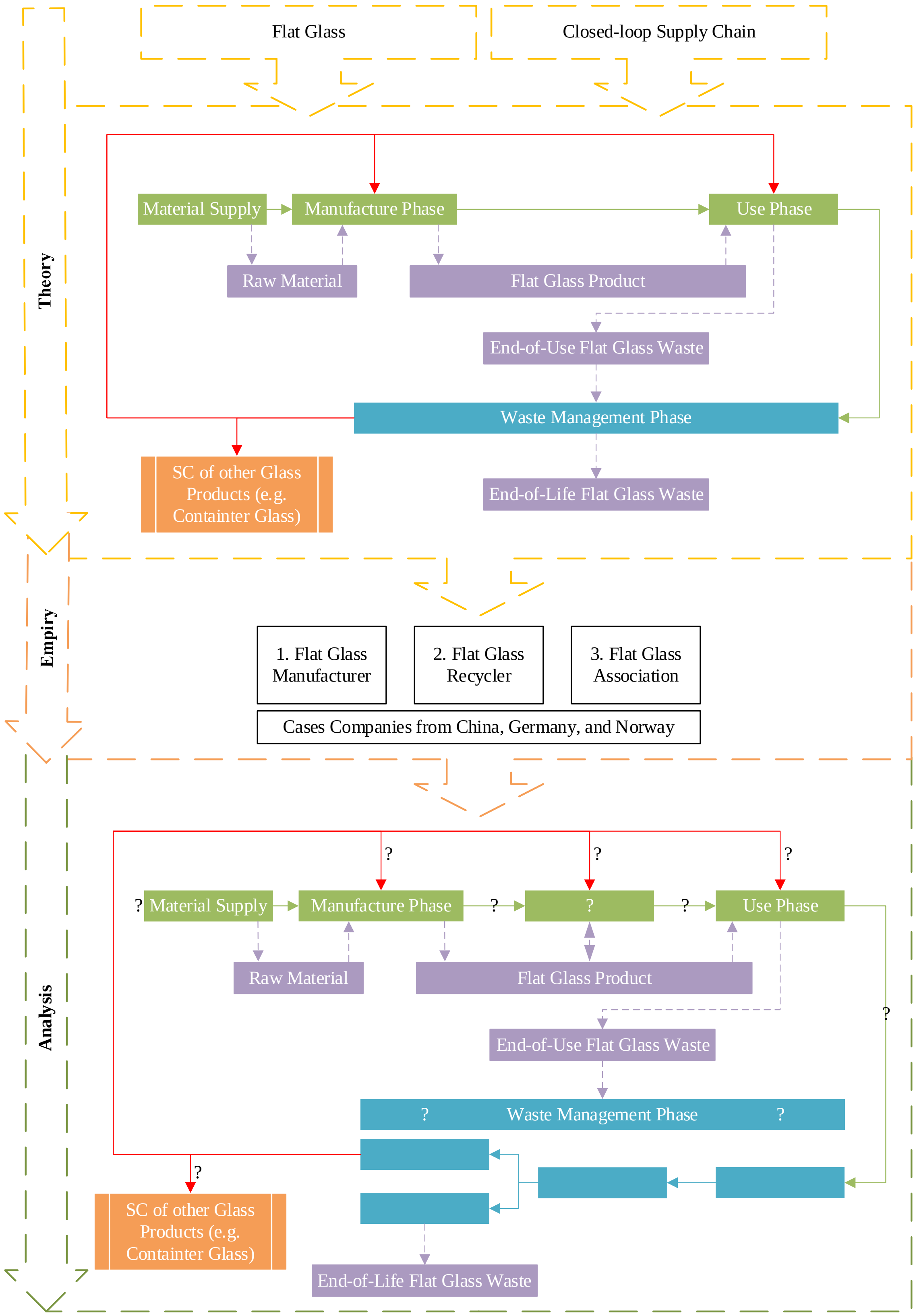


Figure 14: Research Model RQ 1 (Design inspired by Girot and Kopf, 2018).

3.2.2 Operationalization Model

Table 5 is a summary of these concepts which are described in more detail in the previous theory chapters.

Table 5: Operationalization RQ1 (Design inspired by Girot and Kopf, 2018).

Concept	Operationalization
Flat Glass	Flat glass is an amorphous material which is neither a solid nor a liquid, and it is made by silica sand, lime and soda (Hess, 2004; Geboes, 2020). Flat glass products range from "window, automotive glazing, electronic display and solar energy panel" (Li et al., 2017., p. 46). Modern flat glass is also called float glass (Ibid.).
Types of Flat Glass	Flat glass can be classified as annealed glass, tempered glass, insulated glass, coated glass, laminated glass, and others (Market Research Future, 2021).
Life-cycle of Flat Glass	The life-cycle of flat glass mainly contains three phases: manufacture phase, use phase and waste management phase (Geboes, 2020).
Forward Logistics	The distribution of the products from manufacturer to end customer is called forward logistics (FL) (Lippman, 2001 as cited in Ashby, 2018, p. 703).
Reverse Logistics	Rogers and Tibben-Lembke (1998, p. 2) define reverse logistics as "the process of planning, implementing and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal."
Circular Economy	Circular economy is understood as "an industrial system that is restorative or regenerative by intention and design" (Ellen MacArthur Foundation, 2016 as cited in Mahpour, 2018, p. 216).
Reduce	To reduce means to decrease the amount of something specifically in order to reduce waste (Yang et al., 2017).
Reuse	To reuse means to utilize materials again after their initial use (Huang et al., 2018).
Recycle	Recycling is the method of transforming a product or material into a different product (Yang et al., 2017). The product is disassembled into parts which can then be utilized in new products (Huang et al., 2018).
Remanufacture	To remanufacture a used product means to rebuild it by using a combination of parts. Contrary to recycling, remanufacturing is about recovering value (Kenne et al., 2012 as cited in Ashby, 2018, p. 703).
Repair	To repair a product means to restore its parts to working condition (Kumar and Putnam, 2008 as cited in Ashby, 2018, p. 704).

3.3 Empirical Findings

The following subchapters encompass empirical findings related to the closed-loop supply chain of flat glass from China, Germany, and Norway.

3.3.1 Flat Glass Manufacturing in China

3.3.1.1 CHIMA1 – Case Description

The business scope of this company covers deep processing and sales of tempered glass products. Customization is this company's business model: customers provide their requirements of products (size, thickness, etc.) at first, then the company will purchase materials and produce tempered glass products according to customers' needs.

The interviewee is the production manager of this company. The production manager was able to describe the full picture of the company's SC. However, he can only roughly describe the cost aspect due to lack of relevant knowledge. Table 6 shows the respondent overview.

Table 6: Case CHIMA1 Interviewee Overview.

Case	Respondent	Company	Interview Method	Date
CHIMA1	Production Manager	Manufacturer	Voice Call	10.05.2021

3.3.1.2 CHIMA1 – Supply Chain

According to the production manager, CHIMA1 does not produce float glass but purchases float glass as materials for processing tempered glass. Companies that produce float glass are CHIMA1's suppliers. All their materials come from mainland China, and float glass suppliers are responsible for delivering materials to their processing plants.

Construction companies play the role of customers in this company's supply chain. When tempered glass products are ready, most products will be directly transported to construction sites. In a few cases, construction companies will come to pick up tempered glass products from CHIMA1 by themselves.

Today, CHIMA1 does not use recycled materials in processing tempered glass products. According to the production manager, there are three main reasons. Firstly, the production of tempered glass has strict quality requirements for materials, and recycled float glass usually cannot meet these requirements. Secondly, materials for tempered glass are in short supply in the market nowadays, recycled materials which meet the requirements are even scarcer, it is impractical to use recycled materials to produce tempered glass on a large scale. Thirdly, there is the possibility of using recycled materials in manufacturing float glass at first, then processing them into tempered glass, but CHIMA1 does not have the capacity of producing float glass yet. CHIMA1 purchases float glasses from the float glass manufacturers, however, the production manager is unsure whether those float glass contain recycled materials or not. He also points out that if float glass meets the requirements, even if it contains recycled materials, it will not affect the quality of tempered glass.

The production of tempered glass will generate some waste. According to the production manager, recyclers will come to collect waste from the company and categorize them into different grades based on their qualities. The production manager points out that high-grade flat glass waste could be reused in manufacturing new flat glass products, low-grade flat glass waste could be reused in manufacturing other glass products such as container glasses or low-grade windows.

Figure 15 shows CHIMA1’s supply chain.

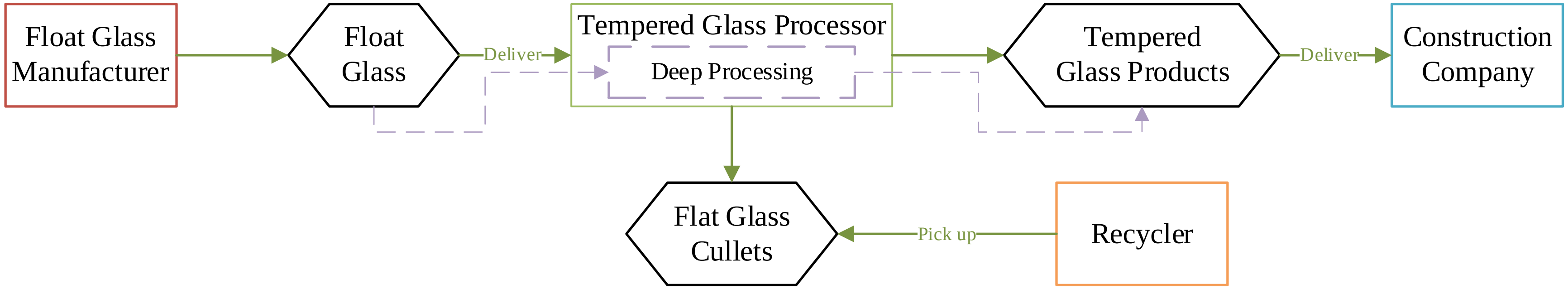


Figure 15: CHIMA1 Flat Glass SC.

3.3.1.3 CHIMA2 – Case Description

The case company is a large-scale state-owned flat glass manufacturing company which occupies 422 acres in Southeastern China. The business scope of the case company includes R&D of energy-saving glass and building materials; production, processing, and sales of flat glass; technology import and export business. On the one hand, the company has 520 ton/day high-quality float glass production lines. On the other hand, the company has deep processing equipment which include LiSEC's Smart Hollow Connection System from Austria, and Glaston tempering furnace from Finland. With advanced technology support, the case company can produce single-piece and composite flat glass deep processing products, such as tempered glass, hollow glass, laminated glass, silk screen glass, coating glass, etc.

Two employees from this company were interviewed: one is the director of the float glass production workshop; another is the deputy minister of the equipment department. Both interviewees have broad knowledge of the entire SC of flat glass and are familiar with costs of their flat glass production. Table 7 shows the respondents overview.

Table 7: Case CHIMA2 Interviewee Overview.

Case	Respondent	Company	Interview Method	Date
CHIMA2	Director of Float Glass Production Workshop	Manufacturer	Voice Call	18.5.2021
	Deputy Minister of Equipment Management		Voice Call	19.5.2021

3.3.1.4 CHIMA2 – Closed-loop Supply Chain

CHIMA2 has capacities of producing float glass and using float glass to deep process other flat glass products. According to the director, their float glasses cannot only be sold as final products, but also can be used as the material for producing the company's other deep-processed flat glass products. Further, the float glass they produced is sufficient for deep processing, so they do not need to purchase float glass from others.

CHIMA2 purchases all raw materials for float glass in China, and suppliers are responsible for delivering raw materials to the company. Some raw materials will be directly sent to the float glass workshops; others will be stored into the company's warehouses.

CHIMA2 sells their products to large-scale glass distributors instead of end customers. They do not deliver their products to glass distributors by themselves, however, they outsource transportations to freight haulers. Usually, the finished flat glass products will be sent to flat glass distributors directly. If there are excess products, the company will store them into warehouses.

CHIMA2 uses recycled flat glass cullet as one of raw materials in manufacturing the float glass. The director points out that adding flat glass cullets can not only save energy because it lowers the melting point of materials but can also meet the requirement of sustainable development. The company has commissioned a third-party recycling agency to collect flat glass cullets, and the company will clean and sort cullets before putting it into float glass production. The director also emphasizes that there are high requirements of recycled cullets, only cullets from flat glass can be reused in producing float glass, other types of cullets cannot meet requirements.

According to the director, freshly formed float glass has irregular natural edges. CHIMA2 cuts float glass according to size requirements, which will also generate flat glass cullets. The deputy minister mentions that in the float glass production line, glass cullets will be put on the conveyor belt and sent back to the material bin. The director also points out that their own cullets are cleaner and have better quality than the one purchased from other companies, hence no additional disposal is required.

The deputy minister mentions that from the internal production process, CHIMA2 has established an internal circulation system: flat glass cullet generated in float glass production line and deep processing will be 100% reused into producing new float glass, therefore there is no waste of flat glass within the company. In addition, CHIMA2 has built a long-term partnership with the third-party recycling agency to collect flat glass cullets as important raw material for float glass production.

Figure 16 shows CHIMA2’s CLSC.

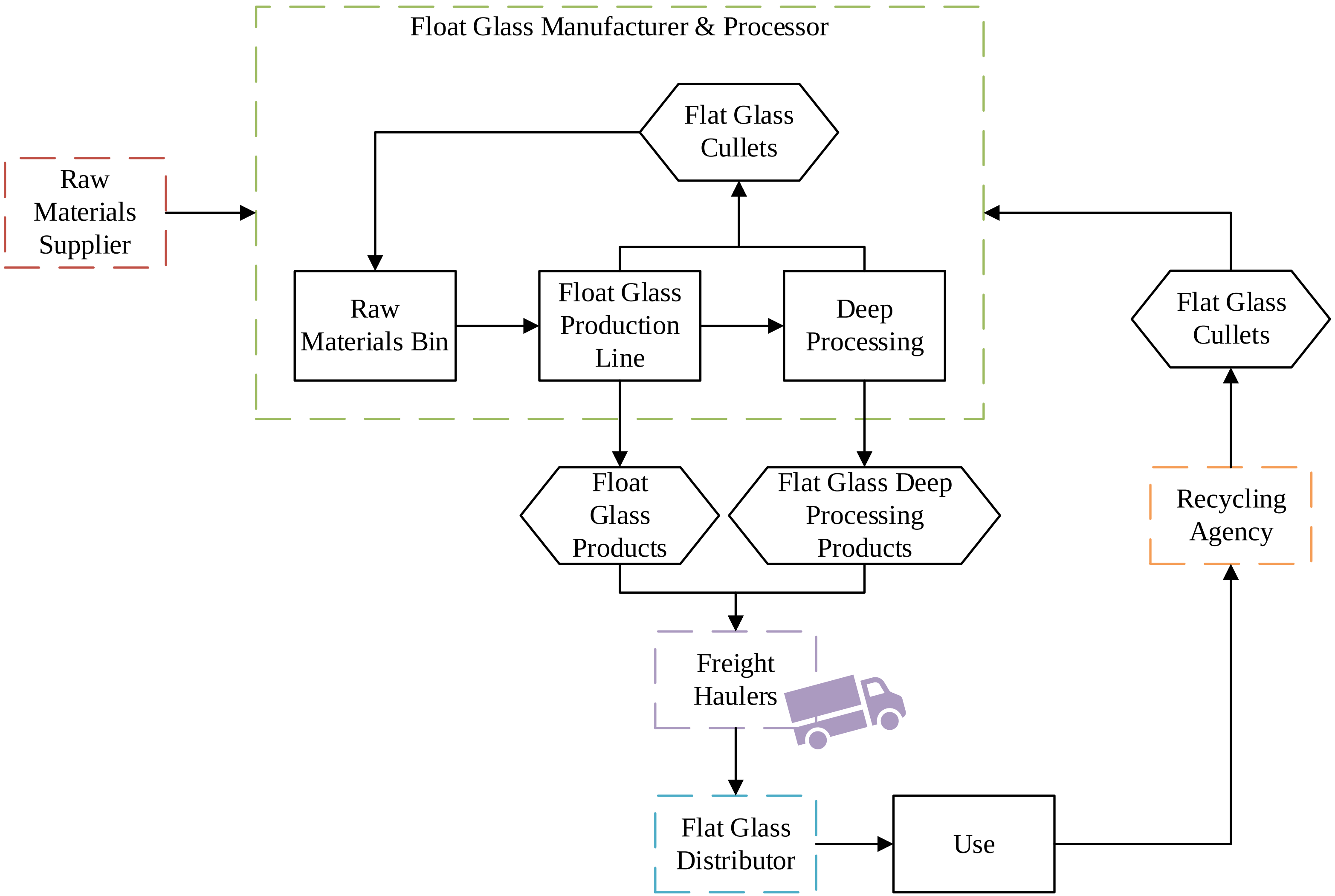


Figure 16: CHIMA2 Flat Glass CLSC.

3.3.2 Flat Glass Recycling in Germany

3.3.2.1 GERRE – Case Description

The company behind case RG is a recycling family business. The company originates in western Germany but has several offices in other European countries. The case company is divided into several subdivisions, but the main focus is on glass recycling, which includes both container glass and flat glass recycling. They offer full service, i.e., consulting on recycling matters, flexible collection methods, processing, as well as high quality recycled glass cullets. The company views flat glass waste as secondary material rather than waste.

The interviewee was an employee working int a product management position in the research and development (R&D) department. The interviewee was able to provide detailed and interesting information into the German waste management phase of the flat glass life-cycle. The only downside was that the interviewee did not have extensive knowledge about cost aspects. Table 8 shows the respondents overview.

Table 8: Case GERRE Interviewee Overview.

Case	Respondent	Company	Interview Method	Date
GERRE	Product Management in R&D	Recycler	Video Call	11.05.2021

3.3.2.2 GERRE – Closed-loop Supply Chain

The recycling process begins with the delivery of flat glass. The case company has its own truck fleet but also works with external haulers. Ideally, the truck loads come from a rather close proximity because flat glass is a fragile material. The longer the distance between point A to the recycler the higher the risk of quality deteriorating. The goal is to keep the distances as short as possible. The company obtains most of its secondary material from within Germany rarely from abroad.

When the secondary material is delivered, the quality is assessed. This step is the most important step in the entire process. The company differentiates between three types of quality: (1) Highest Quality; (2) glass from pre-consumer sources; (3) glass from post-consumer sources.

The first category is pure flat glass. This usually comes directly from flat glass producers or refiners. Here, waste occurs when the pure flat glass is cut into specific sizes form the 3m by 6m glass rectangle. This type of secondary material can be processed in a way that it can be used and melted for flat glass production. This means flat glass waste can be reused for flat glass production as long as it is not contaminated.

The second category, pre-consumer glass, is mainly made up of (high penetration resistant) laminated glass. Here the flat glass has not yet reached the consumer.

The third category, post-consumer glass, includes all flat glass types, which can contain laminated glass, isolated glass etc. It is a mix of glass in which one cannot differentiate between pre- or post-consumer glass. This type of glass can come from constructions and demolitions.

The processing of flat glass as a secondary material is very delicate and underlies numerous specifications and standards to ensure high quality. The interviewee underlines the importance of this process step, i.e., the assessment step; one insufficient delivery that has not been checked properly can destroy various other high quality charges.

After the flat glass has been sorted into the three different categories, it will be roughly crushed. This is necessary because the machines used in the processing step cannot process entire sheets of flat glass.

The crushed material is then processed in different types of machines depending on its initial quality. These machines contain technology for crushing, suction, magnetic separation, filtering, optical sorting and more. The goal here is to clean the flat glass from all impurities that it contains. Cullets are the results of the processing. They fulfill the high standards to be then used in either flat glass or container glass production.

Flat glass as a secondary material can be reused in flat glass production but only if it fulfills the highest standards. If it does not fulfill these standards, it will be recycled and used in container glass production. Here, the interviewee points out that it is nearly impossible to get rid of all the impurities, however the case company has high rates. According to the interviewee, even though the lower quality glass cannot be kept in the flat glass CLSC it is still fed into the container glass loop and is therefore recycled. This is neither a better nor a worse application, i.e., the material is not wasted.

To ensure high quality levels, the processing steps are accompanied by an internal laboratory, which regularly examines the quality of the glass.

The recycling process ends with the cullets ready for delivery. Here a close proximity to the customer is desirable. The interviewee underlines the importance of local production and close proximity due to the fragility of the highest quality cullets that go back into flat glass production. Cullets for container glass can be delivered to customers outside of Germany.

Figure 17 shows the flat glass CLSC in case GERRE with a detailed view onto the recycling process of the case company.

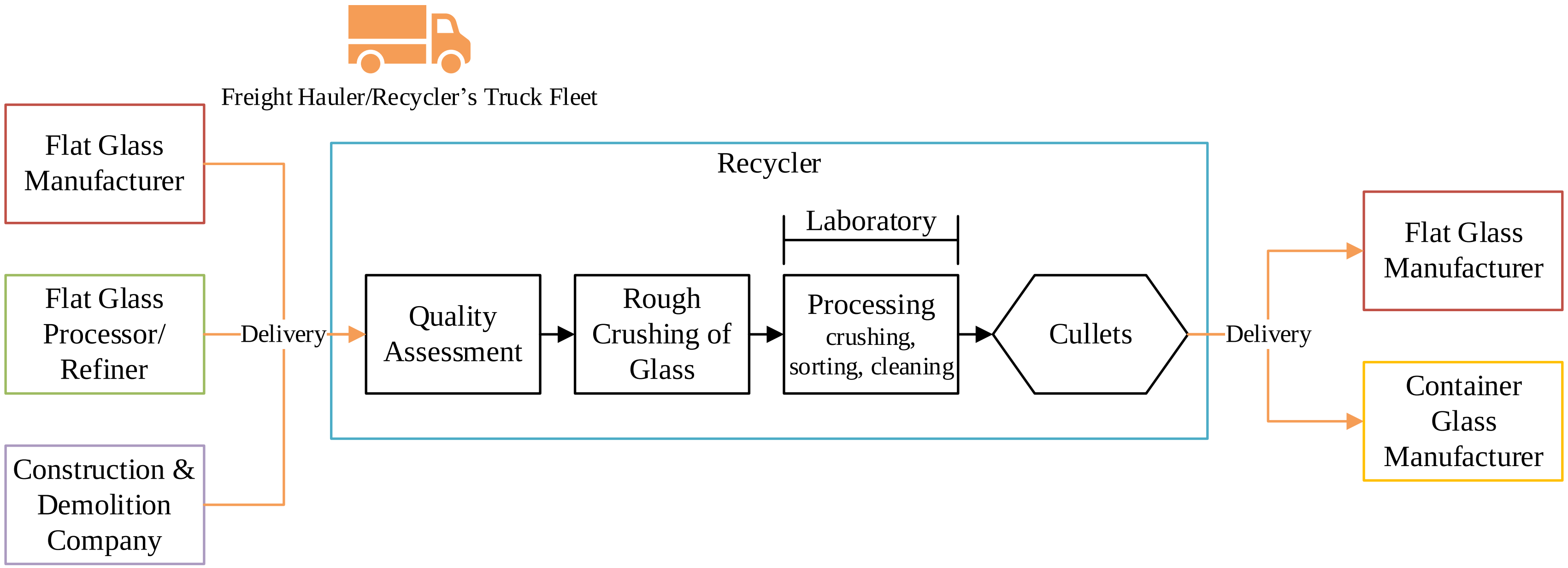


Figure 17: Case GERRE Flat Glass CLSC.

3.3.3 Flat Glass Closed-loop Supply Chain in Norway

3.3.3.1 NORIWA – Case Description

Case interview NORIWA is with an employer and interest organization for the glass and façade industry in Norway. Their aim is to organize the companies involved in the production, processing, assembly and sale of glass and façade products. This means the organization represents companies from a broad spectrum of fields related to flat glass. This includes companies whose operations are to administer, advise, design, produce, process, fit, or sell flat glass products and its components. This gives the association a unique position to offer insights into the life cycle of flat glass from the perspective of multiple actors.

The respondent interviewed from the case company is an expert in the field of architectural and automotive glass and its position in the Norwegian market. The respondent can therefore offer insights into the material flow of flat glass products and the situation of flat glass waste in Norway today. Table 9 shows the respondent overview.

Table 9: Case NORIWA Interviewee Overview.

Case	**Respondent**	**Company**	**Interview Method**	**Date**
NORIWA	Technical Manager	Interest & Employer Association	Video Call	10.05.2021

3.3.3.2 NORIWA – Closed-loop Supply Chain

There is no production of large format float glass in Norway, nor Scandinavia. Thus, glass for windows and facades must be imported from elsewhere in Europe, either as a raw material that will be processed in Norway or as processed units which are more or less ready for use.

According to the respondent 1.9 million insulation glass units are sold every year in Norway. Of those units 250 000 are produced in Norway, meaning roughly 87% of all units are imported. Over the last 15 years there has been a noticeable increase in the number of imported units, increasing from 12% then to the 87% we have today. This is a consequence of EU subsidizing industries in eastern Europe, making it hard for Norwegian companies to compete on price.

For the few actors that still process float glass in Norway, the raw material is delivered in specialized trucks carrying large format float glass. Depending on the company this material is then processed into ready for use products in the size and with the properties the customer ordered. The processing of float glass generates a substantial amount of glass waste in the form of cut-offs.

According to the respondent it can be complicated to offer a description of the use phase of windows and façades as it will differentiate a lot depending on the project. The respondent offers a scenario where a building containing large amounts of glass façades is being built, which is a common characteristic of large buildings in urban areas today. The contractor responsible for the project will usually hire a subcontractor which is specialized in windows and facades to be responsible for these aspects in the construction. This subcontractor will then order the units needed either from a manufacturer in Norway or as previously explained more commonly from a company in eastern Europe. These units will then be delivered to the construction site by truck. In assembly of these units some amounts of glass waste will be generated.

The respondent had also investigated the possibility of reusing old windows again. While it is possible, multiple problems would arise. The first problem relates to the fact that older units may contain toxic material such as PCB (Polychlorinated biphenyl) in the glue and sealant used in frames. These toxins constitute a marginal part of the window as a whole, but these units are nonetheless categorized as toxic material and cannot be reused. The next problems relate to the rapid development in quality and attributes in glass units. As a consequence of this development there have been put in place higher standards to both security and isolation ability today than 20 years ago. Thus, the older units will have problems satisfying the high demands related to glass units today. There are also a lot of new attributes and functions available in the today's market that did not exist 20 years ago. Consequently, customers will often put in requests for functions such as soundproof or sun-dimming, which again older units cannot deliver. Another negative aspect is the fact that the size of the window cannot be changed and potential miss coloring on old units. According to the respondent it is in general good for the environment to reuse, but it is not economically feasible.

The respondent highlights two important issues related to the treatment of flat glass waste. The first is if it should be viewed as waste or raw material. While a glazier might view it as waste, a recycler views it as raw material. It is therefore a question of costs and logistics getting it from one actor to the other. According to the respondent, this system is not optimal today and as a consequence the glass waste often ends up getting landfilled. The other issue is related to the classification of glass waste as dangerous material. This classification leads to rigid rules that limit the solutions available.

The respondent makes a distinction between different sources of glass waste material. The first source is windows from cars. While it is not the subject of this assignment, glass from cars makes up a substantial amount and is well suited for recycling. The next source of waste material comes from the producers and processors. In the production of glass for windows and façades there is a considerable amount of cut-off. This material is very well suited for recycling as there are very few sources of contamination. Though, as the production in Norway has seen a decline the last decade the respondent remarks that this source of waste material might become smaller in the future. The third source is found in the rehabilitation and demolition of buildings. These projects will often generate large amounts of waste material consisting of windows with frames still attached. Then there is replacement of single units. This generates a smaller amount of waste which varies in both size and type. The last source is glaziers. In their work they will generate a smaller amount of cut-offs. This will include different types of glass and thus, a more demanding sorting process.

While the respondent remarks that the system for delivery of the waste material is not ideal today, some material still gets recycled today. This gets sent to a recycling facility in south-eastern Norway, where it becomes a raw material in the form of glass cullets. Out of the 7500-8000 tons produced at the facility each year roughly 40% of the material comes from producers and processors, 40% from the construction industry, 10% from cars, and 10% from glaziers. The raw material is then sent to a manufacturer in Norway, who uses it in their production of glass wool. According to the respondent the glass wool producer has a desire to use up to 70% of recycled material in their production. To achieve this the company would need 26 000 tons of raw material every year and to cover the deficiency, container glass is imported from Sweden. To increase the recycle rate of windows and façades the association is working with other central actors on a return system, but according to the respondent the situation today is still far from ideal.

Figure 18 shows the flat glass CLSC in case NORIWA.

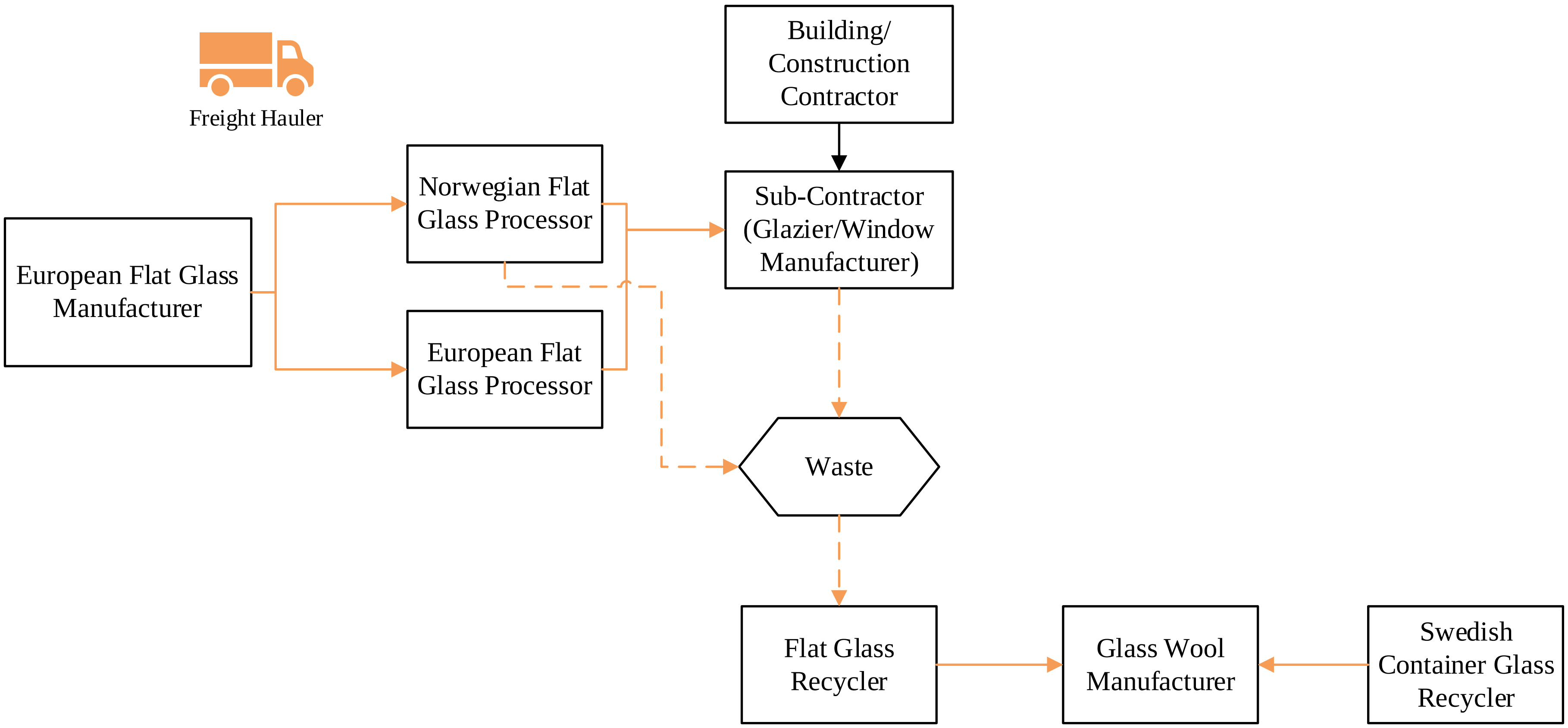


Figure 18: NORIWA Flat Glass CLSC.

3.3.3.3 NORRE – Case Description

The case company is a specialized recycling company that handles windows containing the toxin PCB. Insulating glass units produced in the sixties and seventies often contain the toxin PCB in the glue or sealant. To manage the toxic waste of old units the government in Norway demanded that all producers and importers of insulating glass panes need to have a return system in place. To meet this demand the multiple actors in the industry established NORRE as a non-profit organization in the early 2000. The organization is tasked with both collection and treatment of old PCB units.

The respondent has over 10 years of experience from top management in the waste handling industry. The respondent provides a unique perspective on a successful recycling system for flat glass in Norway. Table 10 shows the respondent overview.

Table 10: Case NORRE Interviewee Overview.

Case	Respondent	Company	Interview Method	Date
NORRE	High Level Manager	Recycler	Video Call	10.05.2021

3.3.3.4 NORRE – Closed-loop Supply Chain

The respondent emphasizes that a central factor to understanding the waste and recycling systems in Norway is that the government obligates all actors to operate a nationwide system which should offer the same services to inhabitants no matter where they live in Norway. For PCB windows the case company is the only actor on the market, but for other types of waste there will be multiple actors with a system in place covering all of Norway.

As a private person the collection process for PCB containing units usually starts at one of roughly 350 local collection facilities spread around Norway. When delivering the window, the person should be met by personnel that are competent on how to handle the units. The still intact unit is then later transported from the local facility to one of 17 regional facilities, where waste from all over the region is gathered before being transported to a recycling facility outside Fredrikstad in south-eastern Norway. Another option is that the waste holder hires a contractor that handles the units for him and deliver them to the facility. These contractors can often have arrangements with other waste management actors, but in the end the material ends up at a collection center or the recycling facility. At the recycling facility the glass gets cut from the frame and made into glass cullets, which is a granulate that can later be used in the production of new products such as in this case glass wool. The cullets are then transported to a glass wool producer, while the frame containing the PCB toxin gets sent to Denmark where they burn it in specialized ovens.

If the cullets could be used in the production of new float glass the respondent was unsure. The respondent was aware of the possibility and offered an example from Germany but was unsure if the cullets produced in Norway had the desired qualities for float glass production. The recipient of their glass material was selected in a bidding call, where criteria such as product quality and environmental effect were central. The respondent also highlights that the recipient of the cullets is very satisfied with the quality of the material they receive as it contains very little contamination. This is a result of the windows being collected whole, instead of being stored in containers that can often include small amounts of other materials which will decrease the quality of the cullets and in worst case scenarios damage the machines.

Figure 19 shows NORRE’s flat glass CLSC.

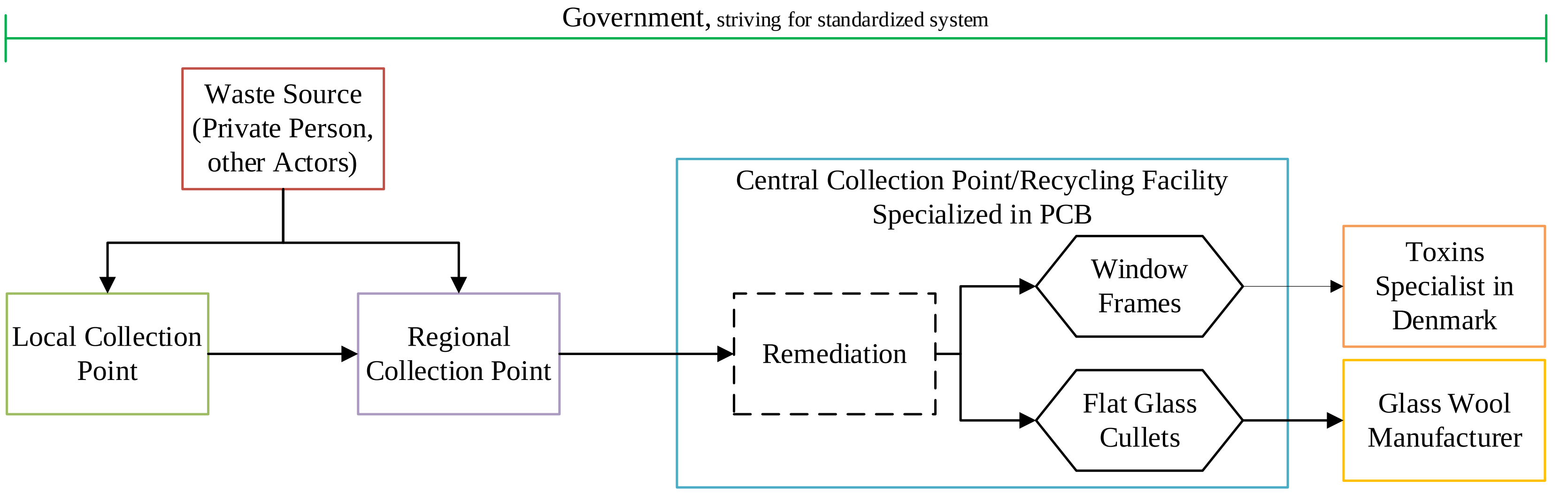


Figure 19: NORRE Flat Glass CLSC.

3.3.3.5 *NORNG – Case Description*

The case company is one of Norway's largest actors in the recycling and environmental services. Their services include waste management, industrial service, household renovation, demolition, and remediation amongst other things. They have roughly 50 facilities spread across Norway as well as some “dealings” in other Scandinavian countries and the UK. The company has over 1750 employees and handles over 2 million ton waste every year. The company can offer the researchers an important perspective into the current recycling situation in Norway and the challenges it faces.

The interviewee has almost 25 years experience in the waste management and recycling sector and acts as production manager as well as head of glass related activities. The respondent can therefore offer an unique perspective into the situation of flat glass related waste from the viewpoint of one of Norway's largest recyclers. This can be especially valuable in regards to what challenges a circular supply chain for flat glass faces and how these can be addressed. Table 11 shows the respondent overview.

Table 11: Case NORNG Interviewee Overview.

Case	Respondent	Company	Interview Method	Date
NORNG	Production Manager, Head of Glass	Recycler	Voice Call	20.05.2021

3.3.3.6 *NORNG – Closed-loop Supply Chain*

The company the respondent represents uses glass waste from the automotive industry and architectural glass to produce glass cullets which can be used in the manufacturing of new glass products. According to the respondent their biggest sources of glass waste is the producers of different glass products in Norway, e.g., producers of windows or glass façades. After that it is public sector through municipalities and inter-municipal companies, as well as other sources of windows with environmental toxins. The glass they receive, which can include car windows, façade glass, cut-offs and much more gets mixed and sent through a shredding process where it is reduced into a granule.

Depending on the source of the glass, the processing of the glass before it can enter the shredder system will differ. The glass they receive from the producers of glass products usually holds a very high quality and is free from other types of material. This type of waste material can therefore be sent directly to the recycling process. In the windows they receive from the public sector and the construction industry, the glass panes need to be removed from the frame and controlled for residue of glue and sealants. This is a manual process in which a glass cutter knife is used to cut the glass around the frame, before it is crushed out. The glass can then be sent to the recycling process, while the frames must be handled in accordance with law and regulations. The recycling process consists of three steps. The glass material needs to go through a coarse grinder, then a fine grinder to reduce the material to the desired proportions. The material is also put through a drum screen to remove any plastic material that the units may contain.

The respondent highlights that there is a high demand for their material on the market from both producers of flat glass and glass wool and that in the future glass waste will be an important resource that should go to recycling. According to the interviewee the biggest obstacle they face in increasing the recycling rate is in the collection processes. In Norway it is still legal to send whole windows to the landfill and this is often a cheaper alternative to recycling, especially in terms of transportation cost. The respondent highlights two main reasons that limit the recycle rate today. The first reason is the mentioned possibility of landfilling windows. According to them there are no signs of the laws related to this being changed anytime soon. The second reason highlighted are the regulations put in place by the Norwegian environment agency. Today these regulations state that windows produced after 1990 should not be deemed as dangerous waste. But broken windows and components of it should be. The respondent says that this creates a grey area in which whole windows can be thrown into the general waste stream, where it ends up at landfills, while attempts to recycle it will be seen as dangerous waste with a lot stricter regulations.

The respondent has limited knowledge about the recycling statistics but refers to a study from Sweden which estimates that roughly 85% of all glass waste ends up in landfills.

Figure 20 shows the flat glass CLSC in NORNG.

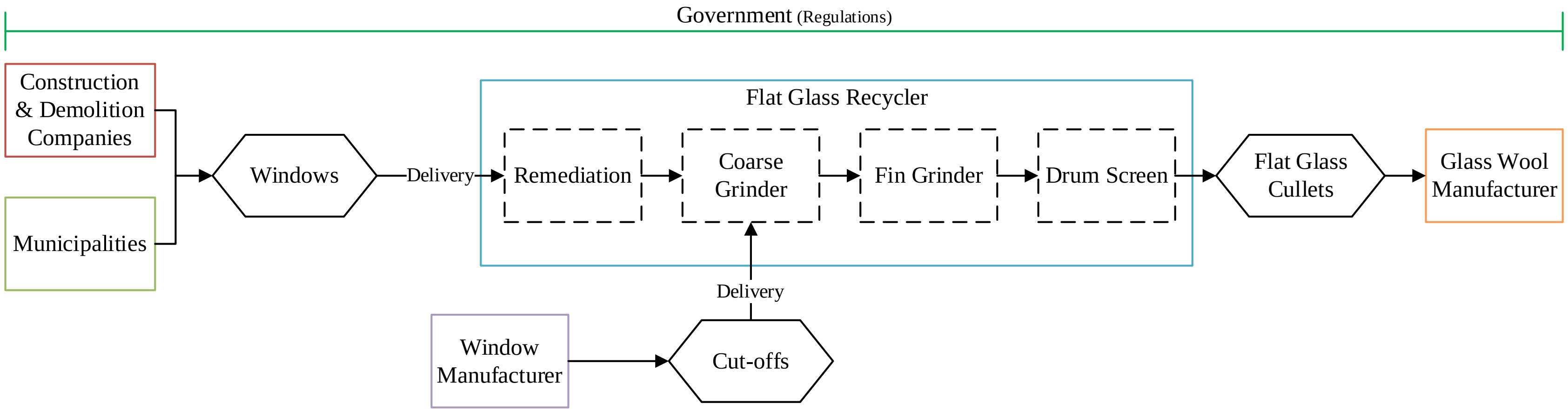


Figure 20: NORNG Flat Glass CLSC.

3.4 Analysis of Findings

The purpose of this thesis is to identify a closed-loop supply chain structure of flat glass, including actors, waste sources, and what can be done with recycled flat glass as well as to propose a cost structure which is done in chapter 4. RQ1: How can closed-loop supply chains (CLSC) for the purpose of flat glass look like? RQ1.A: What actors are a part of a flat glass CLSC? RQ1.B: What are the waste sources of flat glass in a flat glass CLSC? RQ1.C: What are the uses of flat glass as secondary material? In the following sub-chapters, the different building blocks of a flat glass CLSC are analyzed separately and put together in 3.4.5. First the actors of a flat glass CLSC are analyzed, followed by an analysis of the CLSC in the case companies' countries, of flat glass waste sources, and possibilities for recycled flat glass.

3.4.1 Actors of a Flat Glass Closed-loop Supply Chain

Table 12 is a list of all the actors of the CLSC mentioned by each of the interviewees for each case. The data is sorted by actor, country which describes the country the actor comes from, reference, and case country. The reference codes refer to the separate cases. A detailed description of the cases can be found in chapter 3.3 Empirical Findings.

Table 12: CLSC Actors within the different Cases.

Actor	Country	Type	Reference
Case China			
Float Glass Manufacturer	China	Manufacturer	CHIMA1
Tempered Glass Processor			
Construction Company			
Recycler			
Raw Materials Supplier	China	Manufacturer	CHIMA2
Float Glass Manufacturer & Processor			
Glass Distributor			
Recycling Agency			
Freight Hauler (Logistics Company)			
Case Germany			
Flat Glass Manufacturer	Germany	Recycler	GERRE
Flat Glass Processor/Refiner	Germany		
Construction & Demolition Company	Germany/ Abroad		
Freight Hauler (if own fleet not used)	Germany		
Flat Glass Recycler	Germany		
Container Glass Manufacturer	Germany/ Abroad		
Case Norway			
Flat Glass Manufacturer	Non-Norwegian/ European	Interest & Employers Association	NORIWA
Flat Glass Processor	Non-Norwegian/ European		
Flat Glass Processor	Norway		

Glazier/Window Manufacturer	Norway		
Freight Hauler	unknown		
Building/Construction Contractor	Norway		
Flat Glass Construction Sub-Contractor / Glazier	Norway		
Flat Glass Recycler	South-East Norway		
Landfill	Norway		
Glass Wool Manufacturer	Norway		
Container Glass Recycler	Sweden		
Government	Norway	Recycler	NORRE
Flat Glass Recycler specialized in PCB	Norway		
Consumer/Private Person	Norway		
Local Collection Facility	Norway		
Regional Collection Facility	Norway		
Central Collection Facility	South-East Norway		
Third-Party Contractor (transports used PCB window for you to a collection facility)	Norway		
Other Waste Management Actors	Norway		
Glass Wool Manufacturer	Norway		
Toxins Specialist (the ones that burn it)	Denmark		
Glazier/Window Manufacturer	Norway	Recycler	NORNG
Municipality	Norway		
Flat Glass Recycler	Norway		
Construction & Demolition Company	Norway		
Glass Wool Manufacturer	Norway		
Landfill	Norway		
Government	Norway		

Important to note is that the interviewee from NORIWA did not clarify from where the freight haulers operate, which leads to the assumption that the freight hauler is at least European most likely central or eastern European.

Each of the case countries have three things in common, i.e., the CLSCs consist of one or multiple flat glass manufacturers of which all except CHIMA2 are private, a construction company and a recycler. Differentiations are made in the actors' names and tasks: float glass manufacturer, tempered glass processors, float glass manufacturer and processor, flat glass manufacturer, flat glass processor/refiner, glazier/window manufacturer, construction company, construction and demolition company, building/construction contractor, and flat glass construction sub-contractor. However, flat glass is a generic term and covers everything from production method, i.e., float glass manufacturing, and the processing and further refinement of glass produced with the float glass method, for example, tempered glass. This means that according to the cases there are four types of flat glass manufacturers: (1) float glass manufacturer which produces flat glass on the basis of the float method; (2) flat glass processor who processes the flat glass into different types; (3) flat glass manufacturer and processor who utilizes the float glass method to produce flat glass and also has the facilities to process flat glass; and (4) the manufacturer of flat glass products, who uses the processed flat glass to manufacture, e.g., windows.

Furthermore, cases CHIMA1, CHIMA2, GERRE, NORIWA, NORRE, and NORNG have a recycler or recycling agency in their SC. CHIMA1 does not implement recycled material in their tempered glass production due to high-quality criteria, lack of capacity, and short supply. However, the interviewee expresses knowledge about recycling possibilities and a recycler comes to pick up their waste. Important to mention is that CHIMA2 reuses their cut-offs that generate during the production process. All flat glass recyclers of each of the cases are located in their respective countries. This aligns with a remark by the interviewee of GERRE, that it is desirable to have a close proximity to where the glass waste is coming from in order to save costs and ensure high quality.

Cases CHIMA2, GERRE, and NORIWA explicitly mention freight haulers being a part of their CLSC. Freight haulers, i.e., logistics companies, transport goods in between the different actors of the CLSC. In China the freight hauler is Chinese, however, in the case countries Germany and Norway the freight hauler can either from the same country or another European country. This is most likely due to the locations, distance, and price of the transport.

Both cases GERRE and NORNG explicitly mention demolition companies to be a part of the flat glass closed-loop supply chain. Both in Germany and Norway, the companies are usually a combination of construction and demolition meaning they build with new or recycled flat glass products but also produce waste by demolishing buildings.

Both in NORIWA and NORNG landfill was named as an actor. This is simply due to landfill being a (cheaper and) legal option, the recycling system in Norway being not ideal. The other cases do not make a mention of landfills being an actor of a CLSC which can be accredited to the fact that if the waste ends up at a landfill it would mean the CLSC comes to an end and that is not in alignment with the concepts of circularity. In addition to that, most of the cases that did not mention landfills have the view of flat glass waste not being waste material rather than being secondary material that can either be fed back into the flat glass closed-loop or fed into another loop.

Each of the Norwegian cases mention glass wool manufacturers to be part of the flat glass CLSC. However, glass wool manufacturers would not be a part of a flat glass closed-loop supply chain because the flat glass cullets are not being fed back into the flat glass manufacturing or processing. They are fed into the glass wool loop.

Moreover, both Norwegian cases NORRE and NORNG acknowledge the government and municipalities to be actors in the CLSC. The other cases did not explicitly mention this to be the case, however, the German and Chinese government are most likely an actor in one way or another, for example, CHIMA2 is state-owned. Even though the interviewee from GERRE did not mention the government, it must be an actor through legislations etc.

The cases CHIMA2, GERRE, NORIWA, and NORRE mention actors unique to their CLSC. The former mentions raw materials supplier and a glass distributor. GERRE includes a container glass manufacturer. NORIWA includes a Swedish container glass recycler whose material cullets are imported by the glass wool manufacturer. The latter lists local, regional, and central collection facilities as well as third-party contractors, other waste management actors, and a toxins specialist.

Important to note is, that if the other cases have not mentioned a particular actor, it can mean that this actor is not a part of the CLSC, or in the case of CHIMA1 no CLSC exists. However, it can also mean that the interviewees did not have the knowledge of the actor being a part of the CLSC or they simply forgot to mention and/or assumed the research team's knowledge.

When compared to actors of the flat glass CLSC based on literature, i.e., manufacturer, construction and demolition companies, and recyclers, the common theme between the case CLSCs and the literature CLSC is apparent. This means most of the case companies include at least one of the actors listed by scientific literature. However, it is evident that the CLSC in each of the cases have more actors for the same type of actor or even additional actors that were not identified through scientific literature. Furthermore, a non-apparent actor mentioned in the literature review are governmental institutions through, for example, the EU Waste Framework Directive.

Table 13 shows a summarized list of actors which are part of a flat glass CLSC.

Table 13: Possible Flat Glass CLSC Actors Summarized.

Type of CLSC	Actor
Flat Glass	Raw Materials Supplier
	Float Glass Manufacturer
	Flat Glass Processor
	Flat Glass Manufacturer & Processor
	Manufacturer of Flat Glass Products
	Flat Glass Distributor
	Flat Glass Recycler
	Freight Haulers
	Construction & Demolition Company
	Government
	Municipality
	Collection Facility (local, regional, central)
	Third-party Contractors
	Toxins Specialist
	Other Waste Management Actors
Glass Wool	Glass Wool Manufacturer
Container Glass	Container Glass Manufacturer
	Container Glass Recycler

3.4.2 Flat Glass Closed-loop Supply Chains in China, Germany, and Norway

The figures of each of the processes described during the interviews can be found in their respective empirical findings chapter.

The first Chinese case, CHIMA1, describes a flat glass supply chain instead of a closed-loop supply chain out of the view of a flat glass manufacturer. The SC contains elements of closed-loops, i.e., the recycler, however they themselves do not seem to either be a part of a CLSC yet or do not have sufficient knowledge if they are a part of a CLSC. Additionally, they are not using recycled material in their tempered glass production, nevertheless the float glass manufacturer that supplies them with flat glass might be using recycled flat glass knowledge. No information was given on where and how the government is connected to the SC, e.g., legislation, regulations, laws etc. Also, no information was provided on transportation methods, and who is responsible for organizing and execution of transport. This supply chain only consists of Chinese actors.

The second Chinese case, i.e., CHIMA2, describes a CLSC out of the view of a flat glass manufacturer. This CLSC shows the manufacturing phase of flat glass in more detail. The use and waste management phases are shown in much less detailed compared to the previous phase. The actor for the waste management is the recycler yet no information for the actors in the use phase was provided. Here the actors are most likely the construction and demolition companies. The manufacturer itself is state-owned but no further indications on where else in the CLSC the government has influence were made. Transportation is shown in the figure and the CLSC only takes part in China just like the SC in case CHIMA1.

The German case GERRE shows a CLSC out of the perspective of a flat glass recycler. Here the waste management phase of the flat glass life-cycle is described in much detail. Both the manufacture and the use phase are not described merely the actors of each of the phases are included and how these are connected to the waste management phase. In contrast to the Chinese cases, the German CLSC shows actors that are not necessarily located in Germany even though this is rarely the case. Transport is pictured but no information on governmental institutions being a part of the flat glass CLSC in Germany and where these would come into existence were provided.

The Norwegian case NORIWA shows the Norwegian flat glass closed-loop supply chain out of a holistic view, i.e., the view of an association, unlike both Chinese cases and the German case. This means it takes a look at all phases of the flat glass life-cycle. The process itself does not feed back into the flat glass CLSC but feeds into the glass wool loop. Transportation is mentioned but no governmental institutions. This CLSC consists of more than one actor not being from the home country of the interviewed company, as opposed to the other interviewed companies. In this particular case both the manufacturer and the processor can be form other European countries than Norway. In addition to that the container glass recycler that provides the glass wool manufacturer with container glass cullets is located in Sweden. The other actors are Norwegian. Lastly, the flat glass loop makes contact with two other loops, i.e., glass wool and container glass.

The CLSC in the NORRE case pictures the flat glass CLSC from the recycler's point of view. This means the figure does not include any information on the manufacture phase of the flat glass life-cycle. Furthermore, limited information is provided on the use phase. The figure depicts waste source from actors in the use phase. Much more information can be found on the waste management phase. Just like in the NORIWA case, this CLSC fees into the glass wool loop rather than feeding back into the flat glass loop. This CLSC also consists of actors from more than one country; the toxins specialist is located in Denmark. In contrast to the first Norwegian case company, here the government is indicated in the figure but no transportation.

Lastly, the third Norwegian case company NORNG also pictures the flat glass CLSC from the recycler's point of view. However, the process shown in this figure is different compared to the figure of case NORRE. This is because NORRE is specialized in PCB window recycling, NORNG is not. This figure does not show a manufacture phase but shows the use phase and a much more detailed waste management phase. Like the other Norwegian use cases, this does not feed back into the flat glass CLSC and is connected to the glass wool loop. This CLSC consists of only Norwegian actors. Again, the government is indicated but not transportation.

In comparison with the generic closed-loop supply chain built from scientific literature, all the CLSCs mentioned above are much more detailed in the specific phases with CHIMA1 containing the less detailed figure of each of the cases. Only NORIWA shows the CLSC in a holistic view. The generic CLSC does not clearly identify the actors within a flat glass closed-loop supply chain, the CLSCs of the different cases do. The life-cycles of flat glass are easily identifiable within each of the CLSCs. The material flow is clearer in the generic flat glass CLSC than in the CLSC of each of the cases. This can be attributed to the fact that no further information on material flow was provided by the interviewees.

3.4.3 Flat Glass Waste Sources

Table 14 shows the flat glass waste sources according to each of the cases. The waste sources are sorted according to case country, case reference, and theme.

Table 14: Flat Glass Waste Sources within the different Cases.

Theme	Waste Source	Reference
	Case China	
(1)	Production of Tempered Glass	CHIMA1
(1)	Glass cutting during Float Glass Production	CHIMA2
(1)	Glass cutting during Deep Processing	CHIMA2
	Case Germany	
(1)	Glass cutting during Flat Glass Production	GERRE
(1)	Flat Glass Refinement	GERRE
(2)	Construction & Demolition processes	GERRE
	Case Norway	
(1)	Flat Glass Processing	NORIWA
(2)	Construction	NORIWA
(1)	Flat Glass Production	NORIWA
(2)	Rehabilitation and Demolition of Buildings	NORIWA
(2)	Window Replacements	NORIWA
(1)	Cut-offs from Glaziers	NORIWA
(2)	Renovations/demolitions of buildings	NORRE
(1)	Glass Product Manufacturing	NORNG
	Public sector/municipalities	NORNG

Two waste themes become apparent when looking at the table above. These are: (1) flat glass waste that occurs during production and processing processes (highlighted green in the table), and (2) flat glass waste that occurs during construction and demolition processes (highlighted blue in the table). The former produces flat glass waste during activities such as cutting the glass during the float glass production (CHIMA2, GERRE) or deep processing (CHIMA1, CHIMA2). The glass waste that is generated here is, according to GERRE, the highest quality. The interviewees in the cases, i.e., CHIMA1, NORIWA, NORNG have not specified which activities during flat glass manufacturing and processing cause waste to accumulate. The interviewee at NORRE has not mentioned this theme.

The latter, construction and demolition of buildings, generates flat glass waste during processes such as renovations (NORRE) or window replacements (NORIWA). NORIWA also mentions other CD terms that do not further specify the waste source, neither does GERRE specify the waste source. Neither NORNG nor CHIMA1 and CHIMA2 list CD as a waste source.

NORNG lists the public sector or municipalities to be sources of waste without specifying why that is. The reason for this can be that municipalities have public construction sites which in turn generate flat glass waste and the interview has simply not specified any further.

The two themes listed previously can roughly be divided into flat glass waste of pre-consumer sources and post-consumer source. This aligns with the classification of flat glass waste by Geboes (2020) in the waste management phase of the life-cycle of flat glass. In addition to that, it is also reflected in case GERRE in which waste is separated into three types, i.e., high quality, pre-consumer, and post-consumer.

The CD theme is somewhat reflected in scientific literature. The generic flat glass closed-loop supply chain that was developed based on literature shows flat glass product going into the use phase. End-of-Use flat glass waste comes out of the use phase. The same happens during CD, i.e., flat glass product is the input and flat glass waste the output. The figure does not show whether the manufacturing phase produces waste or not.

Additionally, neither the interviewees nor the scientific sources used to build the generic flat glass CLSC list transportation of flat glass products between the different actors as waste sources. However, GERRE underlines the importance of close proximity between the actors due to the fragility of flat glass. Furthermore, NORIWA talks about the difficulties of transporting processed flat glass. Therefore, the research team sees transportation as a source of waste, even though, it was not specifically mentioned as a source of waste.

Important to note is that, according to GERRE, flat glass waste is seen as secondary material rather than waste. The following list summarizes the flat glass secondary material sources identified through literature and interviews.

Table 15: Flat Glass as Secondary Material Sources Summarized.

Flat Glass Secondary Material Sources
• Flat Glass Manufacturing Processes
• Flat Glass Processing/Refinement Processes
• Construction & Demolition
• Flat Glass Transport

3.4.4 Uses of Flat Glass as Secondary Material

Table 16 shows the uses of flat glass as secondary material sorted by case country and case. The option of landfill was purposefully left out of the table because it does not align with the concepts of circular economy and cannot be called a use of flat glass as secondary material.

Table 16: Uses of Flat Glass as Secondary Material.

Possible Uses	Reference
Case China	
Use of high-quality whole pieces of recycled flat glass in Tempered Glass	CHIMA1
High-grade flat glass waste can be used in new flat glass material	
Low-grade flat glass waste can be used for container glass or low-grade windows	
High quality Flat glass cullets can be used in float glass manufacturing	CHIMA2
Case Germany	
High Quality Flat Glass secondary material can be used for Flat Glass Production	GERRE
Lower quality cullets go into container glass production	
Case Norway	
Glass Wool	NORIWA
Glass Wool	NORRE
The use of cullets in new flat glass is possible but not done today	
Cullets can be used in float glass production	NORNG
Glass Wool	

All cases except for NORIWA acknowledge the use of flat glass as secondary material to be fed back into the flat glass CLSC and be turned into new flat glass products. Only cases CHIMA2 and GERRE know for certain that flat glass can be reused in float glass production, given the highest quality possible. The former is a manufacturer and uses flat glass cullets in its float glass production, however, CHIMA2 points out that only flat glass cullets, no other types of glass cullets, can be reused in production. The latter stresses the fact that the highest quality flat glass secondary material can only be reused in float glass production if it has not been contaminated.

CHIMA1 says that reusing flat glass is possible but it is not done in its manufacturing processes due to lack of capacity. NORRE does not specify the reason for why reuse of flat glass cullets is not done in Norway but still acknowledge the possibility of it. Important to note is that as of today there are no flat glass manufacturers in Norway. However, the interviewee from case NORRE says that when they choose who to sell their cullets to one of their criteria is the environmental aspect. Thus, a flat glass manufacturer in eastern Europe does not align with their criteria due to the long distance. According to

NORNG it is possible to reuse flat glass for flat glass production, however, the company solely sells its products to a glass wool manufacturer.

Another use of flat glass as a secondary material is recycling it and using it for container glass production. Both CHIMA1 and GERRE mention this possibility and agree on lower quality cullets being used in container glass. This is most likely due to the lower quality glass being contaminated with different materials. Neither CHIMA2 nor the cases from Norway mention container glass as an option for recycling flat glass cullets.

A third use of flat glass as secondary material is to utilize recycled flat glass cullets in glass wool production. However, only the Norwegian cases acknowledge this possibility. The interviewees do not provide a reason as to why that is the case but considering the fact that Norway does not have flat glass producers the recyclers have, in simple terms, two possibilities to get rid of their cullets: one is to sell it to the glass wool manufacturer in Norway which aligns with the concepts of circular economy and the other is to not process the glass and store it in landfills.

The last use of flat glass as secondary material according to CHIMA2 is to use lower quality flat glass in the production of low-grade windows.

The uses of recycled flat glass mentioned by the interviewees of the different case companies are mainly aligned with the uses mentioned in scientific literature. Both literature and interviewees agree on container glass, flat glass products, and glass wool to be options for used flat glass. However, there are ways to recycle flat glass with other types of waste materials, e.g., ceramic products (Rodrigues et al., 2021).

The following list summarizes the uses of flat glass as secondary material identified through literature and the case studies.

Table 17: Uses of Flat Glass as Secondary Material Summarized.

Uses of Flat Glass as Secondary Material
New Flat Glass Products
Container Glass
Low-grade Windows
Glass Wool
Together with other waste (e.g., ceramic products)

3.4.5 Flat Glass Closed-loop Supply Chain

To answer RQ1, the first step in building a flat glass closed-loop supply chain was to update the generic flat glass CLSC with the information provided in the previous chapters. Figure 21 depicts the updated simplistic flat glass CLSC.

The waste management phase was renamed into secondary (raw) material phase mainly because aligned with the recycling processes and concepts of circular economy the goal here is to keep the flat glass alive. Instead of one the CLSC now has two reverse flows. These reflect the possibilities of recycled flat glass cullets, i.e., the highest quality cullets are connected to the flat glass manufacture phase and the low quality cullets leave the flat glass loop and are connected to either container glass manufacture phase or glass wool manufacture phase. In this updated simplistic flat glass CLSC, the secondary material phase begins at the point when the flat glass leaves the use phase.

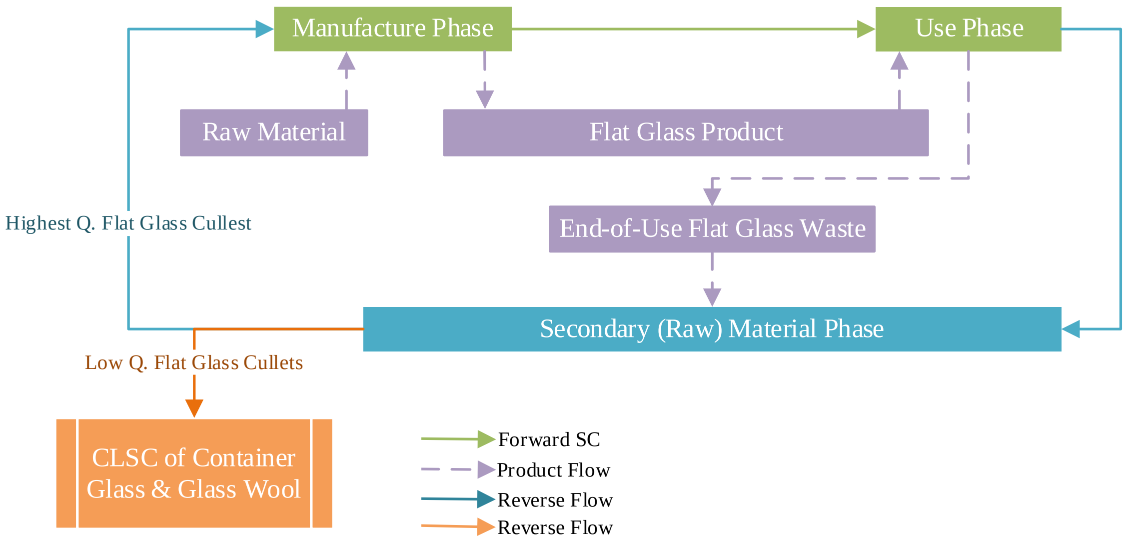


Figure 21: Simplistic Flat Glass CLSC.

To provide a much more detailed view onto the CLSC of flat glass than it is provided in the figure above, the three CLSC building blocks, the three different phases, are looked at in detail.

The first building block is the manufacturing phase of flat glass (figure 22). In this phase the flat glass is produced with the float glass technique and raw materials. The unprocessed, pure flat glass then enters the refinement process. The output of this step are flat glass products which then enter the use phase. The manufacturing phase has two waste sources: (1) the float glass manufacturing process, and (2) the flat glass processing/refinement process. In both processes, cut-offs occur, and the flat glass is pure and of the highest quality possible. The secondary material flows directly into the third building block, i.e., the secondary material phase. It is possible that float glass manufacturers reuse their cut-offs in producing new float glass if they have the capacity to do so. Main actors within the first building block are float glass manufacturers, flat glass processors/refiners, and freight haulers. It is possible to have a manufacturer that both manufacturers and refines, however, these are split up for easier understanding. Additionally, freight haulers come into play when product must be moved from one step to the next and the manufacturers do not have an own truck fleet.

The second building block, the use phase is shown in figure 23. Here, the glass is distributed to construction sites. The glass is then put into the building. After this step, the buildings are demolished, and the flat glass is at the end of its first use. It flows directly into the secondary material phase. The main actors of this phase are flat glass distributors, construction and demolition companies as well as freight haulers. The actors of the construction and demolition steps are usually one and the same actor which does both steps, however, it is possible to have two separate companies. Again, freight haulers come into play when product must be moved from one step to the next and the actors do not have their own truck fleet. Waste occurs during flat glass distribution, the construction of buildings, and in demolishing buildings. The first two create contaminated glass, they might have been broken during transport or putting up windows in the buildings but are not necessarily at the end of their use. The latter flows into the secondary material phase as end-of-use flat glass.

The third and last building block depicts the secondary material phase which in other words is the recycling phase (see figure 24). The process begins with a quality assessment of the glass which then goes through several processing steps to clean it from all its impurities. Depending on the quality of the glass the flat glass loop either continues with the flat glass manufacturing phase or continues with the container glass or glass wool manufacturing phase. This means the flat glass loop is connected with two other CLSCs. Main actors in this phase are the recycler and freight haulers who, again, come into play when product must be moved from one step to the next and the actors do not have their own truck fleet. In this phase now waste occurs. Waste material is the input for the recycling process and is transformed into output for the following phases.

Figure 25 shows the final flat glass closed-loop supply chain and answers RQ1.

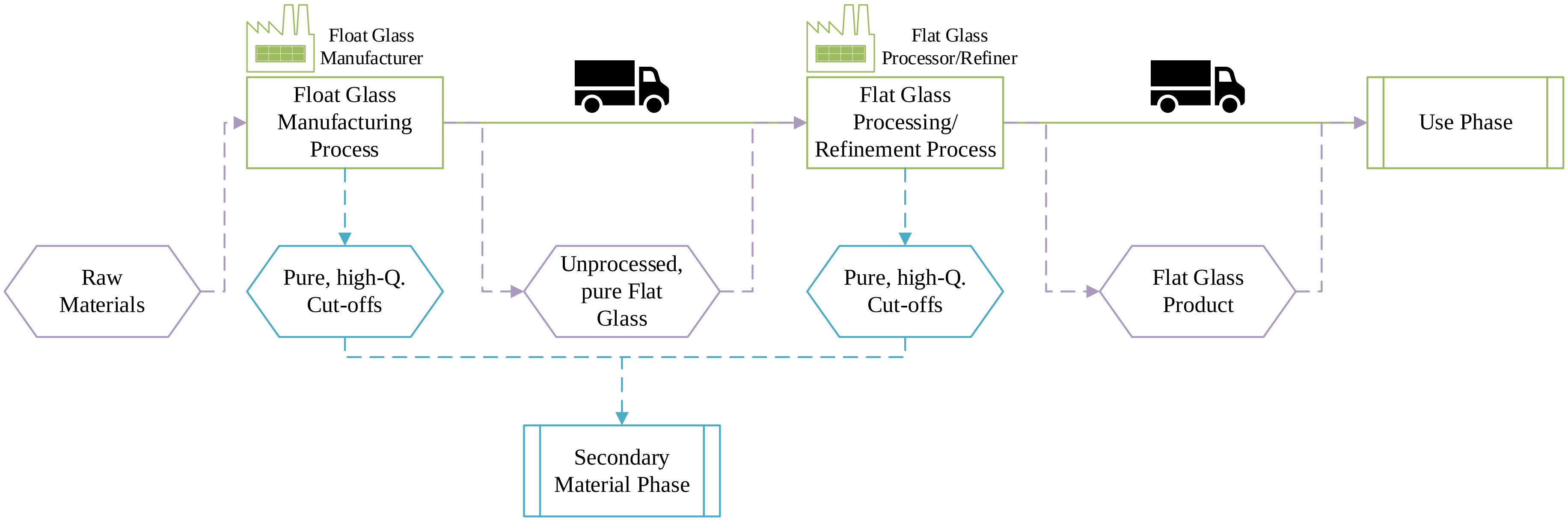


Figure 22: Flat Glass CLSC Building Block 1 Manufacture Phase.

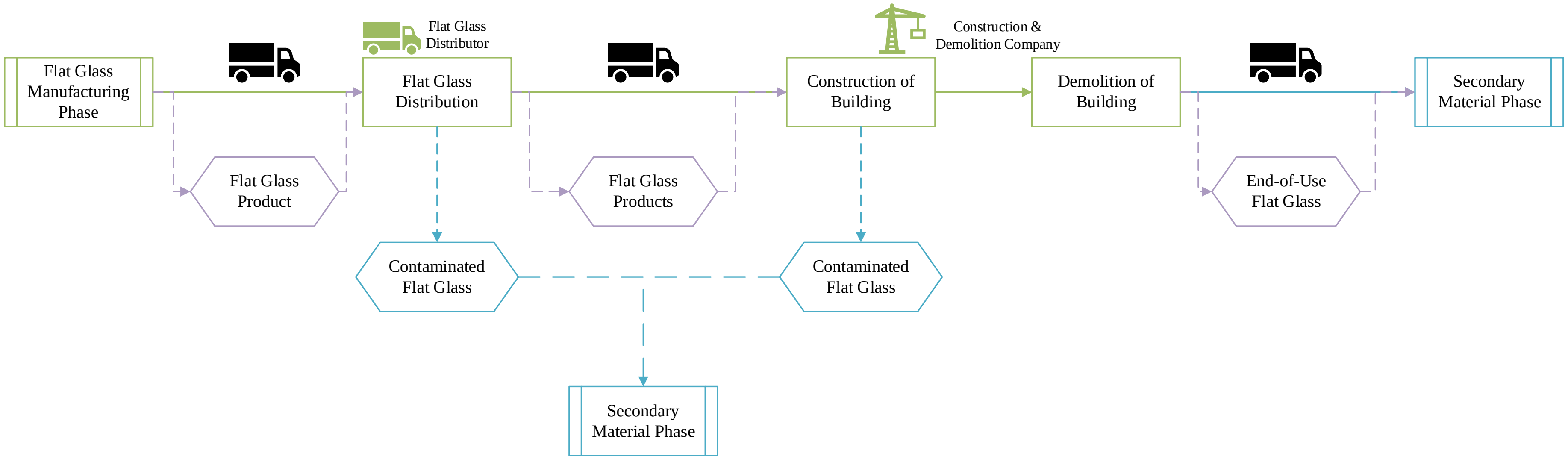


Figure 23: Flat Glass CLSC Building Block 2 Use Phase.

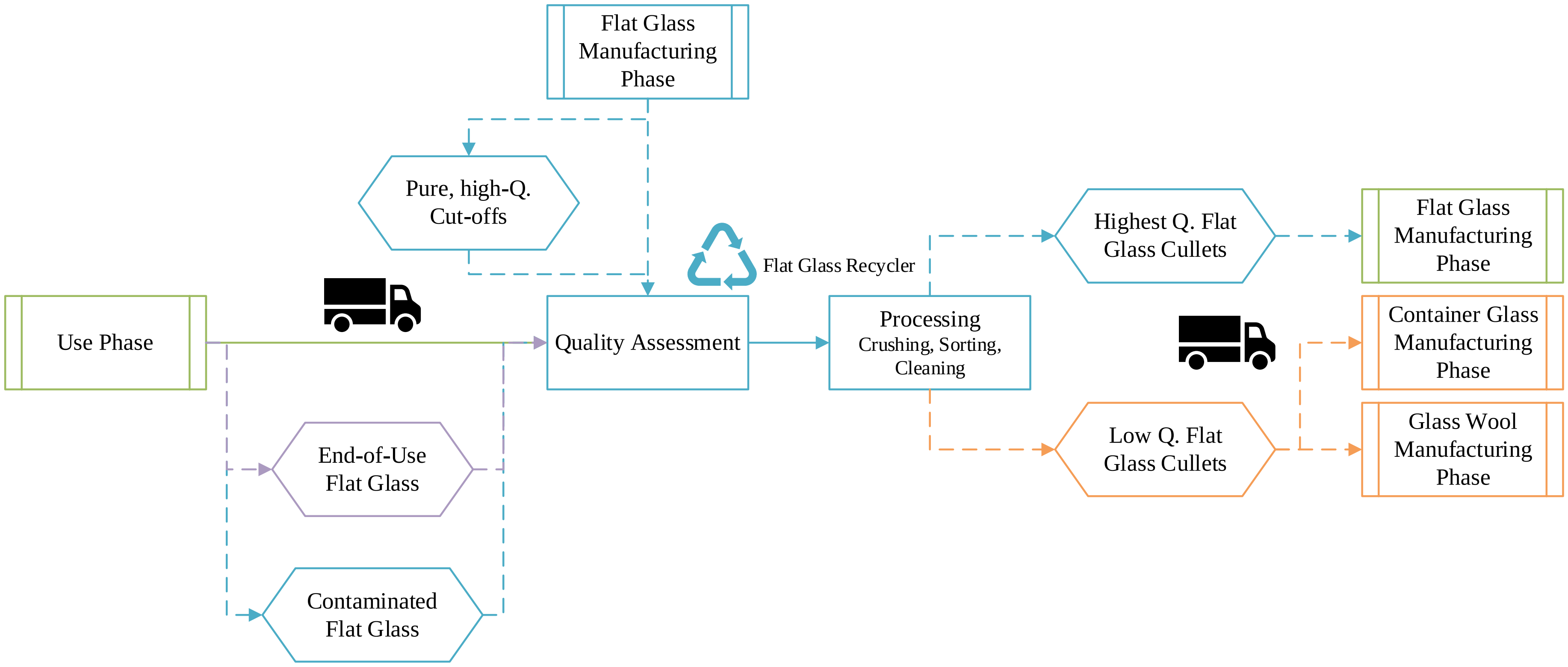


Figure 24: Flat Glass CLSC Building Block 3 Secondary (Raw) Material Phase.

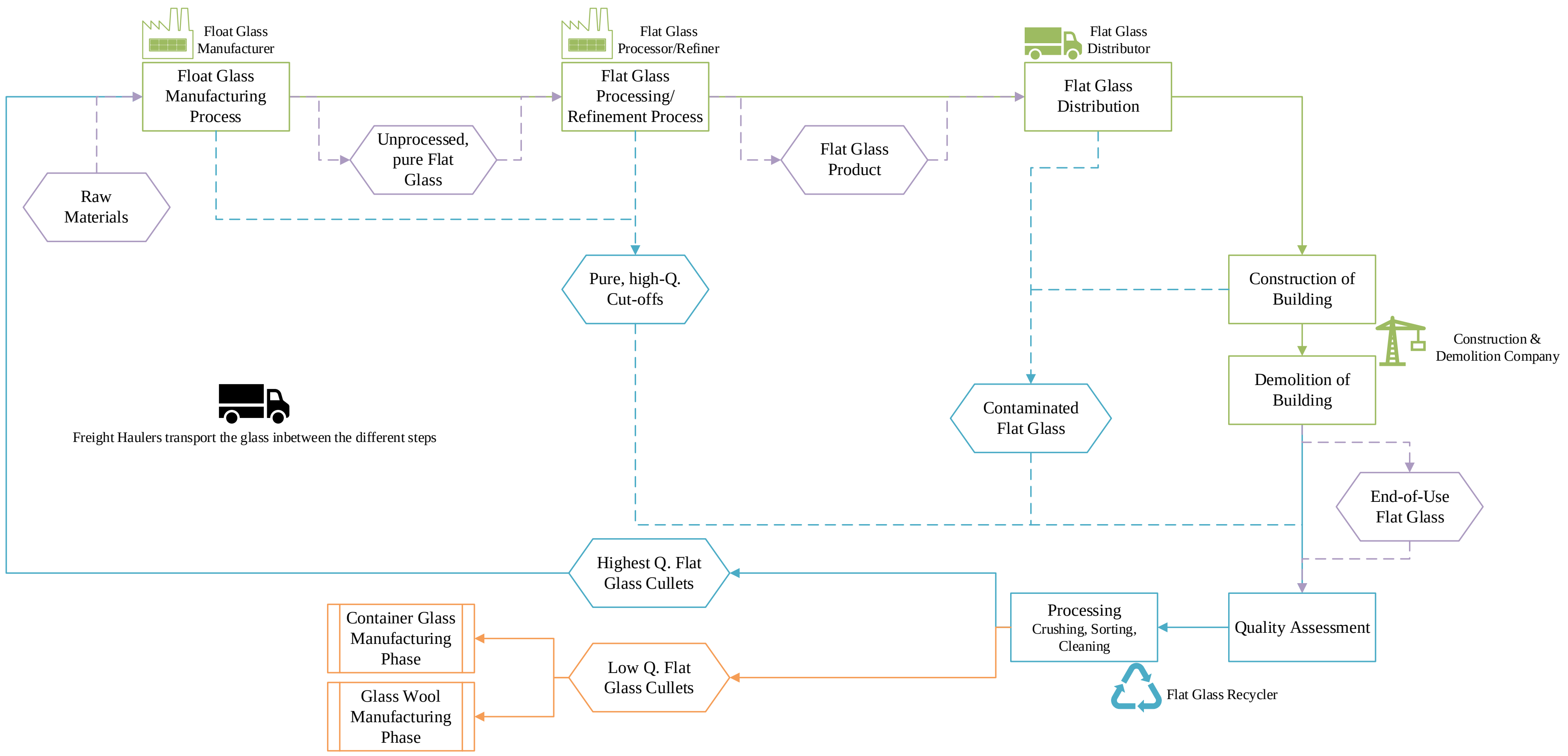


Figure 25: Flat Glass CLSC.

Table 18 shows the actors of the flat glass CLSC proposed in figure 25. The actors are divided into two groups which are main and sub-actors. The former actors are clearly visible. The latter are not pictured in the figure itself mainly to keep its simplicity.

In an ideal case, the raw material supplier would only have to supply raw materials once if the closed-loop runs endlessly. That is, however, nearly impossible due to two reasons: (1) being unable to use low quality flat glass cullets in float glass manufacturing; and (2) the amount of high quality recycled flat glass cullets not being sufficient to solely use it during float glass manufacturing.

Furthermore, the government is an actor within a closed-loop supply chain. However, neither scientific literature nor the interviewees were able to provide sufficient data that it is unclear where exactly the government comes into play. However, there are regulations on, for example, how waste must be treated.

Third-party contractors are sub-actors of the flat glass CLSC and most likely responsible for distribution or serve as a freight hauler. They come into action when neither of the main actors, such as the manufacturers, have their own truck fleet for transporting the products from one main actor to the other.

Both the container glass and the glass wool manufacturer are considered sub-actors because they do not take an active part in the flat glass CLSC. They merely receive the low-quality flat glass cullets.

Table 18: Actors of the Flat Glass CLSC.

Main Actors	Sub-Actors
Float Glass Manufacturer	Raw Materials Supplier
Flat Glass Processor/Refiner	Government
Flat Glass Distributor	Third-party Contractors
Construction & Demolition Company	Container Glass Manufacturer
Flat Glass Recycler	Glass Wool Manufacturer
Freight Hauler	

Table 19 lists the waste sources depicted in the flat glass closed-loop supply chain. There are three types of secondary material: (1) pure, high quality cut-offs; (2) contaminated flat glass; and (3) end-of-use flat glass. Only the first type of secondary material can be reused for float glass manufacturing.

Table 19: Waste Sources of the Flat Glass CLSC.

Process Steps	Type of Secondary Material
Flat Glass Manufacturing	Pure, high quality cut-offs
Distribution/Transport	Contaminated Flat Glass
Construction	
Demolition	End-of-use Flat Glass

The three uses of flat glass as secondary material mentioned in the closed-loop supply chain for flat glass depend on their quality. These uses are:

- Float Glass Manufacturing
- Container Glass Manufacturing, and
- Glass Wool Manufacturing

3.5 Discussion of Findings

The economic situation of flat glass in Sweden and the lack of research on the topic of flat glass CLSCs indicate a clear need for a shift in focus onto CDW and flat glass CLSCs. Thus, this thesis' purpose was to identify a flat glass CLSC structure and to propose a cost structure through an exploratory study by conducting case studies in China, Germany, and Norway. The chapter 3 RQ1: Closed-loop Supply Chain of Flat Glass answers RQ1 through RQ1.C: (*RQ1) How can closed-loop supply chains (CLSC) for the purpose of flat glass look like? (RQ1.A) What actors are a part of a flat glass CLSC? (RQ1.B) What are the waste sources of flat glass in a flat glass CLSC? (RQ1.C) RQ1.C: What are the uses of flat glass as secondary material?*

The answer to the first research question can be found in figure 25 which depicts the flat glass CLSC built from literature and case findings. Furthermore, the actors of the flat glass CLSC are divided into main and sub-actors to reflect their active or inactive role in the CLSC. The main actors are float glass manufacturer, flat glass processor or refiner, flat glass distributor, CD company, flat glass recycler, and freight hauler. The sub-actors of the flat glass CLSC are raw materials supplier, government, third-party contractors, container glass manufacturer, and glass wool manufacturer. Moreover, three waste sources were identified: pure, high quality cut-offs during flat glass manufacturing; contaminated flat glass during distribution or transport and construction; as well as end-of-use flat glass during demolition of buildings. Lastly, three uses of flat glass as secondary material were identified. These are float glass, container glass, and glass wool manufacturing.

This thesis makes several contributions to theory, practice, and society. Altogether, this research adds to two research areas, i.e., flat glass and CLSC, these areas are combined and through the case study the researchers are able to reflect the current practices in different countries. Further, this thesis clearly defines the actors of a flat glass CLSC, provides a clear definition of the waste sources within a flat glass CLSC. It also defines the possible uses of flat glass as secondary material Even though the existing literature is scarce several bodies of work are the basis of this research and subsequently expanded through the researchers work.

The final flat glass CLSC proposed in the analysis shows similarities with the flat glass life-cycle derived from information provided by Geboes (2020). Even though the author's body of work has provided a good theoretical basis for this master's thesis the results are significantly different from each other. For one, Geboes looks at circularity of flat glass out of the architectural perspective. In contrast, the research team substitutes an economic perspective and reflects current practice by providing insights into several use cases. This difference is especially visible when it comes to the concepts of CLSCs, and which can be applied in a flat glass CLSC. This paper's findings clearly indicate the utilization of two concepts, i.e., reuse and recycle. However, Geboes suggests two more concepts based on theory which are repair and repurpose. This contradicts the research team's empirical findings which clearly demonstrate the use of only two concepts: reuse and recycle.

Furthermore, differences in the utilization of each of the concepts exist. Geboes (2020) provides detailed explanations on reusing entire glass units, while this was deemed impossible by the companies interviewed in this thesis. The concept of reuse does appear in the flat glass CLSC, however, only in the manufacturing phase, in which the pure, high quality cut-offs of sheets of flat glass are being reused for float glass manufacturing. This is done by the manufacturer themselves or through a recycler if the manufacturer does not have certain capacities for it. Neither the cases from China, Germany, nor Norway say that reusing entire glass units is possible.

Moreover, for the concept of recycling Geboes (2020) first proposes a closed-loop alternative that feeds the recycled flat glass cullets into the same loop (Figure 39 in Geboes, 2020). Nonetheless, this does not align with this paper's findings which state that merely the concept of reuse feeds the flat glass cullets back into the flat glass loop. In the concept of recycle, the recycled flat glass cullets cannot maintain the initial very high quality that is needed to stay within the flat glass closed-loop. Geboes continues with providing an open-loop alternative for the recycling concept which shows some similarities to the flat glass CLSC model proposed in the previous chapter. For one, the recycled flat glass cullets leave the flat glass loop and can enter the glass wool loop. This is one of the possibilities found in this paper. She further indicates hollow glass and foam glass to be other possibilities for recycled flat glass which were not found during this research. She does not mention container glass to be a possibility of recycled flat glass cullets. Additionally, Geboes' figure of the open-loop shows the three building blocks, i.e., manufacturing phase, use phase, and secondary material phase. Compared to this paper's flat glass CLSC, her model is less detailed. This master's thesis is not concerned with providing hurdles of flat glass CLSC implementation, instead focusses on who the participating actors are, where waste appears, and what its possibilities are.

Geboes (2020) refers to the report by DeBrincat and Babic (2018) multiple times throughout her master's thesis. The report examines the flat glass recycling in the UK and suggests several benefits, barriers, and opportunities. Some of the benefits mentioned are a decrease in CO2 emissions and a decrease of glass ending up in landfills. While the benefits of using recycled flat glass cullets in production was not the focus of this study, the interviewee from GERRE still mentioned these exact benefits. Furthermore, both bodies of work, i.e., the report by DeBrincat and Babic (2018) and this master's thesis have similar intentions which are to close the loop on flat glass. Lastly, the flat glass CLSC proposed in this paper's analysis is, in comparison with the model by authors DeBrincat and Babic (2018), much more detailed and only contains reuse and recycle as concepts of CLSCs. The figure by DeBrincat and Babic show that the recycled flat glass material feeds back into float glass manufacturing and the concept reuse does not feed back into float glass manufacturing but instead goes to a contractor. This does not line up with this thesis' research results.

This thesis' findings are also somewhat aligned with the findings of the paper by Rose et al. (2019). A reason for that is, that Rose et al. investigate Germany's flat glass recycling habits which are similar to the responses by the interviewee from GERRE which is also a German recycling company. Both agree on several benefits of using recycled flat glass cullets such as decrease in usage of raw material, energy, and CO2. In addition, the

CLSC proposed in the report by Rose et al. (2019) shares similar steps with the model proposed in the analysis. These steps are float glass manufacturing, flat glass refinement, construction, and recycling. Rose et al. research suggests that recycled flat glass cullets are used in, for example, container glass manufacturing. This is a possibility that this research team found out during interviews and analysis. Further, both bodies of work agree on pure and high quality cut-offs being reused for float glass production. Nonetheless, Rose et al. still consider land fill to be an option of a closed-loop.

This master's thesis adds to the research done by Rose et al. (2019) by adding different perspectives to the data collection for building the flat glass CLSC. These additional perspectives are the perspectives of flat glass manufacturers, Norwegian recyclers, and associations. Furthermore, this thesis provides insights into different countries, i.e., China and Norway in addition to Germany.

Several other bodies of scientific research were used to underline the research problem and provided a basis for this research such as the articles the articles by Govindan et al. (2015) and Amin et al., (2018). The former have written an extensive literature review on CLSCs and reverse logistics. The latter have conducted research in Canada on how the loop can be closed on pallets made from plastic. Both articles were utilized in the theoretical framework. While neither of the articles deal with CDW or flat glass, they still provided the basis the theory for actors in CLSC. This thesis adds onto both articles by providing a view on the actors of a flat glass CLSC in particular. For example, Amin et al. (2018) present an optimization structure to build a CLSC for plastic pallets in Canada. Similarly, to Amin et al. this research team also presents CLSC model but for flat glass based on data from three different countries.

Both articles by Yang et al. (2017) and Huang et al. (2018) address the use of the different concepts of CLSCs in connection to CDW. The former suggests 4Rs the latter 3Rs, both include reuse and recycle. The purposes of both papers do not align with this thesis' research purpose yet the concepts, i.e., reuse and recycle, were found to be concepts utilized in a flat glass CLSC. The papers examine the concepts of CLSCs in CDW in general, the research team adds onto this research by having an emphasis on flat glass as a part of CDW.

In addition to the contributions to theory mentioned above, the research team made several discoveries that it did not expect, nor did literature foreshadow them. Firstly, the researchers expected the European flat glass CLSC to be fairly similar due to similar geographic and economic structures, however, they did not expect the Chinese flat glass CLSC to share similarities with neither the German nor the Norwegian flat glass CLSC. Nonetheless, that is the case. The flat glass CLSCs depicted in the empirical findings chapters clearly visualize certain building blocks to be the same. The biggest difference here is that the Chinese flat glass CLSC stays within the country.

Furthermore, scientific literature described more concepts of CLSC that can be used for achieving circularity in flat glass than found through the case studies. This deducts to several reasons. First, the literature is purely based on theory and does not base the findings on empirical data. Second, the literature is based on case studies, but the case studies are from countries other than the ones considered for this thesis. Third, the case companies that were interviewed themselves simply do not apply the other concepts, but other companies within these countries may do so. Fourth, the concepts are not applied in the countries.

The research team did expect to find more concepts of CLSCs used, than just reuse and recycle, based on the literature suggesting more concepts. However, according to the findings no other concepts other than reuse and recycle are currently practiced within flat glass CLSCs.

Another unexpected finding is that Norway's flat glass CLSC does not include the reuse of pure, high quality cut-offs for float glass manufacturing. Norway does not have its own float glass manufacturer located in the country. A reason for why the high quality cullets are not reused is because it is not justifiable, in light of sustainability, to ship the recycled flat glass cullets back to the float glass manufacturer in central or eastern Europe.

Lastly, the researchers did not expect to find the possibility of using lower quality flat glass cullets in the production of low-grade windows. While this only seems to be a possibility in China it is still surprising. This is because in most European countries there are uniform standards in regard to construction of buildings.

Besides the theoretical implications described above, this research work implies several other contributions for practice and society. Because this thesis is connected to a bigger research project it provides a flat glass CLSC model which can be used as a starting point for developing a flat glass CLSC in Sweden. Nonetheless it can also be utilized by other businesses in the flat glass supply chain or in other countries. This thesis does not provide a step-by-step guide on how to implement the flat glass CLSC, but the proposed model combined with further research would be a step towards possible implementation. Furthermore, this thesis also makes its contribution to society by examining an important topic, i.e., sustainability and recycling. By researching circularity in CDW, the research team helps the city of Växjö to strive towards a full circular economy not only for flat glass coming from Växjö but also other Swedish cities and thus contributing to reducing waste, energy, and CO2.

4 RQ2: Cost Structure of Closed-loop Supply Chain of Flat Glass

This chapter provides the theoretical framework necessary to build the framework of reference and provide a basis for the analysis. It includes a framework of reference, followed by the empirical findings and lastly, the analysis and discussion of the findings related to RQ2.

4.1 Theoretical Framework

In the following subchapters a theoretical framework will be established. This framework includes theory about supply chain costs as well as closed-loop supply chain costs. This knowledge will then be utilized to build a flat glass closed-loop supply chain cost structure (see figure 26).

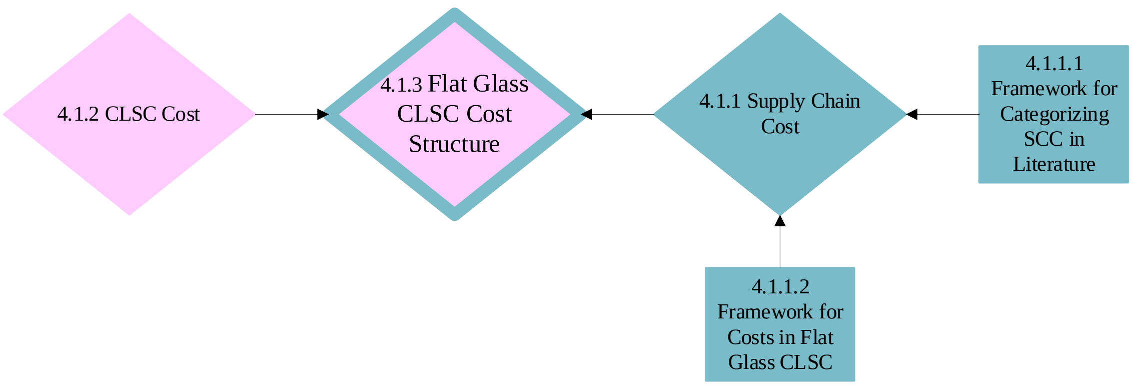


Figure 26: Theoretical Framework RQ2.

4.1.1 Supply Chain Cost

This subchapter will establish a theoretical basis for supply chain costs (see figure 27). This includes describing a framework for categorizing supply chain costs in literature and a framework for costs in flat glass CLSCs.

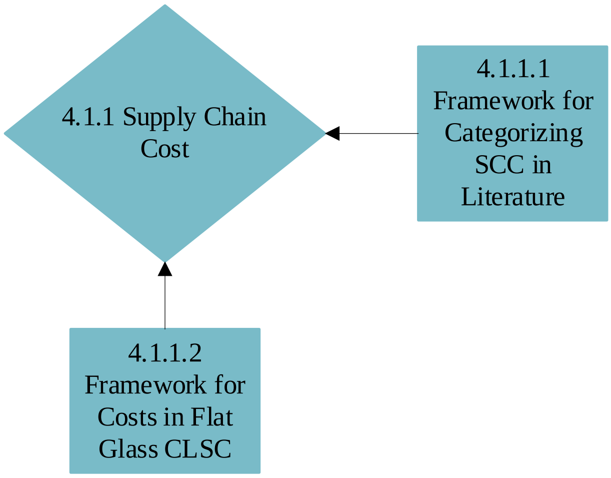


Figure 27: Theoretical Framework Supply Chain Cost.

One of the major uncertainties with the introduction of a CLSC for flat glass is related to costs. Dubois (2013, as cited in Geboes, 2020, 68) asserts that it is often unclear who should bear the costs related to dismantling, transportation, and recycling of the flat glass. Cost is one of the most important aspects of a company's performance and working on reducing cost is a viable strategy for obtaining a competitive advantage (Solvang, 2001). Costs can be divided into two types, i.e., fixed and variable. The former describes the types of costs that are consistent and do not change with the output a company produces. Examples of fixed costs are rent and insurance fees. The latter describes the types of costs that vary depending on the output produced by a company. Examples of variable costs are raw material costs and labor costs/salaries (Thommen et al., 2020). Hosang and Bongju (2005) highlight an issue that might arise when companies work to minimize their costs without considering the effects it will have on the SC as a whole. Improvement in one part of the SC might lower certain costs, while causing problems for other parts of the SC, which can lead to an overall negative effect on the SC as a whole. Bowersox et al. (2013) further underlines this problem by highlighting how a focus on a single firm's costs might lead to sub optimization in the SC as well as attempts from companies to move cost over to others. They further go on to explain that if the goal is to reduce the total costs in a supply chain it is highly reasonable to assume that one company might experience a growth in their cost, as a consequence of other parts of the SC's cost reduction. It is therefore crucial to the overall SC that the companies that get reduced costs compensate those that experience a growth.

Bowersox et al. (2013) suggests that to improve the overall effectiveness a supply chain cost (SSC) perspective should be applied. Chen (1997) describes how examining cost from a SC perspective can be used to remove redundant activities and improve the efficiency of the entire SC, which in turn will benefit everyone in it. Pettersson (2008, p. 34) defines SCC as "all cost in a Supply chain". SCC can be analyzed in different ways and many different cost groupings can be found in literature, often covering the same costs but using different terminology (Ibid., 2008).

4.1.1.1 Framework for Categorizing Supply Chain Cost in Literature

Chen (1997) demonstrates how a competitive advantage can be maintained when every actor in a supply chain constantly works to eliminate inefficiencies. These inefficiencies are unnecessary costs that can be placed in one of five categories:

- Production Costs
- Transportation Costs
- Warehousing Costs
- Inventory Carrying Costs
- Internal Material Handling Costs

The extent of these costs can vary immensely between industries, but in most cases production costs is the largest cost category followed by transportation and inventory costs (Chen, 1997). An important aspect emphasized in the article is the existence of three types of inventory costs: Finished goods cost, in-transit inventory cost, and raw material cost. Chen (1997) also addresses a fundamental issue in SC's, i.e. the questions of who should carry the costs of warehousing and which functions should it have?

Sachan et al. (2005) models the total supply chain costs of an Indian grain SC. The total SCC is divided into four different cost groups. The farmer's price covers the costs of growing and processing grain, as well a margin for the farmer. Waste is the cost of product loss. It can be divided into three types, obsolete, transit, and pilfering losses. The third category is total markup and covers the amount added to the cost to cover overhead and profit by each of the actors in the chain. The last cost group is titled additional costs and includes the additional costs that each of the actors incur. These additional costs can be divided into five elements:

- Inventory Holding Costs
- Material Handling Costs
- Transportation Costs
- Order Processing Costs
- Packaging Costs

Bryne and Heavey (2006) introduce a model that analyses the effect of information sharing and forecasting on the performance of an industrial SC consisting of a producer and a distributor. The overall SCC is used as a performance measure in the model and the different costs are divided into five categories:

- Transportation Cost
- Order Processing Cost
- Production Setup Cost
- Inventory Cost
- Backorder Cost

For this model transportation costs are defined as the costs of shipping finished goods from the company to the distributor. In the SC investigated in this example the transportation cost is paid for by the distributor. Order processing is the cost that occurs when an order is received. Production setup costs are expenses related to the preparation of an order in the manufacturing areas. Inventory costs are the expenses of holding an inventory for a certain amount of time. The last category is costs related to backorders (Bryne and Heavey, 2006).

Pettersson (2008) continues to build on the earlier models. To develop it further she interviews 30 Swedish companies in 10 different industries, among other the manufacturing and construction industry. By analyzing earlier examples in literature in relation to the responses from Swedish industry she proposes a new framework. She divides the total SCC into six separate categories: administration costs, manufacturing costs, warehouse costs, distribution costs, capital costs and installation costs.

The first cost area proposed by Pettersson (2008) is Administration cost. Administration cost includes the cost related to the handling of customers. This includes the costs of processing customer requests, the processing of material purchasing, handling claims, cost of support functions, as well as installation cost in situations where it is applicable. According to Pettersson (2008) giving an exact definition of what should be included in this cost area is difficult, as it will vary a lot between SCs depending on among other things the business they are in.

Manufacturing cost includes the cost that can be directly linked to the manufacturing of products. This includes the cost of material used, costs related to the machine used, direct and indirect labor cost, as well as cost related to testing of the product (Petterson and Segersted, 2013).

The warehouse costs can be further split into three more detailed groups. The first covers the inspection cost of new incoming goods. The second area includes the salary cost of the people working in the warehouse, while the third cost group is related to the cost of the warehouse building such as rent and electricity.

The distribution costs are expenses related to the movement of products and materials. This can be costs in both the inbound and outbound logistics. The most substantial part of these costs will be related to the shipping of material from suppliers or delivery of products to customers. But Pettersson (2008) includes additional aspects such as insurance and inspection of goods, letter of credit for the transaction, and custom clearance as costs that might be relevant to the company.

The capital cost group covers the cost of having capital tied up in either products or invoices. Pettersson (2008) offers three subgroups covering the capital cost of products tied up in warehouses, products in transit, as well as the capital bound up in invoices sent to customers that are not paid yet.

The last group covers the cost that can occur when a new installation is needed in the supply chain. This can be related to buildings, but also new tools and machines at worksites. It also includes the labor costs of the installation (Petterrsson, 2008).

In a more recent study, Visser et al. (2020) analyses the supply chain cost of a wood pellet producer. The supply chain investigated stretches from the raw material supplier to the end user. The authors divide the cost SCC components included in the analysis into six categories. The first group is raw material cost which covers the purchase and delivery of feedstock used in the pellet production. The next is pelletizing cost which covers the production cost of the product. The third category is the cost of transporting the product to an export port. Then there are handling and storage costs at the export port. The fifth category includes the international transportation costs, while the last covers the handling and storage costs at the import port.

The authors also address the fact that most businesses have secured capital through outside investments or loans and amortization of this capital leads to expenses for the business. In the article capital costs are divided into two categories. The first is in relation to equipment for production and warehouses, while the other includes costs for additional equipment, infrastructure, planning, installation and construction.

4.1.1.2 Framework for Costs in Flat Glass Closed-loop Supply Chains

As illustrated in the previous chapter, SCC has been a topic in literature for decades and as a consequence a multitude of different concepts for how to analyze and categorize them have been proposed. For the purpose of this paper the framework proposed by Pettersson (2008) will be used as it has been developed and utilized in collaboration with different Swedish industries. By combining the Pettersson (2008) framework with the phases of the flat glass CLSC proposed in chapter 3.4.5 Flat Glass Closed-loop Supply Chain the following framework for analyzing cost in the CLSC of flat glass is proposed. As indicated in chapter 3.1.3 the researchers expect the major actors in the CLSC to be manufacturers, construction and demolition companies, and recyclers.

Table 20: Initial Framework Structure for Closed-loop Supply Chain Cost.

SCC Categories	Manufacturing Phase	Use Phase	Waste Phase
Manufacturing Cost			
Distribution Cost			
Warehouse Cost			
Administration Cost			
Capital Cost			
Installation Cost			

4.1.2 Closed-loop Supply Chain Cost

This subchapter will establish a theoretical basis for closed-loop supply chain costs (see figure 28).

Figure 28: Theoretical Framework Closed-loop Supply Chain Cost.

Many scholars have tried to structure the cost of CLSC. Bezan (2017) points out the cost structure of CLSC in detail, as shown in the table below.

Table 21: Cost Structure of CLSC (Bezan, 2017).

	Cost Parameters	Cost Objects
Cost Structure of CLSC	Holding Cost	Manufactured and remanufactured items at the sides of the vendor and the buyer.
		Collected items for recovery at the sides of the vendor and buyer.
	Setup Cost	Manufacturing and remanufacturing production
	Batch Ordering Cost	
	Unit Cost	Manufacturing and remanufacturing production
	Investment Cost	The design process
	Disposal Cost	Products that can no longer be remanufactured
	Transportation Cost	
	Greenhouse Gas (GHG) Emissions Cost	Manufacturing and remanufacturing production and transportation
	Energy Cost	Manufacturing and remanufacturing production

Similarly, Taleizadeh et al. (2019) divide the cost of CLSC into the following categories. Firstly, the purchasing cost of raw materials and inventory holding costs of products and raw materials play pivotal roles in the cost of SC. Operation costs (manufacturing cost, remanufacturing cost, collecting cost, recycling cost and disposing cost) and transportation cost are two other important categories in the cost of CLSC. They also point out that the fixed cost of using technology, the cost of employee support, and advertisement cost should be considered while structuring the cost of CLSC. Further, if manufacturers do not have capacities to build the CLSC yet, the cost of establishing additional capacities (recycle center, remanufacturing center, disposal center and plant) will be essential in the cost of CLSC. For manufacturers who are willing to offer discounts that motivate customers to return used products, they need to take the cost of the discount offer into consideration.

Some scientific literature focus on the specific aspects from the cost structure of CLSC. For instance, Gaur et al. (2020) concentrate on the production costs in CLSC. They compare different cost structures between new products and remanufactured products: the total cost from new products is formulated by production cost, waiting cost for backlogged orders, and inventory holding cost, while the total cost from remanufactured products is the acquisition/manufacturing cost of a remanufactured product.

Liu et al. (2019) focus on structuring the disposal costs of CDW in China. Based on different CDW disposal routes, they divided disposal costs as direct costs and indirect costs (see table 22).

Table 22: Disposal Cost Structure of CDW in China (Liu et al., 2019).

	Direct Costs	**Indirect Costs**
Illegal Dumping	• Transportation to illegal dumping places.	• Excavation Cost • Transportation to centralized recycling places. • The cost of new construction of the centralized recycling disposal site.
Controlled Dumping	• Transportation to the legal CDW disposal site. • The admission fee.	• The cost of new construction and operation of the centralized recycling disposal site minus the admission fee
Centralized Recycling	• The transport cost of transporting the CDW into the centralized recycling disposal site. • The admission fee.	• The centralized recycling cost minus the admission fee of centralized recycling disposal sites.
On-site Recycling	• The on-site recycling cost of the CDW that can be resourced. • The transport cost of transporting the remaining CDW to the recycling center. • The admission fee of the recycling center.	• The rate of non-resource recovery multiplied by the centralized recycling, then minus the admission fee of the recycling center.

Some scholars highlight certain factors, which affect the cost, that should also be considered while structuring the cost of CLSC. For instance, Gaur et al. (2020) point out that lead-time is a significant factor which is inversely proportional to direct cost, but positively proportional to inventory holding cost. While configuring a CLSC, manufactures can determine a supplier's financial incentives to reduce the total lead-time, thereby reducing inventory holding cost. Taleizadeh et al. (2019, p. 170) explain why reducing inventory holding cost is important, because “the inventory holding costs of the products and the raw materials are counted as the main cost of the supply chain”.

Panda et al. (2017) point out corporate social responsibility (CSR) is another pivotal factor affecting the cost of CLSC. CSR is incorporated through product recycling in the reverse channel of CLSC. Although CSR cost is pretty high, heavy CSR practices can maximize non-profit objectives, which may bring higher profit margin than the profit maximization objectives.

CLSC has a significant impact on the total annual cost. According to Gaur et al. (2020), companies which conduct all activities of RL have a 12% to 15% lower annual cost than those who cooperate with third-party manufacturers. Hence, although the preparation of CLSC is a costly endeavor, it will bring potential benefits in the future.

4.1.3 Flat Glass Closed-loop Supply Chain Cost Structure

By categorizing the costs found in the CLSC literature in the framework proposed in 4.1.1.2 an indication of the costs found in the CLSC of flat glass can be put forth. As can be seen in table 23 most literature is covering the cost related to production in CLSC, while some cover the waste management phase as well. None in the articles investigated for this thesis covered any cost related to the use phase. Holding costs can be seen in both the warehousing and capital cost category, as it includes both the cost of storing the material/product as well as the opportunity costs of the bound capital.

Table 23: Initial Closed-loop Supply Chain Cost Framework.

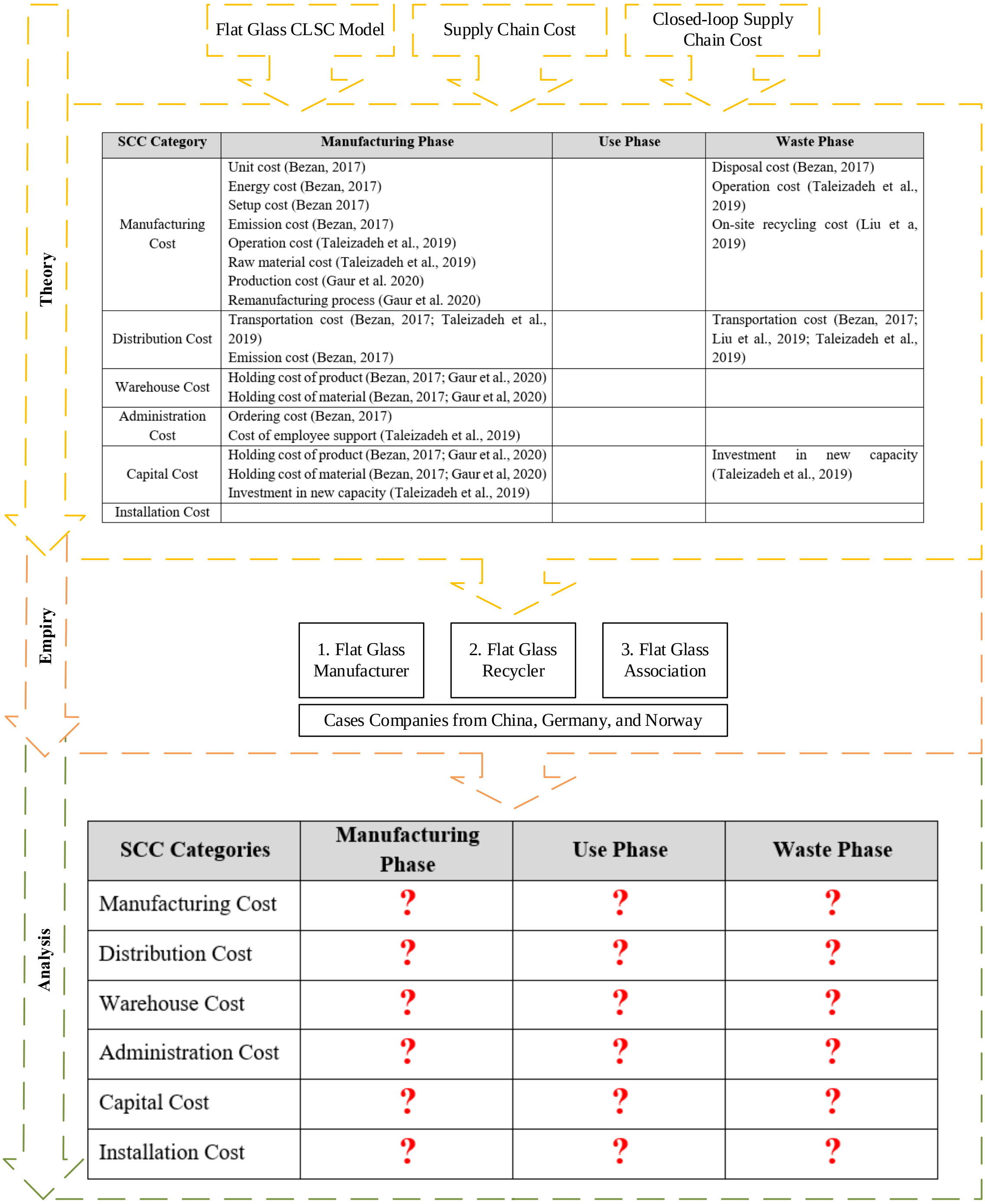
SCC Category	Manufacturing Phase	Use Phase	Secondary Material Phase
Manufacturing Cost	Unit cost (Bezan, 2017) Energy cost (Bezan, 2017) Setup cost (Bezan 2017) Emission cost (Bezan, 2017) Operation cost (Taleizadeh et al., 2019) Raw material cost (Taleizadeh et al., 2019) Production cost (Gaur et al. 2020) Remanufacturing process (Gaur et al. 2020)		Disposal cost (Bezan, 2017) Operation cost (Taleizadeh et al., 2019) On-site recycling cost (Liu et a, 2019)
Distribution Cost	Transportation cost (Bezan, 2017; Taleizadeh et al., 2019) Emission cost (Bezan, 2017)		Transportation cost (Bezan, 2017; Liu et al., 2019; Taleizadeh et al., 2019)
Warehouse Cost	Holding cost of product (Bezan, 2017; Gaur et al., 2020) Holding cost of material (Bezan, 2017; Gaur et al, 2020)		
Administration Cost	Ordering cost (Bezan, 2017) Cost of employee support (Taleizadeh et al., 2019)		
Capital Cost	Holding cost of product (Bezan, 2017; Gaur et al., 2020) Holding cost of material (Bezan, 2017; Gaur et al, 2020) Investment in new capacity (Taleizadeh et al., 2019)		Investment in new capacity (Taleizadeh et al., 2019)
Installation Cost			

4.2 Framework of Reference

This chapter presents the research model and operationalization model for RQ2. In the end, the concepts described in theory are summarized.

4.2.1 Research Model

The research model for RQ2 is visualized in figure 29 In short, the analysis is based on empiry which is based on theory. A framework for costs in flat glass CLSCs was developed by combining theory of supply chain costs and closed-loop supply chain costs with the flat glass CLSC model developed in chapter 3.4.5. The theory will pose as the foundation for the interviews. The findings of the empiry will then be analyzed and used to build a flat glass CLSC cost structure.



SCC Category	Manufacturing Phase	Use Phase	Waste Phase
Manufacturing Cost	Unit cost (Bezan, 2017) Energy cost (Bezan, 2017) Setup cost (Bezan 2017) Emission cost (Bezan, 2017) Operation cost (Taleizadeh et al., 2019) Raw material cost (Taleizadeh et al., 2019) Production cost (Gaur et al. 2020) Remanufacturing process (Gaur et al. 2020)		Disposal cost (Bezan, 2017) Operation cost (Taleizadeh et al., 2019) On-site recycling cost (Liu et a, 2019)
Distribution Cost	Transportation cost (Bezan, 2017; Taleizadeh et al., 2019) Emission cost (Bezan, 2017)		Transportation cost (Bezan, 2017; Liu et al., 2019; Taleizadeh et al., 2019)
Warehouse Cost	Holding cost of product (Bezan, 2017; Gaur et al., 2020) Holding cost of material (Bezan, 2017; Gaur et al, 2020)		
Administration Cost	Ordering cost (Bezan, 2017) Cost of employee support (Taleizadeh et al., 2019)		
Capital Cost	Holding cost of product (Bezan, 2017; Gaur et al., 2020) Holding cost of material (Bezan, 2017; Gaur et al, 2020) Investment in new capacity (Taleizadeh et al., 2019)		Investment in new capacity (Taleizadeh et al., 2019)
Installation Cost			

SCC Categories	Manufacturing Phase	Use Phase	Waste Phase
Manufacturing Cost	?	?	?
Distribution Cost	?	?	?
Warehouse Cost	?	?	?
Administration Cost	?	?	?
Capital Cost	?	?	?
Installation Cost	?	?	?

Figure 29: Research Model RQ2 (Design inspired by Girot and Kopf, 2018).

4.2.2 Operationalization Model

Table 24 is a summary of the concepts of theory which are described in more detail in the previous theory chapters.

Table 24: Operationalization RQ2 (Design inspired by Girot and Kopf, 2018).

Concept	Operationalization
Manufacturing Cost	Manufacturing cost includes costs that can be directly tied to the manufacturing process. This includes "direct material, direct labour and overhead production costs. (Petterson and Segersted, 2013)
Distribution Cost	"Distribution costs include inbound and outbound transportation and its administration" (Petterson and Segersted, 2013)
Warehousing Cost	"Warehouse costs cover costs for stockholding and treatments in warehouses." (Petterson and Segersted, 2013)
Administration Cost	"Administration cost includes all cost related to administration like cost for the people that handles customer orders, people that purchase material and people that book transportation" (Pettersson, 2008)
Capital Cost	"Capital costs are associated with investments in the company's facilities". For example capital tied up in warehouse, products in transit and unpaid products. (Pettersson and Segerstedt, 2013)
Installation Cost	The cost of installing a product. (Petterson, 2008)

4.3 Empirical Findings

The following subchapters encompass empirical findings related to the cost structure of closed-loop supply chain of flat glass from China, Germany, and Norway. The detailed of each of the cases and processes are provided in chapter 3.3.

4.3.1 Flat Glass Closed-loop Supply Chain Costs in China

4.3.1.1 CHIMA1 – Costs

A case description can be found in chapter 3.3.1.1 CHIMA1 – Case Description.

The major cost elements of CHIMA1's manufacturing process are material purchasing cost and employee supporting cost. The production manager explained that they purchase materials when there are customers' orders, and process tempered glass products based on customers' needs. After making the finished products, the company will deliver them straight to customers. Hence, inventory backlog problem does not exist, and inventory holding cost is not the major element of their SC cost. Furthermore, transportation costs play an important role in their entire supply chain, especially in their outbound logistics, because they are responsible to deliver products to their customers.

There are two important variable costs in this company: material purchasing cost and production cost. Nowadays, due to the materials being in short supply in the Chinese market, the price of materials for tempered glass has increased a lot, which makes material purchasing costs become more variable. For the production cost, different tempered glass products costs will differ from each other a lot based on customers' needs. However, the production manager points out there are no significant differences in the unit production cost of different tempered glass products because their processing processes are similar and consume similar energy.

When the research team asks whether the material purchasing cost will decrease by replacing new materials with recycled materials, the production manager says it will increase the cost by doing so. Qualified recycled materials are even in shorter supply in the market, furthermore, recycling materials will have some additional costs such as sorting costs and disposal cost. Thus, the price of recycled materials might even be higher than the price of new materials in the market. The production manager also mentioned that even if they have the capacity of using recycled materials into their new products, the shortage of recycled materials and high price are still unavoidable challenges for them.

This company has a green production line and does not cause environmental pollution. The production manager further explains that their production line only consumes electricity, so additional emission costs do not exist.

4.3.1.2 CHIMA2 – Costs

A case description can be found in chapter3.3.1.3 CHIMA2 – Case Description.

In the process of purchasing raw materials, CHIMA2 conducts on-site inspections and sampling and testing of raw materials before making a decision, these processes incur costs. The transportation cost is usually included in the price of raw materials in the contract. The director says if they pick up raw materials by themselves, the price of raw materials will be cheaper.

After receiving raw materials, warehousing cost is added. The deputy minister says that loss of raw materials due to improper warehousing also increases costs. The director emphasizes that the company will purchase a large amount of raw materials when their prices are cheap, and then the warehousing cost will increase accordingly. The director also underlines that compared with other raw materials, flat glass cullets require extra cleaning and sorting costs.

For the cost of flat glass production in CHIMA2, both the director and the deputy minister point out that energy costs are the major costs. The director explains that as an environmentally friendly company, CHIMA2 uses natural gas as fuel in the float glass production line and electricity in deep processing. Natural gas is clean energy but expensive in the company's region, thus energy costs are the major costs of flat glass production. The deputy minister points out that the sodium carbonate purchasing cost is the second major cost. Apart from these two major elements of the production cost, the deputy minister says that there are equipment costs as the fixed cost and employee salary as the variable costs in the production cost group.

According to the deputy minister, using flat glass cullets affects the total production cost, because cullets can lower the melting point of raw materials, thereby saving natural gas and reducing energy costs. However, the ratio of flat glass cullets should not be so high due to the quality requirement of flat glass. The deputy minister further mentions that the company has a special and complicated method to calculate the balanced point between inputs of cullets and natural gas to control production costs while ensuring product quality. Usually, the company controls the cullet input ratio between 15% - 20% in the float glass production line.

Both interviewees highlight the huge differences in types of costs depending on types of flat glass products. The director explains that different types of flat glass products have different processing requirements, furthermore, some customers have special demands, which will incur different types of cost.

In the process of selling flat glass products, the transportation costs of flat glass products are borne by their customers. CHIMA2 arranges freight haulers to deliver products to their customers, and customers pay the transportation fee to the freight haulers.

CHIMA2 strictly follows governmental regulations to process waste generated in the float glass production, for example, they will desulfurize and denitrify the exhaust gas before discharging it, which incurs additional costs.

4.3.2 Flat Glass Closed-loop Supply Chain Costs in Germany

4.3.2.1 GERRE – Costs

A case description can be found in chapter3.3.2.1 GERRE – Case Description.

According to the interviewee the two biggest matters of expenses in the flat glass recycling processes are: (1) transport; (2) processing. Flat glass as a secondary material needs to be processed in very high volumes to achieve low revenues and sales.

Flat glass recycling is a high-volume business and compared to, for example, recycled electronic secondary material which approximately costs 1.000€ per ton, flat glass as secondary material only costs approximately 10€ per ton. On top of that, the interviewee points out increasing sand prices.

The costs in transport, also procurement, differentiate depending on the quality of the flat glass secondary material. The interviewee further explains that the higher the quality the more expensive it is to procure and transport. Lower quality glass is less expensive in both procurement and transport. The case company gets paid for acquiring material but also must pay for receiving material. No information was provided on why that is the case.

The costs of processing the secondary material are among other ways calculated on the number of machines the company needs to utilize in order to produce high quality cullets. There is a difference in secondary material needing to go through one or multiple machines.

The interviewee further explains that 10% recycled cullets, used in glass manufacturing, can save 2 to 3% of the energy used in production. These 10% additionally save approximately 7% CO_2. That is because when using cullets instead of raw materials, the CO_2 of processing the raw materials is already released. For example, container glass producers who utilize up to 90% recycled material, significantly lower their CO_2 footprint.

In addition, using recycled material instead of raw material results in increased pull, i.e., a higher productivity because the machines can produce more glass with cullets. High quality cullets, that are used to produce new glass, can prolong the machines lifespan.

Lastly, using cullets results in decreasing landfill space and the use of new material.

4.3.3 Flat Glass Closed-loop Supply Chain Costs in Norway

4.3.3.1 NORIWA – Costs

A case description can be found in chapter 3.3.3.1 NORIWA – Case Description.

The respondent remarks that the production process of glass windows and façades follows a pull-strategy. This means that windows and façades are only produced when an order from a customer is received.

Given the geographical nature of Norway, transportation costs have a major impact on companies' costs. The respondent offers an example of the world's northernmost producer of insulating glass panes located in Senja, Norway. When they order their large format float glass from Germany there are high costs attached to transportation, but also environmental costs.

The respondent highlights a clear difference in transportation costs on the large format float glass and finished glass and façade products. Large format float glass has a standardized format making it easier to transport effectively in specialized containers. The transportation of finished products on the other hand contains a lot of what the respondent refers to as uglies. Uglies are factors that complicate the transportation of a product. Finished products will often contain multiple glass panes put together with pockets of air between them. That in combination with the fact that the format of finished products is not optimal for transportation makes it difficult to pack it in an effective way leads to trucks transporting a lot of air. According to the respondent there is no doubt that from an environmental standpoint and strictly looking at transportation costs it is better to transport large format glass to Norway, rather than finished products.

4.3.3.2 NORRE – Costs

A case description can be found in chapter 3.3.3.3 NORRE – Case Description.

To ensure an effective collection system with a nationwide presence, the company runs 350 local and 17 regional collection facilities. The collection system is funded through a 9NOK fee on all new units sold in Norway. The cost of transporting the windows to the recycling facility is highly dependent on the geographical location of the source. As all the PCB windows that go through the collection system ends up at the same facility in south-eastern Norway, the transportation cost will increase the further away from the facility the original source is.

When the window is received at the recycling facility the glass pane is cut from the frame and processed into cullets. This remediation process is manual and costly for the organization. The frames containing PCB are then transported to a facility in Denmark, where they are burned.

4.3.3.3 NORNG – Costs

A case description can be found in chapter 3.3.3.5 NORNG – Case Description.

According to the respondent the cost of their recycling process varies a lot depending on the source of the material. While the glass received from producers of glass products is clean and can easily be sent into the production line, windows are a more costly endeavor. All the activities that are included in the remediation of windows make up the largest portions of costs related to the recycling process. These activities include coordination with the owner of the windows, collection and transportation of the units, the processing of them which must be done in accordance with rules and regulation, and quality controls in the process which is needed to document that the processing is done correctly.

The respondent also highlights that an important cost aspect related to the recycling process today is the cost of landfill. As recycling often has much higher transportation costs related to it, landfill is often a more feasible option for the owner of the glass waste.

4.4 Analysis of Findings

The purpose of this thesis is to identify a closed-loop supply chain structure of flat glass, including actors and actions as well as to propose a cost structure. This chapter answers RQ2 How can a cost structure for a closed-loop supply chain (CLSC) for the purpose of flat glass look like? The cost categories are analyzed separately and in the end the cost structure proposed in the previous chapter is adjusted with the empirical findings.

4.4.1 Manufacturing Costs

Manufacturing costs are costs that can be directly linked to the manufacturing process. Pettersson (2008) suggests material cost, labor cost, machine cost, and testing of finished product as common elements of production cost for companies. The respondents from CHIMA2 explain that the largest cost factor in their production is energy costs, followed by the cost of purchasing the raw material sodium carbonate. Bazan et al.'s (2017) CLSC model accentuate. cost of energy as a central cost aspect. While energy costs will incur in both the production and recycling of flat glass products, only CHIMA2 mentioned it as a major cost element. CHIMA2 and GERRE both mention that flat glass cullets can be used to mitigate the energy consumption of machines used in the manufacturing of new flat glass products. The interview with CHIMA2 highlights that cullets can be used to lower the melting point of the raw materials used, which in turn reduces the energy consumption in the production. CHIMA1 highlights two major cost elements in their manufacturing process, employee support cost and material purchasing. Labour cost can therefore be viewed as an important cost factor in deep processing.

Regarding raw material cost, CHIMA1 mentions that low supply of raw material leads to higher prices, while CHIMA2 mentions that the price fluctuates and is unpredictable. CHIMA1 reports raw material cost as a major cost factor for them, while this is not the case for CHIMA2. A possible reason for this difference can be that CHIMA2 produces the type of float glass material themselves and is thus not affected by the shortages in the market in the same way. An increase in the production of cullets for the float glass production can help stabilize the raw material market and reduce the costs. This might in turn lead to a steady supply of float glass for deep processing and reduce the overall production costs in the closed loop. CHIMA2 has another cost connected to the procurement of raw material. To be able to guarantee a high quality product they conduct on-site inspection at their raw material suppliers. The respondent at CHIMA2 also mentions that their suppliers are responsible for the transportation, thus transportation costs are included in their raw material costs. In the reverse flow the cost of raw material is complicated. As explained by GERRE they will in some scenarios get paid to pick up their raw material, while in other cases they will have to pay for it. Why it is this way the respondent would not declare, but quality and volume of the material could be determining factors.

In the reverse flow the manufacturing costs are highly dependent on the quality of the waste material received. Both the interview NORNG and GERRE show how different types of waste material will require different treatment. According to NORNG high quality waste material such as cut-off from flat glass processing does not need any remediation and can instead be sent directly to the grinder. NORNG and NORRE explain that windows on the other hand need to go through a manual remediation process which accounts for a large portion of the cost related to the manufacturing process. This indicates labor cost being a major cost factor for these companies. The frame that is removed from the glass pane is treated as waste and must be disposed of. The respondent from GERRE did not mention explicitly which processes the different types of materials go through but did instead elaborate that low quality material need to go through more process steps before they are ready for use, than high quality material. This leads to higher costs in the manufacturing process for low quality cullets than high.

Bazan et al. (2017) makes a point of comparing the unit production price of manufactured and remanufactured products. The proposed flat glass CLSC does not consider the concept of remanufacturing products which according to NORIWA is not financially feasible. Nonetheless, the research shows that the manufacturers that utilize secondary material in their processes can lower overall manufacturing costs compared to others using only new raw materials. The case interview with CHIMA1 also highlights how the unit costs of different types of processed glass are fairly similar as they consume similar amounts of energy.

Another important cost aspect for the forward flow of the flat glass CLSC is the generation of waste in the operations of the actors. How this waste is handled has a direct impact on the quality of the waste material available in the reverse flow, but will also affect the costs of the actor. As pointed out by NORIWA and NORNG today's legislation in Norway creates a grey area where the waste generated can be handled in different ways and the most cost efficient is usually not beneficial for the CLSC as a whole. The interview with CHIMA2 also brings up a different type of waste in manufacturing. CHIMA2’s manufacturing process generates exhaust gas that needs to be desulfurized and denitrified before it can be discharged, thus emission costs incur in the manufacturing process. Contrary to CHIMA2, CHIMA1 reports that their production line runs on electricity, hence they do not have any emission costs. Bazan et al. (2017) considers emission costs from sources such as hauling, production and remanufacturing. While the interviews indicate the possibility of emission costs in the manufacturing processes, no information were found regarding the transportation and recycling process. Bazan et al. (2017) indicates that the main source of emission cost from transportation is fuel consumption and the energy consumption in manufacturing processes. While these costs were not expressed in the interviews the researchers find that it is highly likely that these exist in the case of a flat glass CLSC as well. As countries all over the world work to reduce their greenhouse gas emissions the costs related to emission will continue to rise.

Table 25 lists the manufacturing costs.

Table 25: Manufacturing Costs Summarized.

Manufacturing Costs	Phase
Energy cost	Manufacturing; Secondary Material
Raw material cost	Manufacturing
Inspection cost	
Unit cost	
Remediation cost	Secondary Material
Labor cost	Manufacturing; Secondary Material
Waste treatment cost	Manufacturing; Use; Secondary Material
Emission cost	Manufacturing

4.4.2 Distribution Cost

By Pettersson's (2008) definition distribution costs should cover the cost of inbound and outbound transportation of materials and products. Transportation costs are one of the key cost elements in both the forward and reverse flow in the flat glass CLSC as products and material sometimes have to travel long distances between actors. Bazan et al. (2017) treat the transportation costs of the CLSC model as a fixed cost per trip. While this might be the case for stable buyer-supplier relationships in the flat glass CLSC as well, it is not the case for the CLSC in general. In the interview with NORIWA the respondent explains that large format flat glass is more suitable for transportation than processed and ready for use products. This is due to the fact that the glass standardized format makes it possible to reach a higher fill rate by utilizing specialized containers than what is possible with the processed units. This indicates that from a transport cost perspective using local processing companies can be beneficial. This is also a goal in the German CLSC according to GERRE, where they strive to keep distances to a minimum to avoid breakage during transportation. The respondent for CHIMA1 specifies that transportation costs are an important factor for them as they are responsible for the delivery of the finished products. This can also be seen as an argument for local processing companies as this expense would be significantly lower.

In the reverse supply chain, the case of NORNG raises a problem in relation to the transportation costs linked with the options of landfilling versus recycling. This issue is very much in line with the finding in Liu et al. (2019). In the interview with NORNG the respondent highlighted that due to the increased transportation costs connected with the recycling process owners of glass waste will often choose to landfill their waste as it is a more financially viable option for them. As the recycling site for flat glass of the company interviewed is located in south-eastern Norway, the haul distance for flat glass owners in other parts of Norway would be substantial. The flat glass recycler in Germany also points out that flat glass is a low margin business compared to other recycled materials. According to the respondent flat glass recycling needs high volumes to be a profitable business. This indicates that in today's market recyclers cannot necessarily cover the large transportations cost related to the waste material either. The interview with GERRE also highlights that higher quality secondary materials are more expensive to transport than lower quality material. Two of the disposal routes mentioned in Liu et al. (2019) are controlled dumping (landfill) and recycling centers. Their study shows that both the haul costs and admission fee (entrance fee to the landfill or recycling center) is higher for recycling centers, than for landfill. To encourage more recycling the paper suggests a governmental compensation solution. The study also suggests that the least costly solution is on-site recycling as it removes much of the transportation costs. In the case of flat glass in Norway today, this is not necessarily a viable option due to legislation treating windows that are not intact as dangerous material.

As mentioned in the previous chapter Bezan et al. (2017) considers emission costs in transportation as a cost factor in their model. Emission costs were not mentioned by any of the respondents in relation to distribution, but as governments strengthen their legislation regarding emission of greenhouse gases this cost is likely to increase in the future.

The table below lists the distribution costs.

Table 26: Distribution Costs Summarized.

Distribution Costs	Phase
Transportation cost	Manufacturing; Use; Secondary Material
Emission cost	Manufacturing; Use; Secondary Material

4.4.3 Warehousing Cost

Pettersson (2008) defines the warehousing costs as the expenses related to stockholding and treatments in warehouses. In Taleizadeh (2019), CLSC model inventory holding costs of raw materials and finished products are treated as the main cost aspect of the supply chain. The interviews conducted indicate that the role of warehousing costs is vastly different depending on the actor in the flat glass CLSC. CHIMA2 is a manufacturer that produces both large format flat glass using the float process and processed flat glass products. The company reports that raw material prices fluctuate a lot leading them to purchase large amounts of raw material when prices are low, which in turn raises their warehousing costs. The respondents also point out that the company has additional warehousing costs associated with flat glass cullets. These products need extra cleaning and sorting when they arrive. The company also reports costs related to loss of raw material due to improper storage. Even though CHIMA2 reports warehousing costs, they are not considered as one of the major cost aspects of the company.

The respondents for CHIMA1 and NORIWA indicate that for companies whose activity concerns the processing of flat glass products warehousing costs play a minor role. Here the companies follow a strategy where material is purchased when an order is received, and products are shipped out as soon as they are finished. This greatly reduces the need for warehousing and the costs connected to it. In the interview with the three recycling companies GERRE, NORRE, and NORNG neither report that warehousing costs are a major cost factor for them.

Table 27 lists the warehousing costs.

Table 27: Warehousing Costs Summarized.

Warehousing Costs	Phase
Raw material storage	Manufacturing; Secondary Material
Product storage	Manufacturing; Secondary Material
Loss of raw material	Manufacturing
Sorting cost	
Cleaning cost	

4.4.4 Administration Cost

Administration costs should include the expenses that can be tied to the administration of the supply chain. Exactly what is included in this cost group will vary by company, but it should cover the expenses of handling customers, suppliers and transportation of goods. It should also cover the costs of employees who support the supply chain such as secretary and management (Pettersson, 2008). The interviews conducted offered little direct information about this cost group, but transportation of goods is mentioned as an important activity by both recyclers (GERRE, NORNG, NORRE) and manufacturing companies (CHIMA1 and CHIMA2). CHIMA1 mentions that they deliver their products to the customer which means they are responsible for the administration of transportation. GERRE has its own truck fleet which also entails administrative costs. CHIMA2 mentions that for their raw materials transportation is a part of the raw material price and is organized by supplier, while for finished products the CHIMA2 administers the delivery themselves. While waste material will be delivered to collection centers in the NORRE case, they still need to organize the transportation between collection centers and the recycling facility.

The same actors also operate in a supply chain where all of them have both suppliers and customers that need to be administered. It can therefore be safely assumed that there incurs costs related to administration of transportation, suppliers and customers for all of these actors, but how impactful these costs are is unknown.

Table 28 summarizes the administration costs.

Table 28: Administration Costs Summarized.

Administration Costs	Phase
Supplier handling	Manufacturing; Use; Secondary Material
Customer handling	
Transportation handling	
Support functions	

4.4.5 Capital Cost

According to Pettersson (2008) capital costs are expenses related to capital tied up in either products in warehouses, products in transit, or products that have yet to be paid. The first category of costs will depend on how much inventory the companies keep. The interviews conducted indicate that there are different approaches by the companies. As previously mentioned CHIMA2 keeps inventory of both material and products which increases the capital cost of the company as more capital is tied up. The responses from CHIMA1 and NORIWA indicate that processing companies keep lower inventories and thus have lower capital costs. The cost of products in transit or yet to be paid, will vary depending on the individual companies' customers' geographical location and the credit time offered to customers.

The different companies will also have capital costs that are not related to their raw material and product inventory. The different actors will have capital bound up in buildings and equipment used in the supply chain. GERRE also reports having invested in its own truck fleet to handle transportations.

Table 29 lists the capital costs.

Table 29: Capital Costs Summarized.

Capital Cost	Phase
Warehoused material	Manufacturing; Use; Secondary Material
Warehoused product	
Products in transit	
Unpaid products	
Buildings	
Equipment	
Vehicle	

4.4.6 Installation Cost

The interviews conducted did not uncover any installation costs for the companies. It is assumed that either the construction company or their subcontractor will have costs related to the installation of windows and façade products, but since no company within that category was interviewed this cannot be confirmed.

4.4.7 Cost Structure for Flat Glass Closed-loop Supply Chain

Table 30 summarizes the cost found in the analysis of the theoretical and empirical findings.

Table 30: Cost Structure for Flat Glass CLSC.

SCC Category	Manufacturing Phase	Use Phase	Secondary Material Phase
Manufacturing Cost	Energy cost Raw material cost Inspection cost Unit cost Labor cost Waste treatment cost Emission cost	Waste treatment cost	Energy cost Raw material cost Remediation cost Labor cost Waste treatment cost
Distribution Cost	Transportation cost; Emission cost		
Warehouse Cost	Raw material storage Product storage Loss of material Sorting cost Cleaning cost		Raw material storage Product storage
Administration Cost	Supplier handling; Customer handling; Transportation handling; Support functions		
Capital Cost	Warehoused material; Warehoused products; Products in transit; Unpaid products; Buildings; Equipment; Vehicle		
Installation Cost		Installation of windows and façades	

4.5 Discussion of Findings

The purpose of this thesis was to identify a flat glass CLSC structure and to propose a cost structure through an exploratory study by conducting case studies in China, Germany, and Norway. The analysis and discussions of findings for RQ1 and its sub-questions can be found in chapter 3.4 Analysis of Findings and 3.5 Discussion of Findings. To recall, *RQ2 is: How can a cost structure for a closed-loop supply chain (CLSC) for the purpose of flat glass look like?*

The answer to RQ2 can be found in table 30. By comparing empirical findings with the initial CLSC cost framework provided in chapter 4.1.3, cost elements are divided into six supply chain cost categories and the three phases of a flat glass CLSC.

As mentioned in the discussion for RQ1, this body of work makes several contributions to theory, practice and society. Altogether, this research adds to two research areas, i.e., flat glass and CLSC. RQ2 combines these two research areas and uses the information gathered in the case studies to reflect on the costs of the existing practices and how a move towards a flat glass CLSC will affect them. As the researchers could not find any existing literature covering the costs of a potential flat glass CLSC, literature regarding other CLSC was used as a comparison to the empirical study.

The SCC framework provided by Pettersson (2008) has been used to organize and categorize the costs identified in the flat glass CLSC. This thesis has shown how the framework can be utilized in a CLSC by supplementing it with the different phases of the flat glass CLSC.

The analysis conducted on the costs in a CLSC for flat glass shows both similarities and differences compared to existing CLSC literature. The findings indicating landfilling as a more cost friendly alternative to recycling for waste holders are very much in line with the results of Liu et al. (2019). As shown in Liu et al. (2019) recycling CDW waste will lead to higher transportation and admission costs for the waste holder than if they chose to landfill it. This is also the finding in the case country Norway, which displays how the centralized recycling center leads to huge transportation costs for waste sources in other parts of the country. The further away from the recycling center the source is the more financially compelled to landfill the actor will be.

Taleizadeh et al. (2019) CLSC model is built with inventory holding costs as the main cost factor. As a central assumption in the CLSC is that shortages are not allowed, the actors are obligated to stockpile both raw material and products. Consequently, the actors will increase both their warehousing and capital costs. This thesis shows that this is not a common trait in the flat glass CLSC. None of the respondents identified elements of inventory holding costs such as warehousing cost or capital cost as major cost factors for them. While float glass producers stockpile both raw material and finished products, this is not their main source of cost. As products from flat glass processors need to be adapted to customer demands, products are only produced when an order is received. Consequently, the effect of inventory holding costs are greatly reduced. In the reverse flow secondary material will be stored at both local and regional collection points as well as at recycling facilities according to NORRE. But as little capital is invested in secondary material the capital costs are low.

Bezan et al. (2017) investigates how different coordination mechanisms affect environmental issues. Central factors are the emissions from production and transportation and energy usage in production. The empirical findings have shown that cullets can reduce the energy consumption in float glass production by lowering the melting point of the raw material. Additionally, local processing companies will have lower emission cost compared to international, as transportation of large format float glass is more effective than that of processed glass. Emission costs were found in the flat glass CLSC, but they were not a major cost factor today. But as emission fees are likely to increase in the future the effects of emission costs will increase.

The article by Gaur (2019) focuses on specific aspects of the cost structure in CLSCs. It concentrates on the sourcing strategies in CLSC. The article is not concerned with costs in flat glass CLSCs, however, it provides cost types that are deemed important to any CLSCs, by the research team. This thesis then adds onto Gaur's article by providing a more holistic approach to costs in flat glass CLSCs and referring to findings.

Several other scientific articles, such as the article by Ke and Cai (2019) and the article by Meng et al. (2020) were used to underline the research problem and lay the groundwork for this research. The former talks about pricing in a four-actor CLSC and the latter is concerned with governments involvement in CLSCs by providing financial aids. This body of work adds onto both articles by focusing onto costs that appear during a flat glass CLSC.

Generally, there are two main limitations to the use of previous literature concerning costs in CLSC as a basis for a flat glass CLSC. Most Literature focuses on the remanufacturing of different types of consumer goods. As previously emphasized, remanufacturing is not a viable option for the flat glass CLSC. Additionally, literature tends to focus on the end customer as the only source of waste. In the flat glass CLSC waste is generated by different actors, such as processors and glaziers. The thesis can therefore be said to further research by expanding on the current body of knowledge by laying the foundation for future research focusing on recycling of materials from multiple waste sources.

In addition to the contributions to theory mentioned above, the research team made several discoveries that it did not expect, nor did previous scientific research foreshadow them. Firstly, the researchers did not expect the transportation costs to play such a significant role as they actually do according to the cases in Norway. Because of the large geographical distances in Norway transportation between actors is a major cost factor that influences the decisions actors make, especially in the reverse flow.

Furthermore, the researchers did not expect to find such an intricate financial dilemma in the collection process for flat glass, as it was discovered in Norway. If a system that divides the cost and responsibilities for the collection process can be agreed upon by the actors, more of the potential of flat glass recycling can be reached. This can increase the supply of secondary material in Norway and reduce the need for imported material.

The research team expected the flat glass processors to have warehousing costs, however, that was not the case. The flat glass processors do not have warehousing costs because they only produce flat glass products when they are ordered. That means the processed flat glass leaves the facilities immediately after production is finished and is not stored in a warehouse until delivery.

Lastly, the researchers did not expect an increased pull during float glass manufacturing when flat glass is reused. GERRE explains that when float glass manufacturers utilize reused flat glass, they increase the pull. This in turn leads to the manufacturer producing more flat glass than it would without flat glass cullets which results in more glass to be sold.

Apart from the theoretical contributions emphasized above, this cost analysis also carries both practical and societal contributions. As this thesis is connected to a bigger research project which is looking at practical solutions for the flat glass situation in the municipality of Växjö, this analysis can provide a valuable starting point for this work. The thesis has also shed light on some of the financial complications that hinders the development of today's flat glass SC and can help the different actors in moving towards a CLSC. Additionally, the thesis also makes societal contributions by examining and furthering an important topic in today’s society's discourse from a financial standpoint, namely sustainability and recycling.

5 Conclusion and Suggestions for Future Research

This thesis’ purpose was to identify a flat glass CLSC model as well as to propose a cost structure through an exploratory study by conducting interviews in China, Germany, and Norway. The purpose was split up into the following RQs: *RQ1: How can closed-loop supply chains (CLSC) for the purpose of flat glass look like? RQ1.A: What actors are a part of a flat glass CLSC? RQ1.B: What are the waste sources of flat glass in a flat glass CLSC? RQ1.C: What are the uses of flat glass as secondary material? RQ2: How can a cost structure for a closed-loop supply chain (CLSC) for the purpose of flat glass look like?* The answers to the RQs are based on a comprehensive literature review and empirical findings.

RQ1: How can closed-loop supply chains (CLSC) for the purpose of flat glass look like?

Figure 25 shows the flat glass CLSC model that was identified. The flat glass CLSC consists of three building blocks or phases, i.e., (1) manufacture phase, (2) use phase, and (3) secondary (raw) material phase. In the first phase, the flat glass is produced with the float glass technique and then refined into flat glass products. The finished product then enters the use phase in which it will be distributed to construction sites, used in buildings and eventually taken out during the demolition process. The use phase is followed by the secondary material phase in which the used flat glass is assessed, processed and distributed to flat glass, container glass or glass wool manufacturer.

RQ1.A: What actors are a part of a flat glass CLSC?

The actors of the flat glass CLSC are categorized into main and sub-actors to reflect an active and passive role in the model. The main actors are float glass manufacturer, flat glass processor/refiner, flat glass distributor, construction and demolition company, flat glass recycler, and freight hauler. The sub-actors are raw materials supplier, government, third-party contractors, container glass manufacturer, and glass wool manufacturer.

RQ1.B: What are the waste sources of flat glass in a flat glass CLSC?

Flat glass waste is understood as secondary material rather than waste. Secondary material occurs during flat glass manufacturing which includes both float glass manufacturing and processing of flat glass, distribution and transport, construction, and demolition. Secondary materials from flat glass manufacturing are pure, high quality cut-offs. Contaminated flat glass occurs during transport and construction. End-of-use flat glass domes into existence during demolition.

RQ1.C: What are the uses of flat glass as secondary material?

Flat glass can be used in float glass, container glass, and glass wool manufacturing. The quality of the cullets is critical. Only the highest quality non-contaminated flat glass that occurs during manufacturing processes can be reused for float glass manufacturing. Other secondary material goes into container glass or glass wool manufacturing.

RQ2: How can a cost model for a closed-loop supply chain (CLSC) for the purpose of flat glass look like?

The answer of RQ2 is summarized in table 30. The initial CLSC cost framework divides cost elements into six supply chain cost categories, which include manufacturing cost, distribution cost, warehousing cost, administration cost, capital cost, and installation cost, and the three phases of a flat glass CLSC.

5.1 Contributions to Theory, Practice, and Society

This master thesis provides theoretical contributions to two main research areas: Flat glass and CLSC. The main theoretical contribution resulting from this thesis is the proposed CLSC for flat glass. By offering clear and detailed description of the actors involved in the flat glass CLSC, the waste sources found, and potential uses of flat glass as a secondary material, the researchers fill a clear gap in current research literature. The proposed flat glass CLSC model builds on previous work conducted on flat glass such as Gebeos (2020) and Rose et al. (2019) and adds empirical data collected from the three case countries China, Germany, and Norway to enrich the current theory. Moreover, the thesis lays a foundation for future research into the cost aspects of flat glass CLSC by proposing an initial cost structure which can be used as a theoretical foundation for further inquiries into the financial aspects of flat glass CLSC.

The thesis also provides multiple practical contributions. Firstly, the research can benefit the interviewed actors by offering them insight into the current flat glass situation and the possibilities and challenges of a flat glass CLSC. Furthermore, the flat glass CLSC and the cost structure proposed can be used as a basis for a future implementation of a flat glass CLSC in municipalities, regions, and countries around the world. As sustainability becomes increasingly important, more and more countries will look towards a circular economy. This thesis can help countries identify the potential of flat glass as a secondary material and how it can be utilized. This can reduce the need for landfills, reduce emission, and save energy. This is especially the case for the municipality of Växjö (Sweden) as this thesis is a part of larger collaboration between Växjö and the Linnaeus University. Additionally, the research sheds light on some of the challenges in implementing a successful collection system. The research can be used in the work to improve the collection systems that are in place in municipalities, regions, and counties today.

This body of work also has societal contributions. The research contributes to raising awareness of the environmental challenges society faces today. It is the intention of the researchers to highlight the potential of old flat glass material as a secondary material and how it should not be viewed as waste, but rather as a resource for society. Flat glass has a lot of potential as a secondary material and unlocking it can be a crucial part in society’s effort to reduce their negative impact on the planet and reach their emission goals in the future. The research also shows the economic potential in flat glass as a secondary material. Underlining the crucial point that an environmental focus can also lead to better economic performances.

5.2 Limitations

While this master's thesis helps in closing the research gap, it has its limitations and weaknesses. For one, the empirical data that was collected can be seen as insufficient. It was planned to conduct interviews with manufacturers, CD companies, and recyclers from China, Germany, and Norway. However, due to the ongoing corona pandemic the responses were scarce and difficult to obtain. Especially the use phase of the CLSC model lacks empirical data, which decreases the reliability of the findings. Because of this lack of empirical data as well as the research gap, this paper's findings can neither be verified by scientific research nor by empirical data.

The conclusion of this thesis is also strictly theoretical as the proposed solution for a flat glass CLSC has neither been tested or proven to work in practice. This study is also limited in being contextual to the countries that were studied and thus cannot be generalized onto other countries and merely presents a basis for future research. Furthermore, most of the interviewees had limited knowledge about costs which increased the difficulty for answering RQ2 sufficiently.

Additionally, the flat glass CLSC model as well as the cost structure are purely theoretical, while both are based on scientific literature and empirical data they have not been tested.

5.3 Future Research

Future research should be conducted to verify and build on the findings of this paper. Firstly, a more comprehensive investigation into the respective countries would be recommended. This should be done to confirm the findings and to add additional context. In addition, new counties should be studied. For the case of Sweden, looking at other Nordic countries would be preferable as they have both geographical and economical similarities. That said, for research in general other countries would be of interest as well as they could add new and unique perspectives to the topic.

Moreover, the focus of future studies should also be shifted onto financial and logistical aspects of how to create viable flat glass closed-loop solutions. As very little research has been conducted into these aspects of flat glass CLSC a multitude of topics would be relevant. One of which would be especially ideal for future research is the financial and logistical challenges related to the collection of flat glass, as it is one of the key obstacles of a flat glass CLSC.

Additionally, since no data was gathered from an actor of the use phase, another suggestion for future research is to shift the focus onto the use phase and conduct interviews from construction and demolition companies. This way the researcher would be able to see the flat glass CLSC from a fourth point of view.

6 List of References

Amin, S.M., Wu, H. and Karaphillis, G., 2018. A perspective on the reverse logistics of plastic pallets in Canada. *Journal of Remanufacturing*, [e-journal] 8, pp. 153-174, https://doi.org/10.1007/s13243-018-0051-0.

Ashby, A., 2018. Developing closed loop supply chains for environmental sustainability. *Journal of Manufacturing Technology Management*, [e-journal] 29(4), pp. 699-722, https://doi.org/10.1108/JMTM-12-2016-0175.

Bedon, C. and Amadio, C., 2018. Buckling analysis and design proposal for 2-side supported double Insulated Glass Units (IGUs) in compression. *Engineering Structures*, [e-journal] 168, pp. 23-34. https://doi.org/10.1016/j.engstruct.2018.04.055

Beldek, T., Camgöz-Akdağ, H. and Hoşkara, E., 2016. GREEN SUPPLY CHAIN MANAGEMENT FOR CONSTRUCTION WASTE: CASE STUDY FOR TURKEY. *International Journal of Sustainable Development and Planning*, [e-journal] 11(5), pp. 771-780, https://doi.org/10.2495/SDP-V11-N5-771-780.

Bell, E., Bryman, A. and Harley, B., 2019. *Business research methods* (5th edn). Oxford: Oxford university press.

Bezan, E., Jaber, M. Y. and Zanoni, S., 2017. Carbon emissions and energy effects on a two-level manufacturer- retailer closed-loop supply chain model with remanufacturing subject to different coordination mechanisms. *International Journal of Production Economics*, [e-journal] 183, pp. 394-408. https://doi.org/10.1016/j.ijpe.2016.07.009.

Bowersox, D.J., Closs, D.J, Cooper, M.B., Bowersox, J.C., 2013. Supply chain logistics management (4. ed., international ed.). New York, NY: McGraw-Hill.

Byrne, P.J., Heavey, C. 2006. The impact of information sharing and forecasting in capacitated industrial supply chains: A case study. International journal of production economics, [e-journal] 103(1), pp.420–437. https://doi-org.proxy.lnu.se/10.1016/j.ijpe.2005.10.007.

Chen, Jack. 1997. Achieving maximum supply chain efficiency. IIE solutions, [e-journal] 29(6), pp.30-35. Available at: https://search.ebscohost.com/login.aspx?direct=true&db=bsu&AN=9708044871&site=ehost-live.

Coherent Market Insights, 2020. *Flat Glass Market To Surpass US$ 176,748.6 Million By 2027*. [Online] Available at: https://www.coherentmarketinsights.com/press-release/flat-glass-market-2664. [Accessed 1 April 2021].

Commission regulation (EU) No 1179/2012 on establishing criteria determining when glass cullet ceases to be waste under Directive 2008/98/EC of the European Parliament and of the Council, 2012. *Official Journal of the European Union* [online] L337, pp. 31-36. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R1179. [Accessed 1 April 2021].

DeBrincat, G. and Babic, E., 2018. *Re-thinking the life-cycle of architectural glass*. [pdf] ARUP, Available at: https://www.arup.com/perspectives/publications/research/section/re-thinking-the-life-cycle-of-architectural-glass [Accessed 25 January 2021].

Esposito, M., Tse, T. and Soufani, K., 2018. The circular economy: An opportunity for renewal, growth, and stability. *Thunderbird International Business Review*, [e-journal] 60(5), pp. 725-728. https://doi.org/10.1002/tie.21912.

Eurostat, 2020. *Recycling rate of municipal waste*. [Online] Available at: https://ec.europa.eu/eurostat/databrowser/view/cei_wm011/default/table?lang=en. [Accessed 23 January 2021].

Ferronato, N., Rada, E. C., Portillo, M. A. G., Cioca, L. I, Ragazzi, M. and Torretta, V., 2019. Introduction of the circular economy within developing regions: A comparative analysis of advantages and opportunities for waste valorization. *Journal of Environmental Management*, [e-journal] 230, pp. 366-378. https://doi.org/10.1016/j.jenvman.2018.09.095.

Gaur, J., Amini, M. and Rao, A.K., 2020. The impact of supply chain disruption on the closed-loop supply chain configuration profit: a study of sourcing policies.

International Journal of Production Research, [e-journal] 58(17), pp. 5380-5400. https://doi.org/10.1080/00207543.2019.1657244.

Geboes, E., 2020. *Architectural flat glass: Understanding the current barriers of the closed-loop alternatives to support the transition towards a circular life-cycle of flat glass*. Master. VRIJE UNIVERSITEIT BRUSSEL. Available at: https://doi.org/10.13140/RG.2.2.21229.00488 [Accessed 25 January 2021].

Ginga, C.P., Ongpeng, J.M.C. and Daly, K.M., 2020. Circular Economy on Construction and Demolition Waste: A Literature Review on Material Recovery and Production. *Materials*, [e-journal] 13(13), pp. 1-18, https://doi.org/10.3390/ma13132970.

Girot, L. and Kopf, C., 2018. *Creating a closed-loop supply chain model and evaluating it through a business case for sustainability*. Master. Linnaeus University.

Govindan, K., Soleimani, H. And Kannan, D., 2015. Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *European Journal of Operational Research*, [e-journal] 240(3), pp. 603-626, https://doi.org/10.1016/j.ejor.2014.07.012.

He, Q., Wang, N., Yang, Z., He, Z. and Jiang, B., 2019. Competitive collection under channel inconvenience in closed-loop supply chain. *European Journal of Operational Research*, [e-journal] 275, pp. 155-166. https://doi.org/10.1016/j.ejor.2018.11.034.

Hess, R., 2004. Material Glass. *Structural Engineering International*, [e-journal] 14(2), pp. 76-79. https://doi.org/10.2749/101686604777964008.

H&M Group, 2018. *Sustainability Report*. [online] Available at: https://about.hm.com/content/dam/hmgroup/groupsite/documents/masterlanguage/CSR/reports/2018_Sustainability_report/HM_Group_SustainabilityReport_2018_%20FullReport.pdf. [Accessed 25 January 2021].

Hillebrandt, A., Riegler-Floors, P., Rosen, A. and Seggewies, J.K., 2019. *Manual of Recycling*. Munich: Detail Business Information.

Hjelmar, O., Hansen, J. B., Wahlström, M. and Wik, O., 2016. *End-of-Waste Criteria for Construction & Demolition Waste*. Nordic Council of Ministers, ProQuest Ebook

Central. [online] Available at: http://ebookcentral.proquest.com/lib/linne-ebooks/detail.action?docID=4748979. [Accessed 24 January 2021].

Hodgkinson, J. H. and Smith, M. H., 2018. Climate change and sustainability as drivers for the next mining and metals boom: The need for climate-smart mining and recycling. *Resources Policy*, [e-journal], pp. 1-11. https://doi.org/10.1016/j.resourpol.2018.05.016.

Holgado, M. and Aminoff, A., 2019. Closed-Loop Supply Chains in Circular Economy Business Models. In: Ball P., Huaccho Huatuco L., Howlett R., Setchi R. (eds) *International Conference on Sustainable Design and Manufacturing KES-SDM 2019*. Budapest, Hungary, 4-5 July 2019. Singapore: Springer. https://doi.org/10.1007/978-981-13-9271-9_19.

Hosang, J. and Bongju, J., 2005. Decentralised production-distribution planning system using collaborative agents in supply chain network. International journal of advanced manufacturing technology, 25(1), pp.167–173.

Huang, B., Wang, X., Kua, H., Geng, Y. and Bleischwitz, R., 2018. Construction and demolition waste management in China through the 3R principle. *Resources, Conservation and Recycling*, [e-journal] 129, pp. 36-44, https://doi.org/10.1016/j.resconrec.2017.09.029.

Kadambala, D. K., Subramanian, N., Tiwari, M. J., Abdulrahman, M. and Liu, C., 2017. Closed loop supply chain networks: Designs for energy and time value efficiency. *International Journal of Production Economics*, [e-journal] 183, pp. 382-393. https://doi.org/10.1016/j.ijpe.2016.02.004.

Kazemi, N., Modak, N. M. and Govindan, K., 2019. A review of reverse logistics and closed loop supply chain management studies published in IJPR: a bibliometric and content analysis. *International Journal of Production Research*, [e-journal] 57(15-16), pp. 4937-4960. https://doi.org/10.1080/00207543.2018.1471244.

Ke, H. and Cai, M., 2019. Pricing decisions in closed-loop supply chain with collection-relevant demand. *Journal of Remanufacturing*, [e-journal] 9, pp. 75-87. https://doi.org./10.1007/s13243-018-0060-z.

Kua, H. W. and Lu, Y., 2016. Environmental impacts of substituting tempered glass with polycarbonate in construction - An attributional and consequential life cycle perspective. *Journal of Cleaner Production*, [e-journal] 137, pp. 910-921. https://doi.org/10.1016/j.jclepro.2016.07.171.

Linnaeus University, 2021. *GDPR for Students*. [Online] (Last updated 19 March 2021) Available at: https://lnu.se/en/library/Writing-and-referencing/academic-writing/gdpr-for-students [Accessed 24 March 2021].

Li, L., Lin. H., Han, J., Xie, J., Hu, P. and Zhao, X., 2017. Influence of spout lip set-height on flow behavior during the glass float process. *Journal of Non-Crystalline Solids*, [e-journal] 472, 46-54. http://dx.doi.org/10.1016/j.jnoncrysol.2017.07.011.

Liu, J., Teng, Y., Jiang, Y. and Gong, E., 2019. A cost compensation model for construction and demolition waste disposal in South China. *Environmental Science and Pollution Research*, [e-journal] 26, pp. 13773-13784, https://doi.org/10.1007/s11356-018-2887-0.

Mahpour, A., 2018. Prioritizing barriers to adopt circular economy in construction and demolition waste management. *Resources, Conservation and Recycling*, [e-journal] 134, pp. 216-227, https://doi.org/10.1016/j.resconrec.2018.01.026.

Market Research Future, 2021. *Flat Glass Market: Information by Product Type (Clear Float Glass, Tempered Glass, Insulated Glass, Coated Glass, Annealed Glass and Laminated Glass), by End-Use Industry (Building & Construction, Automotive, Consumer Goods and Solar) and by Region (Asia-Pacific, North America, Europe, Latin America and the Middle East & Africa) - Forecast till 2027*. [Online] Available at: https://www.marketresearchfuture.com/reports/flat-glass-market-5415. [Accessed 1 April 2021].

Martínez Leal, J., Pompidou, S., Charbuillet, C. and Perry, N., 2020. Design for and from Recycling: A Circular Ecodesign Approach to Improve the Circular Economy. *Sustainability*, [e-journal] 12(23), pp. 1-30, https://doi.org/10.3390/su12239861.

Meng, L., Qiang, Q., Huang, Z., Zhang, B. and Yang, Y., 2020. Optimal Pricing Strategy and Government Consumption Subsidy Policy in Closed-Loop Supply Chain with

Third-Party Remanufacturer. *Sustainability*, [e-journal] 12(6), pp. 1-29. https://doi.org/10.3390/su12062411.

Moktadir, A., Kumar, A., Ali, S.M., Paul, S.K., Sultana, R. and Rezaei, J., 2020. Critical success factors for a circular economy: Implications forbusiness strategy and the environment. *Business Strategy and the Environment*, [e-journal] 29(8), pp. 3611-3635, https://doi.org/10.1002/bse.2600.

Na, B., Ahmed, S., Nemhauser, G. and Sokol, J., 2013. Optimization of automated float glass lines. Int. J. *Production Economics*, [e-journal] 145, pp. 561-572. http://dx.doi.org/10.1016/j.ijpe.2013.04.024.

Nascimento, M. L. F., 2014. Brief history of the flat glass patent e Sixty years of the float process. *World Patent Information*, [e-journal] 38, pp. 50-56. http://dx.doi.org/10.1016/j.wpi.2014.04.006.

Navarrete, B. A. O., Juárez, H. P., Olmos, L., and Guerrero, J. M. J., 2017. Failure behavior of annealed glass for building windows. *Engineering Structures*, [e-journal] 141, pp. 417-426. http://dx.doi.org/10.1016/j.engstruct.2016.12.050.

Panda, S., Modak, N. M. and Cárdenas-Barrónc, L. E., 2017. Coordinating a socially responsible closed-loop supply chain with product recycling. *International Journal of Production Economics*, [e-journal] 188, pp. 11-21. https://doi.org/10.1016/j.ijpe.2017.03.010.

Pettersson, A., 2008. Measurements of efficiency in a supply chain. Licentiate thesis. Luleå University. http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A999780&dswid=7187.

Pettersson, A. and Segerstedt, A., 2013. Measuring supply chain cost. International journal of production economics, 143(2), pp. 357-363. https://doi-org.proxy.lnu.se/10.1016/j.ijpe.2012.03.012.

Recovery, 2018. *Glass recycling – Current market trend*s. [Online] Available at: https://www.recovery-worldwide.com/en/artikel/glass-recycling-current-market-trends_3248774.html. [Accessed 24 January 2021].

Recycling Magazine, 2020. *Europe waste recycling services market to grow*. [Online] Available at: https://www.recycling-magazine.com/2020/09/28/europe-waste-recycling-services-market-to-grow/. [Accessed 23 January 2021].

Rodrigues, L. P., Junkes, J. A., Savazzini-Reis, A., Louzada, D. M. and Sagrillo, V. P. D., 2021. Potential use of Kraft pulp mill and flat glass cutting wastes in red ceramic products. *Ceramics International*, [e-journal], pp. 1-9. https://doi.org/10.1016/j.ceramint.2021.03.111.

Rogers, D.S. and Tibben-Lembke, R.S., 1998. *Going Backwards: Reverse Logistics Trends and Practices*. Reno: Reverse Logistics Executive Council.

Rose, A., Sack, N., Nothacker, K. and Gassman, A., 2019. *Recycling of flat glass in the building industry–Analysis of the current situation and derivation of recommendations for action.* Germany: ift Rosenheim. [pdf] Available at: https://www.irbnet.de/daten/kbf/kbf_e_F_3202.pdf. [Accessed 24 January 2021].

Sachan, A., Sahay, B. S. and Sharma, D., 2005. Developing Indian grain Supply chain cost model: system dynamics approach. International Jounal of Productivity and Performance Management, [e-journal] 54(3), pp. 187-205. https://doi.org/10.1108/17410400510584901.

Saint-Gobain, 2014. *Collecting and processing scraps of glass: A guide for improved cullet recycling.* [pdf] Saint-Gobain. Available at: https://www.vetrotech.com/document/2775. [Accessed 1 April 2021].

Saunders, M.N.K., Lewis, P. and Thornhill, A., 2019 *Research methods for business students* (8th edn). Harlow: Pearson education limited.

Solvang, W.D., 2001. Architecture for supply chain analysis and methodology for quantitative measurement of supply chain flexibility. Ph.D. Thesis. Norwegian University of science and technology, Trondheim.

Statista, 2019. *Industry revenue of »manufacture of flat glass« in Sweden 2011-2023*. [online] Available at: https://www.statista.com/forecasts/992438/manufacture-of-flat-glass-revenue-in-sweden [Accessed 25.01.2021].

Statista, 2020. *Industry revenue of "shaping and processing of flat glass" in Sweden 2012-2024*. [online] Available at: https://www.statista.com/forecasts/396897/shaping-and-processing-of-flat-glass-revenue-in-sweden [Accessed 25.01.2021].

Taleizadeh, A.A., Haghighi, F. and Niaki, S.T.A., 2019. Modeling and solving a sustainable closed loop supply chain problem with pricing decisions and discounts on returned products. *Journal of Cleaner Production*, [e-journal] 207, pp. 163-181. https://doi.org/10.1016/j.jclepro.2018.09.198.

Taleizadeh, A.A., Mamaghan, M.K. and Torabi, S.A., 2020. A possibilistic closed-loop supply chain: pricing, advertising and remanufacturing optimization. *Neural Computing and Applications*, [e-journal] 32, pp. 1195-1215. https://doi.org/10.1007/s00521-018-3646-3.

Thommen, J.P.; Achleitner, A.K.; Gilbert, D.U.; Hachmeister, D.; Jarhow, S. and Kaiser, G., 2020. *Allgemeine Betriebswirtschaftslehre*. 9th ed. Wiesbaden: Springer Fachmedien.

Topateş, G., 2020. Recycling of waste flat glass in the fabrication of Si3N4 powder by the carbo-thermal reduction and nitridation. *International Journal of Applied Ceramic Technology*, [e-journal] 17 (2), pp. 555-562. https://doi-org.proxy.lnu.se/10.1111/ijac.13442.

Vedrtnam, A. and Pawar, S. J., 2017. Laminated plate theories and fracture of laminated glass plate – A review. *Engineering Fracture Mechanics*, [e-journal] 186, pp. 316-330. https://doi.org/10.1016/j.engfracmech.2017.10.020.

Vefago, H. M. and Avellaneda, J., 2013. Recycling concepts and the index of recyclability for building materials. *Resources, Conservation and Recycling*, [e-journal] 72, pp. 127-135, https://doi.org/10.1016/j.resconrec.2012.12.015.

Visser, L, Hoefnagels, R and Junginger, M., 2020. Wood pellet supply chain costs – A review and cost optimization analysis. Renewable & sustainable energy reviews, [e-journal] 118, https://doi-org.proxy.lnu.se/10.1016/j.rser.2019.109506.

Wu, Z., Yu, A. T. W.and Shen, L., 2017. Investigating the determinants of contractor's construction and demolition waste management behavior in Mainland China. *Waste*

Management, [e-journal] 60, pp. 290-300, https://doi.org/10.1016/j.wasman.2016.09.001.

Wüest, T. and Luible, A., 2016. Increased thermal induced climatic load in insulated glass units. *Journal of Facade Design and Engineering*, [e-journal] 4 (3-4), pp. 91-113. https://doi.org/10.3233/FDE-161146.

Yang, H., Xia, J., Thompson, J. R. and Flower, R. J., 2017. Urban construction and demolition waste and landfill failure in Shenzhen, China. *Waste Management*, [e-journal] 63, pp. 393-396, https://doi.org/10.1016/j.wasman.2017.01.026.

Yin, R.K., 2018. *Case Study Research and Applications: Design and Methods*. 6th ed. London: Sage.

Youhanan, L., Cousins, A.P., Lins, M.S. and Stenmarck, Å., 2016. *Options for increased low-risk recycling of building products*. [pdf] Stockholm: IVL Swedish Environmental Research Institute. Available at: https://www.ivl.se/download/18.4a88670a1596305e782dc/1484131244520/B2269.pdf#%5B%7B%22num%22%3A9%2C%22gen%22%3A0%7D%2C%7B%22name%22%3A%22XYZ%22%7D%2C78%2C760%2Cnull%5D [Accessed 26.01.2021].

Zou, H., Qin, J., Yang, P. and Dai, B., 2018. A Coordinated Revenue-Sharing Model for a Sustainable Closed-Loop Supply Chain. *Sustainability*, [e-journal] 10(9), pp. 1-15, https://doi.org/10.3390/su10093198.

Appendix 1 – Table of Scientific Literature

Table of scientific literature containing the references that were used in problem discussion and theoretical framework.

Source	CLSC/ CE	FL/ RL	Recycling	CDW/ Waste	Flat Glass	Costs
Amin et al., 2018		X	X			(X)
Ashby, 2018.	X	X	X	X		(X)
Bedon and Amadio, 2018					X	
Beldek et al., 2016	X			X		(X)
Bezan et al., 2017.	X			(X)		X
Coherent Market Insights, 2020					X	
Commission regulation (EU) No 1179/2012				X		
DeBrincat and Babic, 2018.	X		X	X	X	
Gaur et al., 2020	X					X
Geboes, 2020	X				X	
Ginga et al., 2020	X		X	X		
Govindan et al., 2015	X	X				
Hess, 2004					X	
Hillebrandt et al., 2019			X		X	
Holgado and Aminoff, 2019	X					
Huang et al., 2018	X			X		
Kazemi et al., 2019	X	X		(X)		(X)
Ke and Cai, 2019	X					X
Kua and Lu, 2016					X	
Li et al., 2017					X	
Liu et al., 2019				X		X
Mahpour, 2018	X		X	X		(X)
Market Research Future, 2021					X	
Martínez Leal et al., 2020	X		X			
Meng et al., 2020	X					(X)

Source	CLSC/ CE	FL/ RL	Recycling	CDW/ Waste	Flat Glass	Costs
Moktadir et al., 2020	X		X			
Na et al., 2013					X	
Nascimento, 2014					X	
Navarrete et al., 2017					X	
Panda et al., 2017	X		X			X
Rodrigues et al., 2021			X	X	X	
Rogers and Tibben-Lembke, 1998		X				
Rose et al., 2019	X		X	X	X	
Saint-Gobain, 2014			X		X	
Statista, 2019					X	
Statista, 2020					X	
Taleizadeh et al., 2019	X					X
Taleizadeh et al., 2020	X					X
Thommen et al., 2020						X
Topateş, 2020			X	X	X	
Vedrtnam and Pawar, 2017					X	
Vefago and Avellaneda, 2013	X		X	X		
Wu et al., 2017				X		(X)
Wüest and Luible, 2016					X	
Yang et al., 2017			(X)	X		
Youhanan et al., 2016	X		X	X		(X)
Zou et al., 2018	X		X			X

Appendix 2 – Information Letter

Sustainability of Construction & Demolition Waste: A Closed-loop Supply Chain for Flat Glass

Information and Request for Participation in an Interview Study

As the challenges of climate change become more apparent, governments are looking for more ways to tackle the obstacles. Waste is just one source of the problem. Construction and demolition waste makes up about 30% of all waste, of which about 924.000.000 tonnes were contributed in 2016 by countries in the European Union (Ginga et al., 2020). Sweden produces a yearly estimate of 1.312.000 tonnes of CDW; of which 4.850 tonnes (0,37%) are contributed by flat glass (Youhanan et al., 2016).

As a part of a larger collaboration between the municipality of Växjö, Sweden and the Linnaeus University, we are therefore conducting a study to investigate the possibilities of a closed-loop supply chain of flat glass.

The purpose of this study is to examine the current treatment of flat glass and how a closed-loop supply chain of flat glass and its cost structure can look like.

We are therefore contacting companies and associations that either manufacture flat glass, generate considerable flat glass waste, recycle flat glass, or have considerable expertise in flat glass to gain insight into the current situation.

Participation in this study is completely voluntary and your participation in it can end at any time. Given the current Covid-19 situation all interviews will be conducted digitally through your choice of program. The interviews are expected to last somewhere between 30-60 minutes and can be held in Chinese, English, German, or Norwegian.

The material from the interviews will be handled and processed confidentially and will be stored in a way that no unauthorised person can access it. No individual persons or companies will be identifiable in the thesis. To participate your consent is required. A consent form is attached with this letter.

Our names are Thor Lobekk Dahl, Yichang Lu, and Sidney C. Thill and we are students at the Linnaeus University in Växjö. We are currently writing our master's thesis in the Business Process Control and Supply Chain

Management Programme. Our supervisor is Prof. Helena Forslund. Any further questions can be directed to us or our supervisor.

Växjo 29/04/2021

Students:

Thor Lobekk Dahl

Yichang Lu

Sidney C. Thill

Phone: [redacted]

E-Mail: [redacted]

Supervisor:

Helena Forslund

Phone: [redacted]

E-Mail: [redacted]

Appendix 3 – Consent Form

Consent form for taking part in the study "A Closed-loop Supply Chain for Flat Glass"

We are conducting a study to investigate the possibilities of a closed-loop supply chain of flat glass. The purpose of this study is to examine the current treatment of flat glass and how a closed-loop supply chain of flat glass and its cost structure can look like.

By signing this consent form, you approve that your personal data is processed within the frame of the thesis/study described above. You can withdraw your consent at any time by contacting one of the contact persons below. In that case, your personal data will not be saved or processed any longer without other lawful basis.

The personal data that will be collected from you is your name, the position you hold/your occupation, the company you work at and what it does. The data you provide will be anonymized. Your personal data will be processed 1st April to 4th June 2021 and after this the data will be deleted.

You always have the right to request information about what has been registered about you and to comment on the processing of the data that has been collected by contacting one of the contact persons below or the higher education institution's personal data ombudsman on dataskyddsombud@lnu.se. Complaints that cannot be solved in dialogue with Linnaeus University can be sent to the Swedish Authority for Privacy Protection.

………………………………	………………………………
Signature	City and date

………………………………

Name in block letters

Linnæus University
Sweden

Contact information:

Student's name: Sidney C. Thill

Student's email address: [redacted]

Supervisor's name: Helena Forslund

Supervisor's email address: [redacted]

Appendix 4 – Interview Guide – Manufacturer

Sustainability of Construction & Demolition Waste: A Closed-loop Supply Chain for Flat Glass

Interview Guide

Background Information:

Name, Place of Work, Name Job Position, Description of Job Position

Word	Definition
Inbound Logistics	Inbound logistics describe the process of transportation, storage, and receiving of incoming products.
Outbound Logistics	Outbound logistics describes the process of storing, transport, and distribution of products that are "leaving".
Closed-loop Supply Chain (CLSC)	CLSC consists of forward and reverse supply chains. The former is in essence concerned with manufacturing products and getting these to the end customer (Kazemi et al., 2019). The latter is "the process of planning, implementing and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal." (Rogers and Tibben-Lembke, 1998, p. 2).
Construction & Demolition Waste (CDW)	Waste produced during construction and demolition of buildings and such.
Flat Glass	windows, transparent walls, glass doors etc. are made from a mixture of silica sand, lime and soda, in other words flat glass (Geboes, 2020)
Cullets	The general term of flat glass waste that can be used again.

Supply Chain:

1. What is the company's connection to flat glass?
2. What does the inbound logistics process look like for flat glass products? Do you get your materials domestically or is it imported? Are your suppliers responsible for the physical delivery of the material or do you pick it up yourself?

3. What does the outbound logistics process look like for flat glass products? Are your flat glass products sold directly to construction companies or through a retailer? Are you responsible for the delivery of the products or do the customers pick them up themselves?
4. Is recycled flat glass material available for you to use in the production of new flat glass products? If it is, is it available domestically or do they need to look abroad?
5. Do you use recycled materials in your flat glass production today? If not, do you have the capability to? Can recycled material be used for all types of flat glass?
6. Does the production of flat glass products generate waste, if so, what happens to it?
7. What needs to be done to move towards a closed-loop supply chain and an increase in flat glass recycling?
8. Which actors would need to be involved to achieve that?
9. Which task/processes steps (in chronological order) are needed in a flat glass closed-loop supply chain?

Cost:

10. How do you calculate the costs of your flat glass production? Which cost groups are included?
    1. What are the major cost elements of your manufacturing process?
    2. What fixed/variable costs do you have?
    3. What does the cost of the inbound/outbound process look like?
11. How have/will the introduction of flat glass cullets in your production affect the costs? Would new investments into technology be needed?
    a. Will the total costs be lower/higher compared with using only new material?

12. Are there differences in types of costs depending on the type of flat glass? If so, what are the differences?
13. Are there governmental regulations in place that affect your costs? If so which and how?

Appendix 5 – Interview Guide – Recycler

Sustainability of Construction & Demolition Waste: A Closed-loop Supply Chain for Flat Glass

Interview Guide

Background Information:

Name, Place of Work, Name Job Position, Description of Job Position

Word	Definition
Inbound Logistics	Inbound logistics describes the process of transportation, storage, and receiving of incoming products.
Outbound Logistics	Outbound logistics describes the process of storing, transport, and distribution of products that are "leaving".
Closed-loop Supply Chain (CLSC)	CLSC consists of forward and reverse supply chains. The former is in essence concerned with manufacturing products and getting these to the end customer (Kazemi et al., 2019). The latter is "the process of planning, implementing and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal." (Rogers and Tibben-Lembke, 1998, p. 2).
R-principles (Reduce, reuse, recycle, remanufacture, and repair)	The R-principles are concepts of CLSC and are utilized in the reverse supply chain. • To reduce means to decrease the amount of something specifically in order to reduce waste (Yang et al., 2017). • To reuse means to utilize materials again after their initial use. The material can only be reused if it is in the condition to be used for the same initial purpose or if it is eligible for a different purpose (Huang et al., 2018). • Recycling is the method of transforming a product or material into a different product (Yang et al., 2017). The product is disassembled into parts which can then be utilized in new products (Huang et al., 2018). • To remanufacture a used product means to rebuild it by using a combination of parts. Used products are returned to the manufacturer for remanufacturing.

	The process consists of "sorting, inspection, disassembly, cleaning, reprocessing and reassembly, and replacement of parts which cannot be brought back to original quality" (Hatcher et al., 2009 as cited in Ashby, 2018, p. 703) • To repair a product means to restore its parts to working condition (Kumar and Putnam, 2008 as cited in Ashby, 2018, p. 704).
Flat Glass	windows, transparent walls, glass doors etc. are made from a mixture of silica sand, lime and soda, in other words flat glass (Geboes, 2020)

Supply Chain:

1. What is the company's connection to flat glass?
2. How do you treat flat glass waste today?
3. Can flat glass waste be processed in a way to be used to produce new flat glass? If not, what other possibilities are there for flat glass waste without ending up in a landfill? What r-principle do you utilize?
4. Which criteria is used to decide on how the flat glass waste will be treated?
5. What does the flat glass recycling process look like? What is the end product of the recycling process?
6. What does the inbound logistics process of flat glass waste look like? Do you get your waste domestically or internationally?
7. What does the outbound logistics process of the recycled product look like? Where does the recycled product go to?

Cost:

8. How do you calculate the costs of your flat glass recycling process? Which cost groups are included?
    a. What are the major cost elements of your recycling process?
    b. What fixed/variable costs do you have?
    c. What does the cost of the inbound/outbound process look like?

9. Is the cost aspect an important factor in the decision of what to do with flat glass waste? If yes/no, why?
    d. Is the low recycling rate of flat glass a consequence of cost?
10. Do the different treatments of flat glass waste differentiate a lot in terms of costs?
11. How can your recycled materials affect the manufacturing costs of new flat glass products?

Appendix 6 – Interview Guide – Association

Sustainability of Construction & Demolition Waste: A Closed-loop Supply Chain for Flat Glass

Interview Guide

Background Information:

Name, Place of Work, Name Job Position, Description of Job Position

Word	Definition
Closed-loop Supply Chain (CLSC)	CLSC consists of forward and reverse supply chains. The former is in essence concerned with manufacturing products and getting these to the end customer (Kazemi et al., 2019). The latter is "the process of planning, implementing and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal." (Rogers and Tibben-Lembke, 1998, p. 2).
R-principles (Reduce, reuse, recycle, remanufacture, and repair)	The R-principles are concepts of CLSC and are utilized in the reverse supply chain. • To reduce means to decrease the amount of something specifically in order to reduce waste (Yang et al., 2017). • To reuse means to utilize materials again after their initial use. The material can only be reused if it is in the condition to be used for the same initial purpose or if it is eligible for a different purpose (Huang et al., 2018). • Recycling is the method of transforming a product or material into a different product (Yang et al., 2017). The product is disassembled into parts which can then be utilized in new products (Huang et al., 2018). • To remanufacture a used product means to rebuild it by using a combination of parts. Used products are returned to the manufacturer for remanufacturing. The process consists of "sorting, inspection, disassembly, cleaning, reprocessing and reassembly,

	and replacement of parts which cannot be brought back to original quality" (Hatcher et al., 2009 as cited in Ashby, 2018, p. 703) To repair a product means to restore its parts to working condition (Kumar and Putnam, 2008 as cited in Ashby, 2018, p. 704).
Construction & Demolition Waste (CDW)	Waste produced during construction and demolition of buildings and such.
Flat Glass	windows, transparent walls, glass doors etc. are made from a mixture of silica sand, lime and soda, in other words flat glass (Geboes, 2020)
End-of-life	Products that are at the end of their lifecycle and cannot be used for the same original purpose again.

Supply Chain:

1. What does your association do? / What is your expertise?
2. How does the general life cycle of a flat glass product in construction look like today?
3. What happens to end-of-life flat glass products in construction today?
4. Could you give us an example of a CLSC of flat glass? How would that process look like and which actors are involved?
5. What legislation is relevant for the treatment of end-of-life flat glass products today? Would new legislation be needed to increase the amount of recycled glass?
6. In green supply chain management, there exists a term called the R-principles, which refers to treatment of end-of-life products. These principles are reduce, reuse, recycle, remanufacture and repair. Which of these are relevant in relation to flat glass?
7. Which criteria does the flat glass waste have to fulfil in order to be further utilized other than ending up in a landfill?
8. Why isn't more flat glass being recycled?
9. What needs to be done to move towards a closed-loop supply chain and an increase in flat glass recycling?

Cost:

10. How would the use of recycled flat glass affect the manufacturing costs of new flat glass products?
11. Would flat glass manufacturers need to invest in new tools and technology if they were to include recycled material in their production?
12. Would gathering flat glass CDW to be recycled lead to an increase in costs for the construction and demolition company?