Master's degree thesis

LOG950 Logistics

Circular Economy in the Norwegian Aluminium Industry: The Role of Recycling Post-consumer Aluminium Scrap

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Preface & Acknowledgments

This thesis marks the end of our five years at Molde University College, concluding the programme of a Master of Science in Logistics. Working on this thesis has given us great experience about conducting a large research project as well as it has educated us about a new topic within the field of circular economy and its role in the aluminium industry, awarding us with great knowledge as graduates.

We would like to express great gratitude to our supervisor, Nina Pereira Kvadsheim, who has guided us in the research process and through the extensive field of the circular economy. Her expertise and dedication to the concept, as well as her good advice and feedback, has been of great assistance and motivation.

We would also like to thank the participating companies for taking their time to be interviewed and for sharing their perceptions and knowledge about the research topic. This has provided valuable contributions which was crucial in the execution of the thesis.

Lastly, we want to thank our family and friends for support and motivation, as well as our fellow students for creating good memories throughout our time at Molde University College.

Molde, May 2023
Julie Leirvåg & Hanna Tveit

Abstract

The purpose of this thesis is to research what role recycling of post-consumer aluminium scrap has in a transition to a circular aluminium system. There is limited research on circular economy (CE) in the aluminium industry, which is a gap this study aims to fill. The study investigates how to achieve a circular aluminium industry by recycling post-consumer aluminium scrap, as well as the potentials and barriers of it. Based on the findings, a conceptual framework is developed to describe the relationship between the research problem and research question.

This is an exploratory multiple case study, based on a qualitative approach by conducting semi-structured interviews with six case companies. This was evaluated as the best methodological approach due to the lack of research on the topic. The case company selection consists of three types of actors in the aluminium supply chain (SC) to provide a diverse and legitimate insight to the topic.

The findings of this thesis reveal the economic potentials as the most crucial, and the environmental and social potential thereafter. The case companies reveal to have implemented circular strategies to a small extent, emphasising the cycle strategy, but have not fully embraced them. Revealed barriers are categorised into market, technological, social, and regulatory, where some barriers are more emphasised than others. The proposed conceptual framework suggests what aluminium industry actors should consider when recycling post-consumer scrap towards a CE.

The limitations of this study is related to the lack of research in the field of CE in the aluminium industry, resulting in limited literature to support the discussion and an increased dependence on the data collection from the interviews. Also, a wider range of aluminium industry actors could have broadened the range of companies that can utilise the conceptual framework.

By understanding the role of recycling post-consumer aluminium scrap in a circular aluminium system, it can aid aluminium industry actors implement CE strategies and overcome barriers to transition from a linear economy to a CE.

Key words: Circular economy, circular economy strategies, barriers, aluminium industry, post-consumer aluminium scrap

Table of Contents

List of Tables

List of Figures

List of Abbreviations

B2B	Business-to-business
CE	Circular Economy
CEAP	Circular Economy Action Plan
CLSC	Closed-loop Supply Chain
CLSCM	Closed-loop Supply Chain Management
CP	Cleaner Production
CSC	Circular Supply Chain
CSCM	Circular Supply Chain Management
EOL	End-of-life
EOS	Economies of Scale
GHG	Greenhouse Gas
GSCM	Green Supply Chain Management
IE	Industrial Ecology
SC	Supply Chain
SCM	Supply Chain Management
SSC	Sustainable Supply Chain
SSCM	Sustainable Supply Chain Management
TBL	Triple Bottom Line

1.0 Introduction

1.1 Chapter Introduction

This chapter introduces the topic of this thesis and identifies a research gap regarding the role of recycling post-consumer aluminium scrap to achieve a CE in the aluminium industry. Further, the research problem and research questions will be described, and lastly, an illustration of the thesis structure will be presented.

1.2 Background

The world is experiencing pressing environmental and social challenges (Johannsdottir 2014), to which the current linear economy is a leading contributor due to its take-make-use-dispose approach (Korhonen, Honkasalo, and Seppälä 2018). As a result, a need for sustainable economic systems has arisen, whereas the CE has emerged as a an approach to achieve economic growth that is in line with sustainable, environmental and economic development (Korhonen, Honkasalo, and Seppälä 2018). As opposed to the current "open-ended" economic system, the core of the CE is to maintain a closed loop material flow where materials, components and products are reused, recycled and recovered at their end-of-life (EOL) to eliminate waste (Yuan, Bi, and Moriguichi 2006; Urbinati et al. 2020). Hence, the CE can be defined as *"a strategy that emerges to oppose the traditional open-ended system, aiming to face the challenge of resource scarcity and waste disposal in a win-win approach with economic and value perspective"* (Homrich et al. 2018 p.534).

The concept of CE is increasingly gaining traction with scholars and industry, as well as policymakers prioritising it on their agendas, which is made evident by the European Commission (Geissdoerfer et al. 2017; Korhonen, Honkasalo, and Seppälä 2018). In 2019, the European Green Deal was signed by the European Commission as an initiative to overcome environmental challenges, of which the CE Action Plan (CEAP) is one of the main building blocks (European-Commission 2023c, 2023a), consisting of 54 actions to be met by 2030 and 2035 (Ellen-MacArthur-Foundation 2023). The Sustainability Development Goals are core values in the policymaking of the European Commission (European-Commission 2023b), however, while the concepts of sustainability and CE share similarities, there are distinctive differences that separate them from each other.

The goals associated with the CE and sustainability differ, where a CE aims at achieving a closed loop, whereas sustainability is comprised of a multitude of goals that are open-ended. Furthermore, sustainability is based on the triple bottom line (TBL) perspective, including the economy, environment and society, holistically treating all three dimensions equally and sharing the responsibilities (Geissdoerfer et al. 2017). While the CE also aims to encompass environmental quality, economic prosperity, and social equity (Kirchherr, Reike, and Hekkert 2017), it becomes evident that the priority is on the economic systems with primary benefits for the environment and only implicit social gains, which is a result of the responsibility lying on private businesses, regulators and policymakers (Geissdoerfer et al. 2017). One can summarise the relationship of the two concepts with CE being a condition of sustainability (Geissdoerfer et al. 2017).

Although the CE has gained increased popularity, the emergence of CE is held back because of existing barriers to its implementation (Galvão et al. 2018). However, while barriers may arise, the reward of successfully transitioning should outweigh the barrier risks, especially for industries that largely contribute to economic, environmental, and social consequences, as the manufacturing industry does. The industrial revolution enabled mass production of goods, resulting in a growth in industrial activity, hence increased emissions, solid waste generation and consumption of limited raw materials (Lieder and Rashid 2016). In addition to the pressure of these challenges, manufacturers are also required to manage the risk of resource supply and volatile resource prices as a result of global resource scarcity. Thus, transitioning to a CE can be considered a solution for manufacturers to secure economic growth and environmental protection (Lieder and Rashid 2016).

Within the manufacturing industry, the metal industry is one of the largest energy consumers, accounting for 33.4 percent of its total CO_2 emissions, in which four metal sectors accounts for a significant share of the emissions (Takayabu et al. 2019). Among these metal sectors is the aluminium sector, which is one of the metals that is expected to have the highest growth rate throughout this century (Watari, Nansai, and Nakajima 2021). The expected increase of demand will be in response to the increasing global population and GDP, in addition to the increased use of aluminium in technologies that enable a net zero economy (IEA 2022).

The reason aluminium is popular is due to its desirable characteristics, such as being resistant, having an exceptional strength-to-weight ratio, and being fully recyclable without losing its properties (Horsth et al. 2021; Idusuyi and Olayinka 2019; Norsk-Hydro 2020a). Due to its resistance, aluminium is utilised in long lifespan applications, causing 75 percent of all primary aluminium ever produced to still be in use (Norsk-Hydro 2021). However, as its EOL is approaching, it is expected substantial flows of post-consumer aluminium scrap, constituting a "pool" of scrap (European-Aluminium 2020). The value of this scrap can be obtained by recycling and reintroducing it back into the SC, only requiring five percent of the primary energy consumption (Sevigné-Itoiz et al. 2014), hence reducing waste generation and energy related emissions. Pursuing this value capturing process, one is also pursuing a transition towards a circular aluminium system, which is revealed as a lack of research on. Hence, highlighting a research gap which this thesis pursues to fill, as further described in the following chapter.

1.3 Research Problem

While scientific literature about the concept of CE is emerging, it still remains scarce, and its content appears superficial with little conceptual development of practical implementation strategies (Homrich et al. 2018; Korhonen, Honkasalo, and Seppälä 2018; Suárez-Eiroa et al. 2019). Cui and Zhang (2018) describe how the lack of theoretical research on CE limits the adoption of circular practices, while Nobre and Tavares (2017) describe how there is a disconnection between scientific research and important industry initiatives. This reveals how the concept of CE is still mainly a theoretical concept, with few industries that have actually implemented circular initiatives, hence the world only being 7.2 percent circular (Circle-Economy 2023).

The aluminium industry is committed to reduce its emissions towards a more sustainable sector (Liu and Müller 2012), in which the development of CE can have a drastic effect on relieving environmental pressure and facilitating sustainable development (Han et al. 2017). However, studies on CE development in the aluminium industry remains scarce, whereas current studies within the aluminium sector focus on material flow analysis (Bertram, Martchek, and Rombach 2009; Ding, Yang, and Liu 2016), life cycle analysis (Gao et al. 2009; Liu and Müller 2012), energy conservation (Lin and Xu 2015), and greenhouse gas (GHG) mitigation (Li et al. 2017). Although these topics are related to the CE, they are not considered circular measures when assessed separately.

Reintroducing waste back into the SC is a core principle of the CE (Velenturf and Purnell 2021), which also applies to the aluminium industry. Sevigné-Itoiz et al. (2014) and Niero and Olsen (2016) describe how recycling of post-consumer aluminium scrap is considered one of the most crucial initiatives to reduce energy consumption and GHG emissions in the aluminium industry, giving it a key role in achieving a circular aluminium system. While recycling is considered the least value capturing measures in the CE (Kirchherr, Reike, and Hekkert 2017), recycling of post-consumer aluminium scrap in this context is considered as an upcycling measure and not downcycling, as the value of the scrap increases when reintroduced back into the SC (Niero and Olsen 2016). While there are scientific articles that study the recycling of post-consumer aluminium scrap (Niero and Olsen 2016; Sevigné-Itoiz et al. 2014; Soo et al. 2019; dos Santos Gonçalves et al. 2021), it is not exclusively studied as a driver to achieve a circular aluminium industry.

Furthermore, the pressure on the environment and society will continue to grow, increasing the importance of a circular transition in resource and energy intensive industries. This includes the aluminium industry, which is a dominating industry in Norway, constituting four percent of the country's total CO_2 emissions (Senanu, Skybakmoen, and Solheim 2021). Norway is among the countries with the highest consumption rates in the world per capita, in which the linear economy is still dominating, making the country only 2.4 percent circular (Circle-Economy 2020). However, several defining aspects of the Norwegian economy can be leveraged to advance a circular transition (Circle-Economy 2020), thereby achieving a circular aluminium industry. Potentials, strategies, and barriers related to a circular transition in the Norwegian aluminium industry are necessary to address in order to provide insight and increase knowledge. Based on this, the following research problem is established:

"There is a lack of knowledge on how recycling of post-consumer aluminium scrap can enhance circular economy adoption in the Norwegian aluminium industry."

1.4 Research Questions

In order to address the research problem and investigate what role recycling of post-consumer aluminium scrap has in the transition towards a Norwegian circular aluminium system, the following research questions are proposed:

RQ1: *What is the environmental, economic, and social potential of recycling post-consumer aluminium scrap?*

The aim of the first research question is to investigate the potentials of recycling post-consumer aluminium scrap towards achieving a circular aluminium system. The potentials are divided into the three dimensions of the CE, economy, environment, and society, to map if the dimensions are equally emphasised, as literature reveals a skewed focus on the dimensions (Geissdoerfer et al. 2017; Kristensen and Mosgaard 2020; Kirchherr, Reike, and Hekkert 2017). The research question will provide insight into what the different actors in the aluminium industry perceive as the potential of recycling post-consumer aluminium scrap, to investigate if there are any differences between the actors' thoughts and experiences, and if their perceptions correspond with the literature.

RQ2: *How can the Norwegian aluminium industry achieve a more circular economy by recycling post-consumer aluminium scrap?*

To fully realise the potentials of a CE, a set of strategies have to be implemented. Fraser, Haigh, and Soria (2023) and Bocken and Ritala (2021) present a set of strategies based on the aims of a CE – minimising material use, regenerating the earth and preventing material losses. The aims are translated into four strategies: Narrow, slow, regenerate, and cycle. The purpose of this research question is to investigate if and how these strategies are present in the aluminium industry today, and how they can be enhanced to increase the circularity. It will also be explored if any of the strategies are more emphasised or relevant for specific aluminium SC actors.

RQ3: *What are the barriers of recycling post-consumer aluminium scrap in achieving a circular economy?*

While the concept of CE is gaining increased attention in scientific literature, there are barriers that hinder companies from implementing it (Galvão et al. 2018). As the importance of a CE is increasing, and industries are experiencing increased pressure to implement circular measures, it is critical to identify and address the barriers to help overcome them (Jaeger and Upadhyay 2020). This research question seeks to identify what barriers aluminium industry actors experience in transitioning to a CE by recycling post-consumer aluminium scrap, and if the different SC actors experience different barriers.

1.5 Structure of the Thesis

The thesis is composed of six chapters, as illustrated in Figure 1.1. Chapter 1 introduces the study by presenting the background, followed by the research problem and research questions that are to be answered. Chapter 2 presents the theoretical concepts that are necessary to answer the research questions, which is divided into three sections: The first section establishes the fundamentals of the CE, the second section introduces the aluminium industry, and the third section explores the implementation of CE in the aluminium industry. Chapter 3 presents the methodological approach that is applied in this thesis, including research philosophy and approach, methodological choice, research strategy, time horizons, data collection and analysis, and quality criteria. The findings of the research are presented in Chapter 4, and the discussion of the findings in relation to the theoretical background is presented in Chapter 5, in addition to a conceptual framework. Chapter 6 presents the conclusion of this research, including a research summary, contributions, limitations, and suggestions for further research.

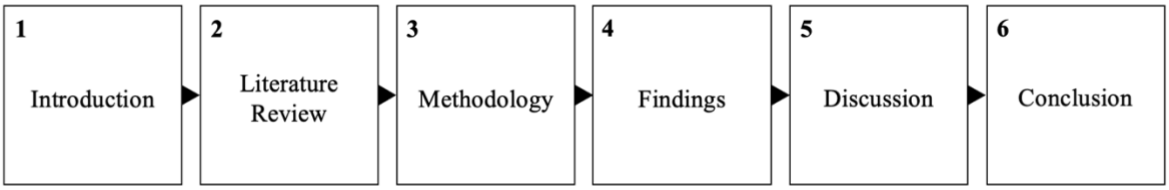

Figure 1.1: Thesis Structure

2.0 Literature Review

2.1 Chapter Introduction

The purpose of a literature review is to provide the reader with an overview of up-to-date and well-structured literature that is the background of the study (Wee and Banister 2016). However, if the literature review is flawed, it may lead to flaws in the rest of the dissertation (Randolph 2009). The contents of this literature review are selected to support the answers to the research questions of this thesis. The review is divided into three main parts: The first part introduces the CE, in which the aim is to establish general knowledge about the concept, as well as linking it to the manufacturing industry. The second part describes the aluminium industry, including an introduction the aluminium market, what types of aluminium exist, how it is produced, and how to recycle it. The third part integrates the two latter topics, where the CE is explored in the aluminium industry.

2.2 Circular Economy

The concept of CE is a comprehensive field of study, which becomes evident in the range of literature about it. Nonetheless, since this thesis is within the field of SC management (SCM), it is necessary to explain its role in the CE, and how their components can be linked together. Progressing from the role of SCM in the CE, the origin of the CE is introduced, followed by its definitions, as well as its core components. The concept is then further explored within the manufacturing industry, in which the ways of how manufacturers can become circular are described. Lastly, the barriers that hinder manufacturers in transitioning to a CE are also discussed.

2.2.1 The Role of Supply Chain Management in the Circular Economy

This subchapter outlines how the to successfully implement CE with the aid of SC processes. The implementation of CE in SCM is essential when promoting the concept of CE; however, there is still a research gap in the literature linked to this topic (Tjahjono and Ripanti 2019). According to MachArthur (2014), the SC is the single most essential element of action for the implementation and achievement of the CE and will serve as the basis for enacting the necessary change. While not always methodical, consistent, or driven primarily by a CE focus, SC managers deal with the difficulties of production and manufacturing processes on a regular basis, and it is precisely because of how closely linked the two fields are that the importance of implementing the circular SC (CSC) is distinct (Russo et al. 2019). Amir et al. (2022 p.2) defines CSC management (CSCM) as "*closing the loop by intention and design with a zero-waste vision where the forward and reverse flows are integrated and optimised for multiple lifecycle products to enable restoration and regeneration of technical cycles*."

The different stages of production have different impacts on the environment, and companies are held more accountable for the environmental performance of their suppliers and vice versa. The environmental accountabilities do not fall on an individual organisation, and to execute these societal responsibilities successfully and efficiently, a number of entities from across the SC must be involved (Hazen et al. 2021). This makes it critical for organisations to integrate a sustainable SCM (SSCM), as they are dependent on implementing sustainable and greener methods in order to be competitive (Seuring and Müller 2008). Using resources to satisfy current demands without compromising the ability of future generations to satisfy their own needs is a general definition of an sustainable SC (SSC), which is different from the CSC as it focuses on making SC more sustainable rather than circular (Linton, Klassen, and Jayaraman 2007). This strategy frequently forces businesses to function less efficiently from a cost standpoint in order to maximise value creation throughout the whole SC (Linton, Klassen, and Jayaraman 2007).

SCM's fundamental procedures can facilitate the shift from linear production and consumption to a more circular approach, and a great deal of the SC literature is similar to the theories emerging in CE, especially within the areas of green SCM (GSCM), SSCM, and closed-loop SCM (CLSCM) (Govindan and Hasanagic 2018; Guide Jr and Van Wassenhove 2009). Given that GSCM integrates environmental factors into all facets of SCM, from product design to material sourcing and selection to production and delivery of the finished product, it can be seen as an extension of SSC (Srivastava 2007). Designing, managing, and running a system to maximise value generation over a product's whole life cycle is known as CLSCM. Although closed-loop SC (CLSC) and CSC share many similar elements, CLSC differs from CSC in that it only addresses business-related issues and ignores social issues (Govindan, Soleimani, and Kannan 2015). Despite the presence of reverse logistics, which is the procedure of transferring goods from their final destination in order to sell them or dispose of them, CLSCM, and recycling in particular industries, there are currently no significant industrial cases of CE concepts being applied to SC processes (Bernon, Tjahjono, and Ripanti 2018). It will be possible to connect GSCM, SSCM, and CLSCM by establishing a CE within the value chains, allowing them to overcome their differences and develop a more focused and coherent goal (Hazen et al. 2021).

As the role of the SCM in CE is explained, the following chapter will explain the origin of the CE.

2.2.2 Origin of the Circular Economy

Since the late 1970s, the concept of CE has gained increased popularity as a solution to the growing scarcity of the natural resources on Earth (Geissdoerfer et al. 2017; Homrich et al. 2018). Several authors (Ghisellini, Cialani, and Ulgiati 2016; Geissdoerfer et al. 2017; Homrich et al. 2018) refer to Pearce and Turner (1990) as the ones who primarily introduced the concept of CE, although it is based on previous studies of Boulding (1966). Boulding (1966) described an idea of the economy as a circular system to maintain the sustainability of human life on earth (Ghisellini, Cialani, and Ulgiati 2016). However, Pearce and Turner (1990) were the first to use the term "circular economy" (Prieto-Sandoval, Jaca García, and Ormazabal Goenaga 2016), and they pointed out how the environment is treated as a waste reservoir due to the traditional open-ended economy not having any recycling initiatives implemented (Su et al. 2013). Because of this, Pearce and Turner (1990) saw the need for the economy and environment to be considered as a circular relationship with closed-loop material flows in the economy (Su et al. 2013).

However, the concept of CE can be traced back further to different schools of thought. Several authors discuss concepts that have influenced the concept of CE, and that the CE is based on a collection of different ideas related to sustainable science (Korhonen, Honkasalo, and Seppälä 2018; Homrich et al. 2018; Ghisellini, Cialani, and Ulgiati 2016; Geissdoerfer et al. 2017). As with the concept of sustainability, the CE includes the three sustainability elements: economic, environmental, and social, known as the TBL (Javed et al. 2021). Moreover, the way CE is applied in economic systems and industrial processes involves different features and contributions from a variety of concepts that share the same idea of closed loops (Geissdoerfer et al. 2017). This includes concepts such as industrial ecology (IE), cradle-to-cradle, biomimicry, the blue economy, regenerative design, and performance economy (See Table 2.1).

Table 2.1: Concepts Influencing the CE

Concept	Concept description	Source	References that link with CE
Industrial Ecology	*"It is a systems view in which one seeks to optimise the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal"*	(Graedel 1996 p.70)	(Ellen-MacArthur-Foundation 2013; Geissdoerfer et al. 2017; Ghisellini, Cialani, and Ulgiati 2016)
Cradle-to-Cradle	"*The Cradle to Cradle design framework moves beyond the goal of only reducing an organisation's negative impacts (eco-efficiency) by providing an engaging vision and comprehensive strategies for creating a wholly positive footprint on the planet (eco-effectiveness)"*	(McDonough and Braungart 2005 p.2)	(Ellen-MacArthur-Foundation 2013; Geissdoerfer et al. 2017; Lewandowski 2016)
Biomimicry	Biomimicry translates to "the imitation of life" and can be thought of as innovation that is inspired by nature. It is an approach that uses the nature's solutions as an inspiration in design and processes for societal challenges.	(Volstad and Boks 2012; Kennedy 2004)	(Ellen-MacArthur-Foundation 2013; Geissdoerfer et al. 2017; Lewandowski 2016)
The Blue Economy	*"A sustainable ocean economy emerges when economic activity is in balance with the long-term capacity of ocean ecosystems to support this activity and remain resilient and healthy"*	(The-Economist-Intelligence-Unit 2015 p.7)	(Ellen-MacArthur-Foundation 2015a; Geissdoerfer et al. 2017; Lewandowski 2016)
Regenerative Design	*"Regenerative design means replacing the present linear system of throughput flows with cyclical flows at sources, consumption centres, and sinks"*	(Lyle 1996 p.10)	(Ellen-MacArthur-Foundation 2013; Geissdoerfer et al. 2017; Lewandowski 2016)
Performance Economy	The performance economy focus on the maintenance and exploitation of stock rather than linear or circular flows of materials and energy. It represents a shift to servicization where revenue is obtained from services and not selling goods.	(Stahel and Clift 2016)	(Ellen-MacArthur-Foundation 2013; Geissdoerfer et al. 2017; Lewandowski 2016)

Next, the definition of a CE is given.

2.2.3 Defining Circular Economy

Although the concept of CE has gained increased attention over the past decades, it has yet to attain a globally agreed upon definition. The growth of articles on CE has increased drastically, and the concept is of interest for both scholars and practitioners, resulting in a variety of definitions in the literature. Kirchherr, Reike, and Hekkert (2017) addresses this by collecting 114 definitions of CE to create transparency of its different understandings. Their study uncovers the definition by Ellen-MacArthur-Foundation (2015b p.7) as the most used definition, which is as follows:

"[CE is] an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models."

This definition emphasises the use of business models as an enabler in a CE transition, which is a reoccurring element in other definitions of CE as well (Kirchherr, Reike, and Hekkert 2017). Furthermore, Kirchherr, Reike, and Hekkert (2017) examine the frequency of the components of the 4R-framework in the definitions, which includes the activities reduce, reuse, recycle, and recover. Although the definition by Ellen-MacArthur-Foundation (2015b) does not include either of the activities, it was found that the majority of the definitions include one or a combination of the R-framework. A definition including the R-framework is by Geissdoerfer et al. (2017 p.759):

"[CE is] a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling."

A simplified definition of CE, compared to the two latter, is the definition by European-Commission (2015 p.2), presented below. This definition is more compatible for people with little to no knowledge about this subject, and as it is published by a policymaker, it is easily accessible for the public.

"…[CE is] where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised…"

The presented definitions are all different ways of describing CE, each emphasising different key aspects of the concept. Although it is important to highlight the fundamental elements of a CE, it can also create very technical definitions that can be difficult to grasp. However, the latter definition by European-Commission (2015) is considered too simple for this paper. Therefore, this study has applied the definition by Homrich et al. (2018 p.534), as this is a definition that accomplish to explain the overall picture of a CE without making it too complicated. The definition is as follows:

"CE is a strategy that emerges to oppose the traditional open-ended system, aiming to face the challenge of resource scarcity and waste disposal in a win-win approach with economic and value perspective."

While the chosen definition for this thesis provides an overview of the concept of CE, the following section will go into more detail about the components of a CE.

2.2.4 Core Components of a Circular Economy

This section describes the core components of a CE to give a better understanding of what a CE involves. It is divided into two parts: The first part presents the three key principles of a CE, as described by Ellen-MacArthur-Foundation (2015b). In order to reintegrate the economy into the planet's system, which is the ultimate ambition of a CE, while the second part explains the fundamental characteristics that describe a CE.

Key Principles of a Circular Economy

The CE rests on three principles, as described by Ellen-MacArthur-Foundation (2015b). The first principle is to "preserve and enhance natural capital", through controlling finite stocks and balancing renewable resource flows (Ellen-MacArthur-Foundation 2015b). The concept "natural capital" focuses on environmental assets that can provide ecosystem services, directly or indirectly to humans (Chenoweth et al. 2018). In a CE, natural capital is improved by encouraging nutrient flows throughout the system and by facilitating regeneration of nutrients. Moreover, this principle largely emphasises delivering utility effectively and using renewable energy and better-performing resources when possible (Ellen-MacArthur-Foundation 2015b). As one of the earliest users of the concept natural capital, Schumacher (2011) describes how capital provided by nature is far larger than capital provided by man. The second principle of a CE is "optimising resource yields". To maximise resource yields, products, components, and materials must be circulated at their highest level of utility in both technological and biological cycles, as depicted in Figure 2.1.

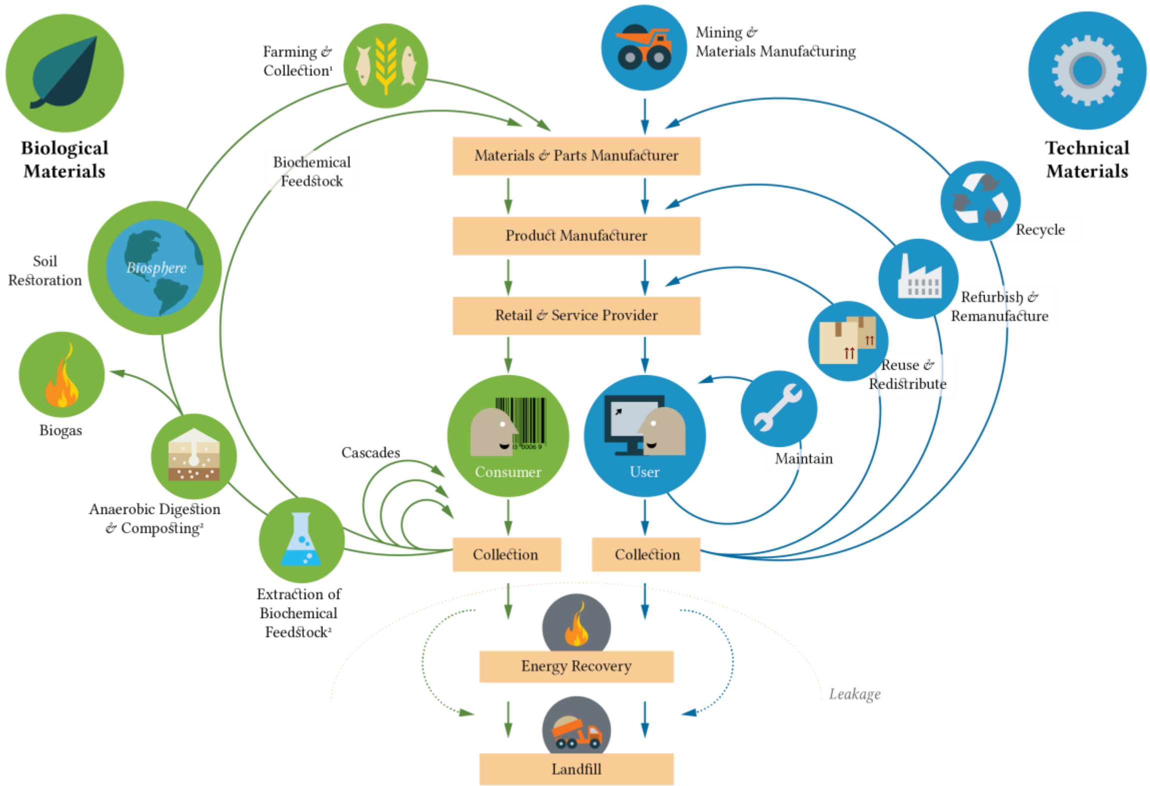

Figure 2.1: CE Butterfly Diagram (Ellen-MacArthur-Foundation 2015)

Technical cycles consist of non-renewable abiotic resources that cannot return to the biosphere, whereas biological cycles are composed of renewable biotic resources that can be returned to the biosphere (Navare et al. 2021). This fundamental difference makes the processes of maintaining materials in the loop very different for the two types of cycles. In a biological cycle the products are designed with the intention of either being consumed or decomposed and returned back to the soil. While products in a technological cycle are finite, therefore, they have to be designed for the purpose of being looped in order to preserve as much value of the materials as possible. This is done through maintenance, reuse, and repair. The aim is to maximise the number of cycles simultaneously as increasing the time spent in each cycle (Navare et al. 2021). The last principle of a CE is "fostering system effectiveness", and the purpose of this principle is to reveal and design out negative externalities. Although the technological revolution may improve resource efficiency and per-unit cost, ultimately helping the economy, it does not solve challenges of externalities (Ellen-MacArthur-Foundation 2015a). Areas that need to be protected from damage are for example education and health, while negative externalities are such as air, water, and noise pollution, and release of toxic substances (Ellen-MacArthur-Foundation 2015b). While these are principles of action, the subsequent section goes into more detail about the specific activities in a CE.

Fundamental Characteristics of a Circular Economy

Ellen-MacArthur-Foundation (2015b) list five characteristics that describe a CE. The first characteristic of a CE is that “waste is designed out”, meaning that waste does not exist in a CE. When a product reaches its EOL in a linear economy it ends up as waste in a landfill. In contrast, the purpose of a CE is to eliminate this final stage of a product’s life cycle and instead reintroduces the “waste” back into the SC to minimise the use of virgin materials (Homrich et al. 2018). The second characteristic of a CE is “diversity builds strength”. An example of this is living systems, which are dependent on biodiversity to survive environmental challenges. This logic is also present in economic systems. A CE requires a diverse economy with different scales of businesses to build resilience and survive long term. The optimal thing is achieving a balance of large businesses that deliver volume and efficiency, and smaller businesses that offer alternative solutions during crises (Ellen-MacArthur-Foundation 2015b). The third characteristic is “renewable energy sources power the economy”. Today, the most utilised energy sources are fossil fuels (IEA 2021), which conflicts with a CE’s aim of having sustainable industrial cycles. In addition to its negative environmental effects, it is also an energy source that lack reliability due to its volatile prices and supply. In order to decrease resource dependency and increase system resilience it is necessary to shift to renewable energy sources (Ellen-MacArthur-Foundation 2015b).

The fourth characteristic of a CE is to “think in systems”. The CE is labelled as a system in many ways: an economic system, a circular system, a closed-loop system, or a regenerative system, among others (Geissdoerfer et al. 2017). Applying systems-thinking is common in many different settings, such as information systems or ecological systems. A system is defined as a group of interacting elements that work together according to a specific plan or rules, where the environment surrounding the system also have an influence (Gundersen 2023). Therefore, one cannot think of a CE as an isolated system, it is crucial to understand how the parts within and outside of the system interact in order to achieve a successful CE transition (Ellen-MacArthur-Foundation 2015b). The fifth and last characteristic of a CE is “prices or other feedback mechanisms should reflect real costs”. In a CE the prices should reflect all costs incurred, which includes external costs. This is to create transparency about negative externalities that may have been generated in the process, as it can act as a barrier in a CE transition if not informed about (Ellen-MacArthur-Foundation 2015b).

In the next section, the strategies of transitioning to a CE in the manufacturing industry are presented, which reflect both the principles and characteristics of a CE.

2.2.5 Circular Economy in the Manufacturing Industry

Growing awareness of environmental challenges and need for social responsibility has influenced manufacturing companies to adopt new ways of running their businesses (Kumar et al. 2019). For this thesis, the manufacturing industry is defined as "*industries that use highly equipped machines and digital instruments that are helpful in their production"* (Jaeger and Upadhyay 2020 p.730). While this industry has become a vital player in improving people's living standards, it is also a large contributor to environmental challenges (Bjørnbet et al. 2021). The 12th sustainable development goal by United Nations is "responsible consumption and production" (United-Nations 2022), which encourages systems to apply new and sustainable strategies. This includes consumer behaviour as well as industrial actors, whereas the latter includes the manufacturing industry, which is considered one of the most pollutant industries and resource greedy sectors (Acerbi and Taisch 2020). Because of this, manufacturers are encouraged to become sustainable, of which the CE is considered as a promising model to apply (Acerbi and Taisch 2020; Bjørnbet et al. 2021). Fraser, Haigh, and Soria (2023) describe four strategies for achieving a CE: narrow, slow, regenerate, and cycle, which will be further described in the context of the manufacturing industry.

Narrow Strategy

The narrow strategy requires the sector to use less material and energy. The manufacturing industry uses resources and energy inefficiently, even when considerably less can be used to achieve an equivalent social result (Fraser, Haigh, and Soria 2023). When focusing on narrowing, the aim is to streamline and make the design and manufacturing processes efficient, which will result in a decrease in the volume of resources utilised during the production stage (Bocken and Ritala 2021). The use of fewer resources reduces pollution while also saving raw materials and materials overall including a decline in virgin materials. The environmental effects related to the reuse of waste, such as land usage and harmful emissions to ground and water, can be reduced by reusing wastes and by-products (Patala, Salmi, and Bocken 2020). Additionally, the direct reuse of production waste or scraps within of factory boundaries will be value creating (Bocken and Ritala 2021). The future of generations is a key objective of CE, and by utilising less raw material, it prevents the resources from being depleted (Dissanayake and Weerasinghe 2021). It will be possible to derive more value from materials by increasing resource efficiency (Kennedy and Linnenluecke 2022). The manufacturing industry is a big reason for the considerable increase of metal ores, which is also a material requiring high energy consumption (Fraser, Haigh, and Soria 2023).

Manufacturing has a direct impact on ecosystem destruction and biodiversity loss which is due to the material- and energy-intensive industrial activities in which predominantly consumes metals and fossil fuels. Therefore, the manufacturing industry has great potential for improvement by narrowing down, as making changes in this sector will have a major impact globally (Fraser, Haigh, and Soria 2023). Brändström and Saidani (2022) discusses the encouraging of sufficiency and product sharing as two strategies for narrowing loops. Sharing of products is an example of how one can maximise the capacity of products, by having an industry working for others rather than everybody having the product needed for that particular job themselves (Brändström and Saidani 2022). Encouragement of sufficiency occurs when a business urges its clients to limit their consumption (Brändström and Saidani 2022). Because it often lowers costs while also conserving resources, this method is already widely used in the present-day linear economy. In considering the fact that advances in technology and operational procedures enable businesses to accomplish more with less, they need to adopt this approach regardless of their overall company model. However, these efficiency improvements shouldn't be achieved at the expense of quality or customer satisfaction (Bocken and Ritala 2021).

Slow Strategy

The following strategy is called slowing loops, which is the second flow to achieve a CE in a manufacturing business. Slowing the loops refers to extending the product life cycle, where materials, single components and products should achieve longevity (Brändström and Saidani 2022). Design and physical durability serve as the foundation for slowing loops. If a product's performance deteriorates over time more gradually than competing items on the market, it is physically more durable (Konietzko, Bocken, and Hultink 2020). The manufacturing industry can contribute to an increased product life by optimising its processes and high-quality maintenance (Fraser, Haigh, and Soria 2023). The manufacturing industry are responsible for the material choice and the suppliers they get it from. By making the best use of the available resources, they may significantly improve social and environmental performance, adding value for both the industry and its clients (Carter and Easton 2011). In order to make things last, repair and maintenance will be a big part of keeping materials in use for as long as possible. By performing inspections and services that preserve or restore a product's functions, repair and maintenance processes lengthen a product's lifespan at the point of use (Lüdeke-Freund, Gold, and Bocken 2019). An important part of slowing the loops is reusing. Reuse focuses on reintegrating structures and resources into the system without requiring significant change or resource consumption. The product's purpose may stay the same or vary depending on whether it is reused in the same or a new area. Reuse is a foundational component of strategies like "reduce primary resource inputs" and "design for reversibility" (Çetin, De Wolf, and Bocken 2021).

For the development of new products, business models, and ecosystems, Konietzko, Bocken, and Hultink (2020) has developed a set of circularity principles. Turning disposables into reusable services, where a company sells the product as a service, preserves ownership with the business and creates incentives to extend its lifespan, is an ecosystem principle for slowing loops. Designing for emotional durability, which results in creating goods that people will value and trust for a long time, is an example of a product business strategy in slowing loops, and it enables interaction and fosters a strong emotional connection between the consumer and the product. Finally, a product's design for simple disassembly and reassembly adheres to the slowing loop circularity concept. Here, the items have to be made to be simply detachable and reassembleable (Konietzko, Bocken, and Hultink 2020). The slowing loop is one of the strategies that has either been adopted or is widely used, and it will therefore require more innovative thinking for the manufacturing industry to start this process (Lüdeke-Freund, Gold, and Bocken 2019).

Regenerate Strategy

The definition of regeneration has been inadequately discussed, which has led to many describing and using this strategy in different ways. The objective of regeneration is to improve the status of systems while aiming to have a net positive influence on the environment (Çetin, De Wolf, and Bocken 2021). Regenerating loops is a term used to gradually replace toxic or hazardous components and procedures with renewable biomass and nontoxic resources, renewable energy, and preserving the natural ecosystem services (Çetin, De Wolf, and Bocken 2021). The CE's biological cycle is the focus of this approach, but it additionally incorporates features that are essential to the technical cycle, particularly in relation to the consumption of renewable energy (Çetin, De Wolf, and Bocken 2021). A CE tries to mirror natural cycles while also increasing the amount of circular biomass that enters the system, for example by switching to more sustainable farming methods (Fraser, Haigh, and Soria 2023). In the CE, the word regenerate refers to the utilisation of pre-existing materials to produce new ones (Ogunmakinde, Sher, and Egbelakin 2021). It entails putting eco-design into practice, eliminating poisonous and hazardous materials and emphasises product reuse while substituting renewable materials for non-renewable ones (Ogunmakinde, Sher, and Egbelakin 2021).

The manufacturing industry can contribute to the shift towards regeneration, as it will be involved from the system levels in addition to the product level. This means that the manufacturing industry can be a part of designing and/or producing regenerative processes, or by implementing them into their own manufacturing (Fraser, Haigh, and Soria 2023). Producing using renewable energy is a business model tenet for regeneration which is relevant to the high energy consumption within the manufacturing industry (Çetin, De Wolf, and Bocken 2021). Recover nutrients from urban areas is an ecology principle for regeneration. This principle focuses on finding methods to salvage important nutrients from metropolitan environments that are commonly wasted. This may call for various ecosystem players, such as businesses that gather, transport, process, and redistribute nutrients as well as end consumers that create nutrient output (Çetin, De Wolf, and Bocken 2021).

Cycle Strategy

The final strategy is called cycle, often referred to as recycling, is the practise of reusing materials after they have been used by consumers (Bocken and Ritala 2021). When materials are discarded due to the fact that they are of poor quality, they may be repurposed for purposes of lesser value or worse, they may be burned to produce energy, a process known as downcycling. Upcycling is the process of turning a lower-quality product into a higher-quality one (Bocken and Ritala 2021). Cycle techniques seek to recycle and repurpose materials as much at their highest value. This strategy can be considered as the one that influences the other loops to the highest degree, because it emphasises increasing the amount of secondary materials re-entering the system, thus reducing the demand for new material inputs and consequently narrowing flows (Fraser, Haigh, and Soria 2023). The manufacturing sector has a responsibility to not only provide products that are recyclable at the EOL, but also to start the transition to reuse and/or use secondary materials in its own production. The manufacturing sector is unable to eliminate virgin materials because they are required for a variety of products to retain strength and functioning (Fraser, Haigh, and Soria 2023). The industry can enable this cycle by reusing materials that are outside their SC by buying products that have been recycled, or by reusing all the material from their own pre-consumer scrap and another possibility is that manufacturers produce products that contain a certain amount of recycled material (Fraser, Haigh, and Soria 2023). When products approach their end-of-use stage, the cycle loop principle seeks to reintroduce resources into the economic cycle. A strategy within cycle is to recycle, which concerns remanufacturing materials into resources of equal or lesser value, and the processes often call for both energy and water (Çetin, De Wolf, and Bocken 2021).

The major distinction between the cycle approach and the narrowing strategy is that cycling generates value through post-consumer recovered resources, whereas narrowing takes place in the pre-consumer stage (Bocken and Ritala 2021). Cycling occurs inside the confines of the organisation and enables a corporation to present value propositions that depend on resource recovery from clients, whether they be consumers or companies, in different ways. This enables extracting value through cost- and efficiency-saving measures (Bocken and Ritala 2021). The cooperation between Jaguar Land Rover and its aluminium supplier Novelis to close the aluminium loop is an illustration from the automotive sector. They gathered offcuts and scrap from manufacturing, had it reprocessed, and delivered back to the factory, and the firm has since they started this project boosted its recycled inputs from 33 percent to around 50 percent. By introducing resources from external ecosystems and integrating them in various ways to consumer offers, cycling provides value. The value offer frequently includes a product with a less environmental impact and its less resource demanding (Bocken and Ritala 2021).

Designing with recycled inputs is manufacturing products with materials that have been recycled from previous goods and/or components, is a circular principle. Another method of product design is to make it simple to disassemble the product at the end of its useful life so that the parts may be more easily recycled (Patala, Salmi, and Bocken 2020). Reusing and selling materials from abandoned goods is a business model suitable for the cycle approach. Through this, discarded goods and components are given new worth. A different business strategy is to encourage and facilitate product returns. This is accomplished by ensuring that you can recover the goods you sold. Finally, an ecosystem for the cycle strategy is building local waste-to-product loops, or converting waste from one facility into new goods that can be sold back to that facility (Patala, Salmi, and Bocken 2020). Figure 2.2 is designed by (Fraser, Haigh, and Soria 2023), which illustrates the four strategies for achieving a CE.

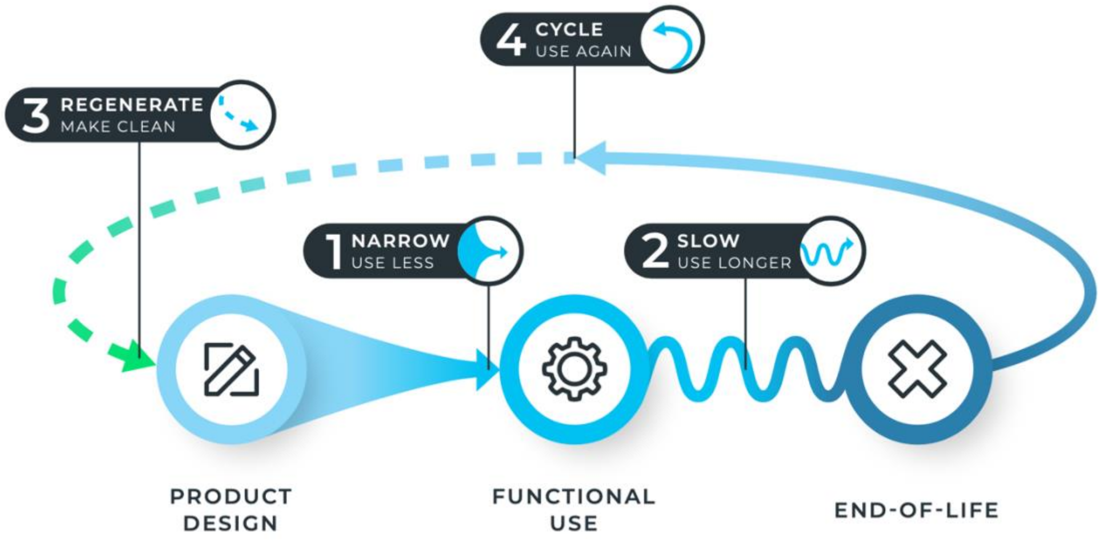

Figure 2.2: The Four Loops to Achieve Circular Objectives (Fraser, Haigh, and Soria 2023)

Following these four strategies for achieving a CE within the manufacturing industry, the next section describes the barriers that can arise during CE implementation.

2.2.6 Barriers of a Circular Economy in the Manufacturing Industry

Although the concept of CE is gaining increased interest, there are barriers to its implementation that are hindering its emergence (Galvão et al. 2018), in which a barrier is defined as a hindrance that makes a passage difficult or impossible (NAOB 2023). The literature about circular barriers is comprehensive, revealing a wide range of barriers within a variety of industries. However, a common method is to categorise the barriers into different barrier categories as a way to systemise them. There are different approaches of categorising the barriers, but one can identify a recurrent pattern that is applied. Kirchherr et al. (2018) categorise the barriers into cultural, regulatory, market, and technological. Similarly does Grafström and Aasma (2021) who divide the CE barriers into technological, market, institutional, and social. Ritzén and Sandström (2017) have a slightly different approach and divide the barriers into five categories: financial, structural, operational, attitudinal, and technological. As this research is conducted within the aluminium industry, the literature will only concern barriers within the manufacturing industry.

The study by Jaeger and Upadhyay (2020) investigates CE barriers within manufacturing companies of different sizes, in which the larger companies already have a sustainability strategy established and the small companies do not. Among the seven barriers that was revealed, high start-up cost is the barrier most of the manufacturers identified. Among the manufacturers expressing this barrier is a "world-leading manufacturer of aluminium" who explain the cost element as a constant challenge, needing to balance the trade-off between investment and earnings. In addition to a smaller company explaining how the cost picture is a barrier, as potential solutions will not be used unless it is a clear way to get profit from it. Furthermore, the second most identified barrier by the manufacturers is challenging business-to-business (B2B) cooperation, including perceptions such as customers preferring short delivery time over environmental improvements. Barriers related to quality is also identified by multiple companies, including a manufacturer of lighting solutions explaining how reused parts potentially are not as good as virgin parts and a manufacturer of marine thrusters describing how metal parts experience structural damage when subjected to strains (Jaeger and Upadhyay 2020). Most of the identified barriers in their study are expressed by the large companies, indicating how company size affects how fast companies are able to transition to a CE. This is also highlighted by (Kumar et al. 2019), explaining how the size, industry and location will affect what barriers companies meet upon. The study also uncovers that the manufacturers mainly focus on the lower impact CE strategies and less on elevated strategies with higher impact, such as focus on recycling and reducing waste.

Unlike Jaeger and Upadhyay (2020), the studies by Badhotiya et al. (2022) and Kumar et al. (2019) divide the barriers into social, economic and environmental categories, whereas Badhotiya et al. (2022) rank the barrier categories according to importance, meaning what barriers to prioritise. This reveals the social barriers as the most important, followed by the economic barriers, and then the environmental barriers. The barrier Badhotiya et al. (2022) identify as the most important is low demand and acceptance of remanufactured products, which Kumar et al. (2019) also reveal as one of the main social barriers. This is followed by the barrier of lack of government support and legislation, lack of top management commitment and lack of knowledge of CE, among others. Kumar et al. (2019) also identifies the lack of attention to the EOL phase as a barrier, whereas Badhotiya et al. (2022) identifying the lack of design tools for circular products. While the purpose of the ranking is to highlight which barriers are most critical, Badhotiya et al. (2022) also highlights the importance of focusing on the barriers simultaneously, and how it is necessary to find the interrelationship between the barriers and its categories.

The study by Kashyap, Kumar, and Shukla (2022) also ranks the identified barriers using a method based on the cause and consequence of the barrier. However, this study focuses specifically on the aluminium industry. The results of the study reveal the lack of decision making from the top management level as the top barrier, explaining how it contributes to slow down the processes. Thereafter, the lack of research and development of new ways to reuse local by-products or wastes in production process is revealed as the second most important barrier, describing how there is a need for techniques to recycle generated waste and scrap to reduce the environmental effects and increase the economic potential. Another barrier identified in the study is the lack of technology application in waste collection systems, describing how a proper management system is necessary for industries to achieve the objectives of a CE. Kashyap, Kumar, and Shukla (2022) explain that the purpose of ranking the barriers is to highlight the critical barriers to be eliminated as fast as possible, while less critical barriers are de-prioritised and assessed afterwards.

Table 2.2 presents an overview of all the identified barriers in the manufacturing industry based on the discussed articles.

Table 2.2: Overview of CE Barriers in the Manufacturing Industry from the Literature

Barrier	**Source(s)**
Associated risk in transitioning from linear to CE	(Badhotiya et al. 2022)
Company culture	(Kumar et al. 2019)
Complex SC	(Jaeger and Upadhyay 2020; Kashyap, Kumar, and Shukla 2022)
Decomposer companies do not have enough capacity	(Kumar et al. 2019; Badhotiya et al. 2022)
Disassembly of products formed in the aluminium industry is time consuming and expensive	(Kashyap, Kumar, and Shukla 2022)
Disassembly of products is time-consuming and expensive	(Jaeger and Upadhyay 2020)
High cost of eco-friendly material	(Badhotiya et al. 2022)
High start-up/investment cost	(Jaeger and Upadhyay 2020; Kumar et al. 2019; Badhotiya et al. 2022; Kashyap, Kumar, and Shukla 2022)
Inadequate policies and legislations	(Kumar et al. 2019; Badhotiya et al. 2022; Kashyap, Kumar, and Shukla 2022)
Inadequate waste resource management systems	(Kumar et al. 2019; Badhotiya et al. 2022)
Lack of a standard system for performance measurement	(Kumar et al. 2019; Badhotiya et al. 2022; Kashyap, Kumar, and Shukla 2022)
Lack of advanced technology and equipment	(Kumar et al. 2019; Badhotiya et al. 2022)
Lack of appropriate partners in SC	(Kumar et al. 2019; Badhotiya et al. 2022; Jaeger and Upadhyay 2020)

Lack of demand of remanufactured products because of appearance	(Kumar et al. 2019; Badhotiya et al. 2022)
Lack of financial support mechanisms and tax incentives	(Kumar et al. 2019; Badhotiya et al. 2022)
Lack of information on product design and production	(Jaeger and Upadhyay 2020; Badhotiya et al. 2022)
Lack of integration between market actors and transition	(Kashyap, Kumar, and Shukla 2022)
Lack of integration of industry 4.0 technologies into CE practices	(Kashyap, Kumar, and Shukla 2022)
Lack of personnel with an expertise on the CE	(Kumar et al. 2019; Badhotiya et al. 2022)
Lack of public awareness of CE principles	(Kumar et al. 2019; Kashyap, Kumar, and Shukla 2022)
Lack of research and development of new ways to reuse local by-products or wastes in production process	(Kashyap, Kumar, and Shukla 2022)
Lack of strategy development for managing routine processes	(Kashyap, Kumar, and Shukla 2022)
Lack of suitable material for improving the productivity of Hall-Heroult cell for aluminium production	(Kashyap, Kumar, and Shukla 2022)
Lack of technical skills	(Jaeger and Upadhyay 2020; Kumar et al. 2019; Badhotiya et al. 2022; Kashyap, Kumar, and Shukla 2022)
Lack of technology application for waste collection systems in industries	(Kashyap, Kumar, and Shukla 2022)
Lack of willingness of the management	(Kumar et al. 2019; Badhotiya et al. 2022; Kashyap, Kumar, and Shukla 2022)
Limited incentives to save energy, water, and material	(Kumar et al. 2019; Badhotiya et al. 2022)
Logistics impediments within processes	(Kashyap, Kumar, and Shukla 2022)
Low cost of virgin materials	(Kumar et al. 2019; Badhotiya et al. 2022)
Low customer acceptance of remanufactured products	(Kumar et al. 2019; Badhotiya et al. 2022)
Poor attention to EOL phase in product design	(Kumar et al. 2019)
Quality compromise	(Jaeger and Upadhyay 2020)
Reluctance to replace old products even when reaching EOL	(Kumar et al. 2019; Badhotiya et al. 2022)
Scepticism to quality of refurbished and recycled products	(Jaeger and Upadhyay 2020; Badhotiya et al. 2022)
Unregulated e-waste recovery sector	(Kumar et al. 2019)

The subsequent section presents the aluminium manufacturing industry.

2.3 Aluminium Industry

The aluminium production industry is global, as there are both mining operations and production all over the world. China is the country with the largest production of aluminium, surpassing all other countries (International-Aluminium 2023). Over the past 100 years, aluminium production has increased significantly on a global scale. The average price has fluctuated but has experienced a continuous growth over the past decades (Lumley 2010). Because of the material's advantageous qualities, demand for aluminium is rising. In Europe and North America, this rise in product demand is related to the automotive sector's explosive expansion as a result of efforts to reduce emissions from vehicles by making them lighter (International-Aluminium 2023). As a result, the primary forces driving the development of related businesses are those driving the global aluminium industry (Dudin et al. 2017). The market for aluminium is known for its fierce competition and concentration. The combined weight of the six major producers exceeds 40 percent of the total output of this non-ferrous metal worldwide, which is associated with considerable entry barriers for new market entrants. Unfair competition within the aluminium manufacturing industry has also received a lot of attention, as various import, export, subsidy, and environmental regulations have been brought up (Dudin et al. 2017).

In order to gain an understanding of how the aluminium production industry collects and processes aluminium, the next section explains the different types of aluminium.

2.3.1 Types of Aluminium

Aluminium is separated into two groups, primary and secondary aluminium, where the content of the aluminium determines which category they fall under. Primary aluminium is made from new aluminium, which means that it is produced from the raw material bauxite. While secondary aluminium is made from recycled aluminium scrap and can be further divided into two categories: pre- and post-consumer scrap (Blomberg and Söderholm 2009). Pre-consumer aluminium scrap is aluminium scrap that is generated during the manufacturing process, while post-consumer aluminium scrap is waste generated after consumption (Moulin 2020).

Pre-consumer aluminium scrap, also referred to as process scrap or new scrap, is formed during the manufacturing of aluminium goods like rolled foil or extruded profiles, and is remelted and returned back into the primary production process (Migliore, Oberti, and Talamo 2020; Søreide 2019). The International Organisation for Standardisation (ISO) has its own usage of terms, where environmental labels and declarations are defined in the ISO 14021. ISO 14021 defines pre-consumer scrap as "*Material diverted from the waste stream during a manufacturing process. Excluded is reutilisation of materials such as rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it*" (ISO 2016 Section 7.8.1). Typically, 20 to 30 percent of aluminium during processing is lost as process scrap. However, the recycling rate of this process scrap can be 100 percentage (Søreide 2019).

Pre-consumer aluminium scrap is produced during the production of aluminium and its alloys, as well as during the production of semi-fabricated goods and finished goods (Moulin 2020). Pre-consumer aluminium scrap is the main source of aluminium recycling in the world today (Liu, Bangs, and Müller 2013). Due to the extensive use of raw materials and the significant amounts of waste in the manufacturing industry, pre-consumer aluminium scrap from the manufacturing sectors can represent significant sources of secondary materials. This material is beneficial for lowering the high environmental impacts of the manufacturing sector (Migliore, Oberti, and Talamo 2020). Pre-consumer aluminium scrap is also referred to as recycled aluminium processed from secondary production. As the pre-consumer aluminium scrap has not yet reached its EOL, the carbon footprint from its initial production process still sustain (Søreide 2021). Hence, the carbon footprint of secondary aluminium with pre-consumer aluminium scrap is equal to the carbon footprint of the original primary aluminium plus 0.5 tonnes CO_2 per ton aluminium (Søreide 2019). Pre-consumer aluminium scrap in the manufacturing industry is mainly found on the site of production, which makes it easily available, simple to locate and thus the material is low cost and high in value (Migliore, Oberti, and Talamo 2020).

The scrap that results from disposing of goods following their last utilisation is known as post-consumer aluminium scrap and is also referred to as old scrap. Before being remelted in recycling facilities, the post-consumer aluminium scrap needs to be gathered, cleaned, and divided (Moulin 2020). ISO 14021 defines post-consumer scrap as "*Material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product which can no longer be used for its intended purpose. This includes returns of material from the distribution chain*" (ISO 2016 Section 7.8.1). The carbon footprint of post-consumer aluminium scrap is around 0.5 tonnes CO_2 per ton of aluminium, as it needs only five percent of the energy used in the primary production process, not adding the initial carbon footprint of the primary production as with pre-consumer aluminium scrap. Emissions associated with collecting, sorting and transportation are also added (Søreide 2021, 2019). Secondary aluminium with post-consumer aluminium scrap includes everything that is recycled after consumption, and can therefore be anything from products that have a shorter lifespan, such as aluminium cans, to infrastructure that has a lifespan over 50 years (Søreide 2019). Post-consumer aluminium scrap is currently primarily found in the form of discarded beverage cans and cars, which is due to the high aluminium consumption in the products and their comparatively short lifespans (Liu, Bangs, and Müller 2013).

After defining pre- and post-consumer aluminium scrap, the next section describes how aluminium is produced.

2.3.2 Aluminium Production

Bauxite is the raw material used in primary aluminium production, and 90 percent of the world's bauxite reserves are found in tropical and subtropical areas. The principal raw materials used in the manufacturing of aluminium are the bauxite ores gibbsite, böhmite, and diaspore. Since bauxite is usually always found close to the surface, open cast mining is typically used to obtain it (The-International-Aluminium-Institute 2018). Big blanket deposits are flat layers that are close to the surface and dispersed across a large region, possibly spanning several square kilometres. The existing biome is mapped, operational and external impacts on biodiversity are analysed, and potentials to minimise impacts or encourage enhanced biodiversity are reviewed in the well-established biodiversity management plans used by bauxite mining corporations. After the predatory work, the extraction process can begin (The-International-Aluminium-Institute 2018). With the use of large bulldozers, techniques including blasting, drilling, and ripping are used to dislodge the bauxite layer that underlies the overburden. Once the bauxite has been broken into smaller pieces, it is typically placed onto trucks, railroad cars, or conveyors and sent to stockpiles, and lastly transported to alumina refineries, which are typically situated close to bauxite mines. Due to the fact that the majority of the bauxite extracted is of an adequate grade, it doesn't require extensive processing. Beneficiation, or the removal of clay, is a procedure that can increase the quality of the ore, and beneficiation techniques include washing, wet screening, and mechanical or manual sorting (The-International-Aluminium-Institute 2018).

After the extraction and sorting of bauxite, the electrolysis process is initiated. The electrolytic method, also referred to as the Hall-Héroult process, is used to create primary aluminium metal (Gupta and Basu 2019). In a smelter, the cells or pots are linked in series by aluminium busbars. The liquid electrolyte (cryolite), molten metal (aluminium), molten electrolyte (carbon anodes), and the carbon cathode blocks are all the areas where the current in a cell flows downward. The external busbars, which connects to the subsequent cell, receive the current leaving the cathodes through the steel collector bars incorporated into the cathode blocks (Gupta and Basu 2019). The electrolyte, commonly referred to as “bath”, is mostly composed of cryolite with a few additives, including fluorides of aluminium, calcium, and magnesium. By lowering the liquidus temperature, these additives enable cell functioning at temperatures of 920-970 Celsius degrees. Aluminium, which is denser than the electrolyte, continuously deposits on the surface of the cathode while the electrolytic process continues. Finally, primary aluminium is either used for producing aluminium alloys or is cast into ingots and sold to customers (Gupta and Basu 2019).

It is crucial to monitor what happens to aluminium once it has been manufactured and distributed to users, and the topic of aluminium recycling is therefore covered in the following section.

2.3.3 Recycling of Aluminium Scrap

Since the beginning of its commercial production, aluminium has been recycled, and in 2010, around one-third of the aluminium consumed globally came from secondary aluminium (Lumley 2010). As aluminium is a material that can be recycled endlessly, it is therefore important that industries re-enter the secondary aluminium scrap to its production. Using recycled aluminium in manufacturing has advantages for the manufacturing sector as it offers tremendous energy savings. Due to the high value of aluminium scrap, recycling aluminium is also economically beneficial for the aluminium recyclers. In 2010, 56 million tonnes of aluminium were produced worldwide, of which 18 million tonnes were recycled from both pre-and post-consumer aluminium scrap, which corresponds to 32 percent of the production. Due to aluminium’s long lifespan and its use in production at a high rate, this percentage of recycled aluminium is significant (Lumley 2010). Both Europe and North America have produced enough aluminium waste, mostly pre-consumer aluminium scrap, since the 1940s to support the growth of a robust recycling sector. Most nations have developed markets for recyclable aluminium with clearly defined distribution networks (Lumley 2010). When compared to the relatively small number of primary producers, there are a substantial number of businesses engaged in secondary aluminium production. This is partly due to regional recycling regulations and the ability of secondary refineries to operate profitably at very modest quantities (Lumley 2010).

Pre-consumer aluminium scrap is frequently produced by the aluminium manufacturers, it is impractical to separate the different aluminium alloys at the source for recycling to a composition-compatible alloy. Therefore, the pre-consumer aluminium scrap is gathered into a degraded low-grade aluminium foundry alloy, where it is employed after the alloy content in the aluminium alloy scrap melt is chlorinated (Gesing and Das 2017). Given that the pre-consumer waste tends to remain uncoated, pre-processing it prior to melting only takes a modest amount of resources (Lumley 2010).

Post-consumer aluminium scrap is collected through recycling systems or scrap yards, and the aluminium is not sorted separately from other materials. The recyclers then have to sort the different materials to collect only the aluminium, which is recovered from non-magnetic metals via density separation and eddy current rotor cleaning. However, they do not sort by alloy (Gesing and Das 2017). Thus, it is often up to the aluminium producers to sort the post-consumer aluminium scrap they receive according to alloys (Gesing and Das 2017). Purifying post-consumer aluminium scrap by removing alloying elements is very challenging with aluminium, in addition to very costly and energy consuming (Paraskevas et al. 2015). To do so, the refiners have to flux the metal by removing oxides, intermetallic, as well as alloy elements to the necessary criteria (Lumley 2010). Therefore, the most common ways to address the contamination challenges are either by diluting the impurities with primary aluminium, or by down-cycling to alloys with lower purity requirements. However, this causes dilution losses and reduced product value, respectively (Paraskevas et al. 2015). While recycling is considered among the least circular measures in the CE hierarchy (Kirchherr, Reike, and Hekkert 2017), the recycling of post-consumer aluminium scrap is considered as upcycling as the value of the scrap increases when reintroduced back into the SC (Niero and Olsen 2016).

The subsequent section explores and discusses the implementation of circularity in the aluminium industry.

2.4 Circular Economy in the Aluminium Industry

The aluminium industry is committed to transition towards a more sustainable sector in the future (Liu and Müller 2012), in which the development of a CE can opt as a sufficient solution, relieving environmental pressure and facilitating sustainable development (Han et al. 2017). Recycling of post-consumer aluminium scrap is identified at one of the circular measures with the largest potentials of reducing energy consumption and GHG emissions, making it a critical unit of action in the shift from a linear economy to a CE (Sevigné-Itoiz et al. 2014; Niero and Olsen 2016). The following chapter discusses existent literature about CE implementation in the aluminium industry (see Table 2.3), focusing on the role of recycling post-consumer aluminium scrap.

Table 2.3: Overview of Studies about CE in the Aluminium Industry

Title	Author(s)	Description
Circular economy measures that boost the upgrade of an aluminium industrial park	(Han et al. 2017)	The focus of this study is to investigate how the implementation of CE measures impacts the overall performance of an aluminium production base.
Circular economy: To be or not to be in a closed product loop? A Life Cycle Assessment of aluminium cans with inclusion of alloying elements	(Niero and Olsen 2016)	This study explores if reuse or remanufacture as a CE strategy should be promoted in keeping aluminium cans within a closed loop system.
Environmental consequences of recycling aluminium old scrap in a global market	(Sevigné-Itoiz et al. 2014)	The objective of this paper is to determine the GHG emissions of collecting, sorting, and recycling post-consumer aluminium scrap while considering the market interactions.
Economic and environmental evaluation of aluminium recycling based on a Belgian case study	(Soo et al. 2019)	This paper evaluates the economic and environmental effects of recycling different aluminium scrap qualities based on data from a recycling facility.
The Use of Circular Economy Indicators to Improve Sustainability in the Recycling Aluminium Context	(dos Santos Gonçalves et al. 2021)	The aim of this study is to analyse how CE indicators can contribute in improving the sustainability of recycling aluminium cans.

As the aluminium industry has a high level of resource insensitivity, consuming substantial amounts of bauxite and electricity in addition to generating large amounts of waste, it is in need of recirculation to keep the materials within a closed-loop system (Han et al. 2017). Hence, the CE is a suitable solution. CE measures can be carried out on different levels in an organisation depending on what type of business and which processes that are most critical. In the study by Han et al. (2017), circular initiatives are explored on three levels in an aluminium industrial park: process, inter-process, and industrial park levels, including measures such as cleaner production (CP) auditing, industrial symbiosis, and refined management, respectively. After ten years, the results of these circular measures demonstrate an improvement in the overall performance of the industrial park. The economic performance was enhanced as several of the CE measures induced cost reductions, including the reuse of materials and waste and improved resource efficiency, as well as process improvement and optimisation that reduced energy consumption and production costs. This also contributed to reduce the environmental impacts where the solid waste intensity was reduced as well as the industrial waste gas emissions (Han et al. 2017).

While the study by Han et al. (2017) researches CE measures in an aluminium industrial park, the focus of the study is limited to measures within the industrial park, not including the aspect of reintroducing post-consumer aluminium scrap into the production again. However, the study by Niero and Olsen (2016) assesses a closed loop aluminium system including the element of post-consumer aluminium scrap. The study investigates the recycling of aluminium cans with the presence of alloying elements, and explores if a closed product loop, where used beverage cans are turned into new ones, should be promoted over a closed product category loop, where mixed aluminium packaging is used to manufacture cans. The results show that a closed product loop approach has a lower environmental impact, which corresponds with the hierarchy logic of the CE where it is more circular to reuse than to remanufacture or repurpose (Kirchherr, Reike, and Hekkert 2017). However, to attain this environmental enhancement, some adjustments have to be made to the product. This includes reducing the weight of the lid, creating methods that allow for separation of the parts of the product, and to investigate the potentials of a CLSC for aluminium cans from an economic, environmental and social perspective (Niero and Olsen 2016).

Although the results of the study by Niero and Olsen (2016) found the closed product loop as the best solution, it was only considered from an environmental point of view. However, when including the economic aspect, a closed product system becomes an unfeasible solution due to additional costs incurred to the recycler (Soo et al. 2019). These additional costs are a consequence of the alloying elements that is normally found in aluminium products, also referred to as impurities (Soo et al. 2019). When achieving a closed product loop system with aluminium, there cannot be any significant changes in the chemical composition between the input and output metal, meaning that the quality of the scrap streams has to be controlled (Paraskevas et al. 2015). Moreover, the presence of impurities in aluminium is not only a problem when achieving a closed product loop, but with any secondary production of aluminium. The quality of secondary aluminium is largely impacted by the purity level of the scrap sources, which limits the environmental and economic benefits of recycling aluminium (Soo et al. 2019).

Further in the study by Soo et al. (2019), it is discussed how the environmental gains are affected by the different types of alloying elements that are present in the aluminium, where some types of alloy produced to secondary have a lower environmental impact than other combinations. This way, by gaining an indication of the alloy composition, one can target types of secondary aluminium production to enhance the environmental performance of recycling. As a result of the additional costs imposed to the recycler and the sensitivity of the environmental impacts of recycling, Soo et al. (2019) describes how there is a trade-off between the economic and environmental aspects of recycling aluminium, where the environmental aspect of recycling is often secondary to the economic aspect due to the recycling market being largely driven by profits. However, implementation of policies, such as a primary aluminium production tax or setting targets on impurity levels in aluminium scrap, can have an effect on the supply and demand of aluminium scrap (Soo et al. 2019). The study by dos Santos Gonçalves et al. (2021) also discuss the need for public policies to encourage companies to implement circular initiatives, as they discovered that the major issue was the lack of circular practices in the aluminium SC.

While the latter discussion points are critical for an organisation to review in a transition towards a CE, an essential prerequisite is to map the flows of raw material and waste and measure the GHG impacts of recycling (Sevigné-Itoiz et al. 2014). Aluminium is mainly used in long-life applications such as buildings and transportation, with packaging as an exception, as revealed in previous paragraphs (Rombach 2013). Because of this, approximately 75 percent of the primary aluminium ever produced is still in stock (Norsk-Hydro 2021), accounting for about 700Mt (Rombach 2013), whereas in 2019, 20Mt of post-consumer aluminium scrap were collected for recycling (Das 2021). This reveals how low the stock levels of EOL aluminium scrap are, and how small the share of the aluminium demand can be covered by post-consumer aluminium scrap. Hence, Rombach (2013) explains how the recycling content of aluminium products is not low because of poor recycling, but because of the demand of long-life products. This means that the growth of demand and increasing lifespan determine the share of recycled materials in the global aluminium production (Rombach 2013), which may create difficulties of producing circular aluminium in current time.

Regarding the GHG consequences of producing primary aluminium versus recycled aluminium there are regional differences due to the energy input, in addition to market dynamics affecting it. The importance of market dynamics is highlighted when export flows are considered. If the amount of post-consumer aluminium scrap exportation increases, the GHG savings increase due to the global marginal primary aluminium production substitution, meaning higher benefits of recycling are achieved. This creates a dilemma as export flows go against the objectives of a CE, in addition to exporting aluminium is a loss of a key resource and the displacement of primary production can create a loss of local industry (Sevigné-Itoiz et al. 2014). Sevigné-Itoiz et al. (2014) concludes their research by explaining that to achieve a CE with a systematic change in the use and recovery of resources in the economy, diverse strategies for waste management, recycling, and primary industries should be proposed in order to adapt the sector to future material and quality flows, reduce reliance on imports, and reduce material loss through the export of scrap.

2.5 Chapter Summary

The purpose of the literature review is to support the argumentation to the answers to the research questions. First, it was necessary to explain the role of SCM in CE and the fundamentals of a CE to attain an understanding of the concept as well as the importance of modifying the SC to achieve circular objectives. Next, in order for manufacturers to transition to a CE, it is crucial to understand the strategies they must employ as well as the barriers they may meet along the way. Moreover, as this study is positioned within the aluminium industry, it is essential to obtain a fundamental understanding of the aluminium types, main processes, and recycling abilities. Lastly, the implementation of circular initiatives in the aluminium industry is discussed, whereas the lack of research proves the research gap this thesis is pursuing to fill. The next chapter presents the methodology employed in this thesis to answer the research questions.

3.0 Methodology

3.1 Chapter Introduction

This chapter presents the methodology applied in this thesis. The structure of the methodology is based on the research onion developed by Saunders, Lewis, and Thornhill (2019). The philosophy behind the research onion is that the researcher has to peel away the layers of the onion before arriving at the centre where the data collection and data analysis is positioned, in which each layer covers critical elements of the methodology. Figure 3.1 illustrates the layers of the research onion, which are systematically assessed for this study in the following sections, where the highlighted areas of the figure is what this study employs.

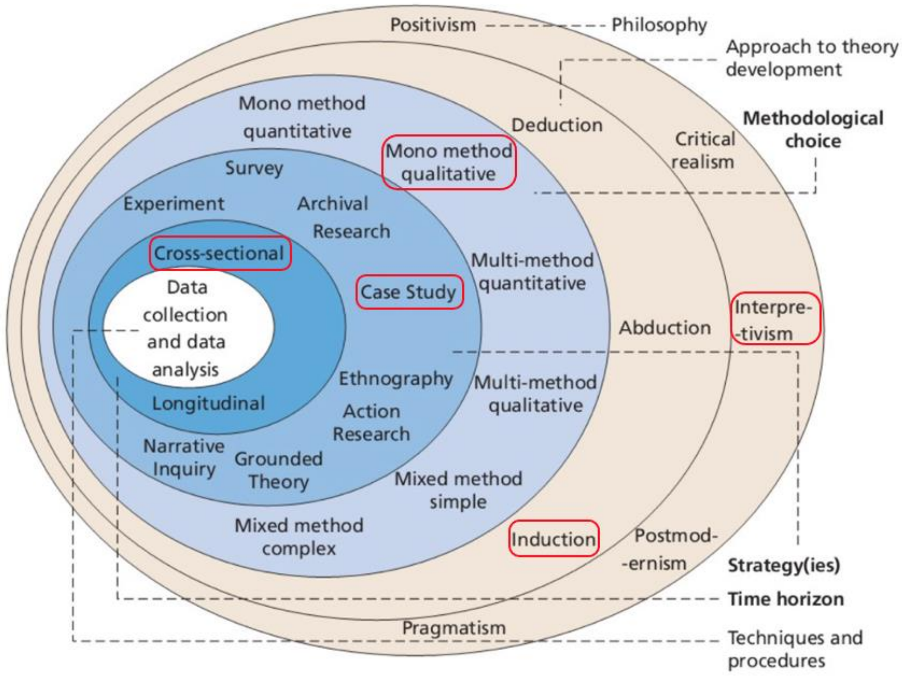

Figure 3.1: The Research Onion (Saunders, Lewis, and Thornhill 2019)

3.2 Research Philosophy

Important presumptions about one's perspective are included in the research philosophy chosen. This chapter's objective is to strengthen the comprehension of the thesis methodology when researching the specific field of study (Saunders, Lewis, and Thornhill 2009). It is crucial to be mindful of the philosophical commitments made through the adoption of a research strategy, as it has a pronounced influence on how the research is conducted and how one sees the subject of the investigation. The perspective on the relationship between knowledge and the method by which it is developed is considered to have the greatest impact on the philosophy chosen (Saunders, Lewis, and Thornhill 2009). The three major ways of thinking about research philosophy are ontology, epistemology, and axiology.

Ontology describes assumptions about the nature of reality, how scientists interpret how the world works, and dedication to specific viewpoints. In a way, ontology describes how people have different perceptions on how the possible outcomes may be, and how this affects the study itself and therefore also the research's outcome. By changing the ontological assumption, the focus can be shifted and give the researchers a new and different point of view on the research (Saunders, Lewis, and Thornhill 2009). The two aspects of ontology are objectivism and subjectivism, something researchers utilise to acquire scientific knowledge. The natural sciences' premises are incorporated into objectivism, which believes that the social world we study is independent of ourselves and other people (Saunders, Lewis, and Thornhill 2019). As a result, objectivism adopts realism from an ontological standpoint, which argues that social entities are similar to physical ones within the natural world in that they exist regardless of human conceptions, labels, or even awareness of them (Saunders, Lewis, and Thornhill 2019).

The second aspect is called subjectivism, which includes assumptions from the humanities and arts, claiming that social reality is created by social actors' views and behaviours as a result. Ontologically subjectivism embraces nominalism, which is a more extreme form, and social constructionism, which is on the contrary a less intense version (Saunders, Lewis, and Thornhill 2019). This study is subjectivist in that its conclusions are based on human thoughts and perceptions about knowledge on how the Norwegian aluminium industry can achieve a circular aluminium system, as well as the potentials and barriers. This means that it was relevant to get new and innovative thoughts from the people working within this business. In order to answer the research question regarding the environmental, economic and the social potential, the thesis depended on the employees' thoughts and opinions.

What constitutes valid scientific knowledge is the subject of epistemology. Researchers may have different perspectives on what is to be considered as important within the same field of study, therefore, the chosen data will determine how the research is going to be positioned.

Hence, there are two different positions in epistemology, each of which is based on the researcher's preferred methods of inquiry and sources of data (Saunders, Lewis, and Thornhill 2009). Positivism refers to the philosophical perspective of the natural scientist and involves using a visible social reality to create generalisations that resemble laws. It guarantees transparent information that is accurate. The positivist approach sets an emphasis on scientific empiricist methodology intended to produce unadulterated information and statistics free from human interpretation (Saunders, Lewis, and Thornhill 2019). One is likely to employ existing theory to construct hypotheses in order to create a research strategy to obtain these information or data, and then do further research on the subject (Saunders, Lewis, and Thornhill 2009). Realism, which is related to scientific inquiry, is the second viewpoint within epistemology, the principle of realism is that things exist independently of human perception. The last position is called interpretivism, where it is critical for the researcher to comprehend how individuals differ in the potential as social actors. An important part of interpretivism is that it highlights the distinction between studying people as opposed to things when conducting research (Saunders, Lewis, and Thornhill 2009).

This study subscribes to interpretivism as the research philosophy in the field of epistemology. How CE can be achieved in the aluminium industry was researched through interaction with the employees of the case companies, as well as collecting information and data from similar studies. As the main form of data collection was from interviews with the people working at the studied case companies, their thoughts, experiences, and interpretations were taken into consideration.

Axiology describes the function of morals and values. Additionally, it explains how a researcher must deal with their own and the values of the subjects of their investigation. All human behaviour is motivated by the value of people; thus, it is inevitable to incorporate personal values into the study process. As a result, it is crucial that these values are acknowledged and reflected upon. When a researcher chooses a subject to study, it suggests that the chosen topic is more important than the other possible ways to study the subject. Therefore, the thesis itself, including research problem and research questions, are a reflection of the researchers' values, as well as the method used for gathering information (Saunders, Lewis, and Thornhill 2019). By making the choice to write about CE in the aluminium industry it shows how highly we value these subjects and prioritise to link the logistics part of our education to a particularly important and highly relevant topic, CE. By choosing to collect data from interviews, it suggests that we place greater importance on direct communication with respondents over raw data.

As the research philosophy is outlined, the thesis research approach will be discussed in the next section.

3.3 Research Approach

The relationship between theory and research can be viewed through three different approaches: deductive, inductive or abductive theory (Bryman 2012; Saunders, Lewis, and Thornhill 2012). Deductive theory is an approach where the conclusion is drawn from a set of premises, with the conclusion being true when all premises are true (Saunders, Lewis, and Thornhill 2012). A hypothesis is derived by the researcher based on what is understood in a given field and theoretical considerations related to that field, which must then be verified by actual study. The researcher have to translate the hypothesis into operational terms, which means that they have to outline the specific method for gathering data in relation to the ideas that make up the hypothesis (Bryman 2012).

The opposite of a deductive approach is an inductive approach. With this approach, the theory is the outcome of the observations and findings of the study and not the basis before conducting the study, as with deductive theory (Bryman 2012). An inductive approach is usually concerned with the context in which the events take place, normally of a small sample of subjects. Another difference between the two theories is that a deductive approach has a tendency of conducting a rigid methodology, which can be limiting, whereas an inductive approach has more freedom that allows for alternative explanations (Saunders, Lewis, and Thornhill 2007). The last approach that can be conducted is an abductive stance. This approach begins with a “surprising fact” that is observed, which is then explained based on a set of potential premises that are considered sufficient or nearly efficient. If the set of premises are true, then the conclusion is true. With this approach, existing theory is incorporated where appropriate, existing theory is modified, or new theory is created (Saunders, Lewis, and Thornhill 2012).

For this study, an inductive approach is applied, as the purpose is to build theory and not test already existing theory. The data collection is from a small sample of subjects, gathering qualitative data. This approach is also consistent with the characteristics of an interpretive stance, as described in the previous section. Collecting data through interviews forms a theoretical basis with knowledge and perceptions from the participants, which is used to explore what role recycling of post-consumer aluminium scrap has in a transition towards a CE in the Norwegian aluminium industry. In combination with known concepts of a CE, the research questions have been answered, aiming to fill the identified research gap.

After defining the study's approach, the next step of the methodology is to determine the research design.

3.4 Methodological Choice & Purpose of Research Design

The terms qualitative and quantitative are widely used in research to differentiate both data collection techniques and data analysis procedures. Making the distinction between numerical and non-numerical data, which are quantitative and qualitative data, respectively, is an easy way to understand the differences between the two terms (Saunders, Lewis, and Thornhill 2012). However, distinguishing between qualitative and quantitative can become narrow. Therefore, a third method is to apply a mixed method, which is when elements from both qualitative and quantitative methods are used (Saunders, Lewis, and Thornhill 2019). As the data in this research was collected through interviews, the informants' perceptions and experiences were the form of data that was collected and analysed. Meaning that this is a qualitative study. As the study is about a topic with a lack of previous research, a qualitative study was evaluated a suitable approach to better understand the phenomenon through informants' perspectives. A qualitative approach also corresponds with the research philosophy and research approach for this study.

Having established the methodological choice of the study, the purpose of the research design must also be described. One can distinguish between four types of purposes: exploratory, descriptive, explanatory, and evaluative purpose (Saunders, Lewis, and Thornhill 2019). This research is characterised as an exploratory study as the purpose is to explore and gain insights into a topic of interest to clarify the understanding of a problem. According to Saunders, Lewis, and Thornhill (2019), this type of study can be conducted in three ways: through a search of the literature, interviewing experts in the subject, and conducting focus group interviews. This research involves a search of the literature in addition to interviewing experts within the subject. As this is a study with the aim of filling a research gap within a topic where there are few studies done, the research process has to be flexible and adaptable as new data and insights occur along the way that affect the direction of the study.

Next, we describe the research strategy that is applied in this research.

3.5 Research Strategy

A research strategy is a plan for the researcher on how to answer the research questions of the study. It can be viewed as the methodological link between the selected philosophy and method of collecting and analysing data (Saunders, Lewis, and Thornhill 2019). The purpose of selecting a research strategy is to achieve a level of coherence throughout the study in order to sufficiently answer the research questions. The choice of research strategy is influenced by three elements: the research questions and objectives of the study, their link to the philosophy, research approach, and purpose, and also the extent of existing knowledge, time spent, and access to potential participants and other sources of data (Saunders, Lewis, and Thornhill 2012). Further, Saunders, Lewis, and Thornhill (2019) list eight types of research strategies: experiment, survey, archival and documentary research, case study, ethnography, action research, grounded theory, and narrative theory, where some are more suitable for qualitative research and others are better for quantitative research.

3.5.1 Case Study

In the present study, case study is selected as the research strategy. Robson and McCartan (2016) describe case study as a method of doing research that entails using a variety of sources of data to conduct an empirical analysis of a specific contemporary phenomenon in its actual setting. Moreover, Yin (2018) recommends selecting case study research when the research questions are "how" and "why" questions, when one has little or no control over behavioural events, and if the focus of the study is a contemporary phenomenon. It has the similar quality as an exploratory research, in which the purpose is to gain a rich understanding of the context of the research and the processes involved, leading to empirical descriptions and development of theory (Saunders, Lewis, and Thornhill 2019). The phenomenon that is studied in this thesis is what role post-consumer aluminium scrap has in a transition to a CE in the Norwegian aluminium industry, and as the phenomenon has not been researched before, to our knowledge, it was optimal to select case study as the research strategy. This way, an in-depth understanding of the case can be established by collecting qualitative data through interviews with informants from the industry.

Furthermore, Yin (2018) distinguishes between single- and multiple-case studies. A single-case study is usually chosen for a critical or unique case, while a multiple-case study is chosen to find out whether the phenomenon occurs in several cases. Yin (2018) argues that multiple-case studies are preferable to single-case studies as the results can be considered more convincing than the results from a single case study. Within both single- and multiple-case studies, a holistic or embedded approach can be conducted, which refers to the unit of analysis. A holistic approach applies a single unit of analysis, whereas an embedded approach applies a multiple unit of analysis (Yin 2018). For this study, a multiple-case study approach has been employed. Due to the lack of research on this topic, a multiple-case study was evaluated as the best option in providing more inputs and different insights to the case to sufficiently answer the research questions. Ultimately, it made the findings more robust, thereby creating a more solid base for building theory. As for the unit of analysis, this study employs an embedded approach where the company itself is the unit of analysis.

3.5.2 Case Selection

When conducting a multiple-case study approach, the case selection is a critical process. According to Yin (2018), a multiple-case study has to follow a replication logic and not a sampling logic. Following the replication logic, each case must be carefully selected so that they either predict similar results (literal replication) or predict contrasting results but for predictable reasons (theoretical replication) (Yin 2009). The purpose is to attempt to achieve replications, meaning that the same method is applied in each case in order to compare the results (Steenhuis and de Bruijn 2006). Moreover, Yin (2009) describes the processes of the replication approach to multiple-case studies, where the first step in designing the study must consist of theory development, and thereafter the cases can be selected. The development of a rich theoretical framework is considered a key step in a multiple-case study. It needs to include under what conditions the phenomenon is likely to be found, in addition to when it is likely not to be found (Yin 2009). As the replication logic allows for analytic generalisation, previously developed theory can be used as a template to compare the empirical results of the study. Furthermore, if some of the empirical cases do not work as predicted, the theory must be modified (Yin 2009; Steenhuis and de Bruijn 2006). The number of cases included in the study depends on the certainty the researcher wants in their results. Yin (2009) exemplifies that one can settle for two to three replications if the uncertainty degree is low, but if there if a high degree of uncertainty, one should include five or more replications.

In the beginning of the case selection phase, it was presumed that the case selection would only include aluminium production companies. However, while creating the theoretical framework, it was discovered that if the data collection only came from the production-end of the aluminium industry, the results would possibly become too one-sided, which contradicts the philosophy of a CE that all actors in the SC must cooperate (MachArthur 2014). Therefore, it was decided that the case selection would include a more diverse set of actors that are present in different stages of the aluminium life cycle. This way, the given context was described from a wider point of view, as well as the answers to the research questions were more reliable and legitimate. There are two criteria in the case selection, and that is that the case companies must handle aluminium in some way, and they must be based in Norway. This led to a selection of six cases that represent different stages of aluminium's life cycle. Thus, the case selection can be divided into three groups that describe where in the aluminium life cycle the company belongs to and there are two companies in each group: as a producer of aluminium, a customer[1] of aluminium, or a recycler[2] of aluminium. Although an even higher number of cases would increase the certainty even more, it had to be limited to six cases due to limited time.

In the subsequent section, we introduce a case description of all of the case companies studied.

3.5.3 Case Description

Table 3.1 gives an overview of the case companies, including their key functions and some of their characteristics (i.e., the role aluminium plays in their company, the stage they are in a CE transition). Due to confidentiality purposes, some of the studied companies are anonymised and are therefore identified as Aluroco and Recalu. Company information is retrieved from the interviews in addition to their company websites.

[1] The aluminium customer is actually a supplier of goods. However, as the focus of this study is on aluminium recycling, they are viewed as customers that purchase and produce with aluminium.

[2] The aluminium recycler is a recycler that handles all types of waste. However, this study focus on their functions that recycle aluminium.

Table 3.1: Overview of Case Companies

Company	Key Function	Characteristics
Hydro Sunndal (Aluminium producer)	Primary aluminium production company	- Leading producer of primary aluminium. - Already pursuing circular initiatives and producing with post-consumer aluminium scrap.
Aluroco (Aluminium producer)	Aluminium roller company	- Subsidiary of company with high ambitions for a circular society. - In the start-phase of using post-consumer aluminium scrap.
Glamox Molde (Aluminium customer)	Supplier of professional lighting solutions	- Large company with well-established position in the market. - Not using post-consumer aluminium scrap in their products, but aware of the possibility.
Marine Aluminium Karmøy (Aluminium customer)	Supplier of access solutions	- Large consumer of aluminium. - Unfamiliar with post-consumer aluminium scrap.
RIR Molde (Recycler)	Local recycling and waste management company	- Mainly collector and sorter of household waste. - Collects a small share of aluminium.
Recalu (Recycler)	National environmental services provider	- Own metal division that collects aluminium. - On the pathway towards a circular society.

Hydro Sunndal

Hydro Sunndal, hereby referred to only as Hydro, is the largest and most modern production facility of primary aluminium in Europe, with a yearly production capacity of 400,000 tonnes of primary aluminium (Norsk-Hydro 2023c). It is a subsidiary of an international aluminium production company and is one of the five production facilities in Norway. The products they make are *extrusion ingots*, which are used in areas such as the automotive industry, building and construction, and electronics (Norsk-Hydro 2023a), and *primary foundry alloys*, which are found in automotive wheels and decorative applications where highest the corrosion resistance is needed (Norsk-Hydro 2023b), among others. Their customer base is mainly spread throughout Europe, with the largest volumes going to Poland, Spain, and Portugal, whereas their suppliers are found locally as well as abroad. Sustainability and circularity is important for Hydro, and the parent company has set a goal of becoming net-zero by 2050, where one of the paths to achieve this is to recycle post-consumer aluminium scrap with decarbonised operations (Norsk-Hydro 2022). In 2022, Hydro used 2,000 tonnes of post-consumer aluminium scrap in their production, and they have a goal of increasing this input to 4,000 tonnes in 2023. By 2026, their goal is to have an input of 90,000 tonnes of post-consumer aluminium scrap in their production. Other circular initiatives implemented by Hydro include the production of Reduxa 4.0, which is a low-carbon aluminium with a maximum of four CO_{2e} per kilo of aluminium, constituting a fourth of the global industry average (Norsk-Hydro 2020b), in addition to reducing the bi-products from their production that normally end up in a landfill.

Aluroco

Aluroco is a subsidiary of an international aluminium roller and recycler company and is one of the two production facilities in Norway. Unlike Hydro, Aluroco does not produce primary aluminium, but supplies it to produce aluminium rolls. First, the aluminium is melted, and depending on the order, alloying elements are added to meet requested quality. Further, the liquid metal is solidified and cast into a continuous belt, which is then rolled into a coil. Depending on what the customer demands, the thickness of the aluminium coil is adjusted, in addition to the strength of the aluminium being modified as well. Lastly, the coil is either cut into narrower belts, created into plates, or sold as they are in a large coil. Mainly, they produce to the construction industry and the automotive industry, as well as for electronical application, where their customers are mostly located in Europe, including some in Norway. According to the company website, the parent company is already incorporating circularity in their strategies and operations and have set a goal of using 40 percent recycled metal in their production by 2025. Aluroco recycles approximately 20 percent pre-consumer aluminium scrap from their own production but is only in the start-phase of recycling post-consumer aluminium scrap. However, they have ambitions to use as much as possible of post-consumer aluminium scrap in the future. Moreover, they show that they have a good understanding of the concept of CE and the need to pursue a transition towards it.

Glamox Molde

Glamox Molde, hereby referred to only as Glamox, is a company that develops, manufactures, and distributes professional lighting solutions. It is a subsidiary of global company, where Glamox is one of the eleven production facilities that are spread globally. Glamox supplies to onshore and offshore industries and manufactures standardised products as well as solutions that are customised to customer needs. They offer a wide range of lighting solutions, where aluminium can be found in different components of the light fixtures. The aluminium is purchased as thin plates and rolls and is cut and shaped according to product design. The two main components that are made of aluminium are the framing and reflectors of the light fixtures. The reflectors are only produced with primary aluminium as there are strict requirements to for the aluminium to be as "clean" as possible to maximise the reflection from the lighting, hence maximising energy output. However, the profiles contain pre-consumer aluminium scrap, as the same requirements to not apply for this component, but Glamox produces small quantities of this at their location. The parent company have implemented sustainable strategies to reduce their environmental impacts to become net zero by 2030, which includes circular design criteria for the development of new products (Glamox 2022). While Glamox does not incorporate post-consumer aluminium scrap in their products today, they are open for the possibility if the technical requirements can be met. However, they have implemented other circular initiatives in their business, including maximising the lifespan of their products and their energy output, proving that they are on the pathway to a CE.

Marine Aluminium Karmøy

Marine Aluminium Karmøy, hereby referred to only as Marine Aluminium, is a supplier of safe access solutions and outfitting for offshore, marine, wind and construction, and is one of the two locations based in Norway. They have traditionally been a supplier in the oil and gas industry and the maritime industry, and now as the energy industry is in a sustainable transition, they have become suppliers for the offshore wind industry as well. However, they also deliver products to onshore customers as well. Their main products include helidecks, handrail and walkway systems, and outfitting solutions, and they are responsible for the engineering, purchasing, manufacturing and installation of their products. As their name reveals, their products are made of aluminium. For the different types of products, they have different requirements regarding the qualities of the aluminium. Therefore, they have separate suppliers for the different aluminium qualities, with the alloying elements being the main difference. Their suppliers are mainly located in Europe, as well as their customers, including Norway. In 2022, they consumed 900 tonnes of aluminium profiles and 150 tonnes of aluminium plates, whereas 25 percent of the profiles were secondary aluminium with pre-consumer aluminium scrap. Their company website does not describe any strategies or goals towards a sustainable shift or circular transition, and they still are in the early stages of spreading awareness on this subject throughout the organisation. Although they use secondary aluminium with pre-consumer aluminium scrap and recycle own scrap from production, the cost aspect is still the main driver of these initiatives, and not circularity. However, they show a positive attitude towards a circular transition.

RIR Molde

RIR Molde, hereby referred to only as RIR, is a local recycling and waste management company that is a part of an organisation of three companies owned by an intermunicipal parent company. The organisation mainly collects household waste and runs eight recycling facilities. There is also a main facility where sorting processes have been conducted, including post-sorting as well, as the waste is primarily sorted by the customer before it is collected. RIR collects waste from all of their companies, in addition to other actors who purchase services from them. Waste from households is collected and transported to their facility, in addition to larger customers that deliver waste directly to them. After collecting and sorting the waste, materials such as cardboard and metal are sold to a local recycler, including aluminium. It is estimated that they receive 30-35 tonnes of post-consumer aluminium scrap yearly, which is a small proportion compared to their total collection of waste. Their company website does not describe any specific strategies or goals to achieve a CE, only including short statement about it: "*The idea of a circular economy must underlie all activities in the company*" (RIR 2023). However, RIR implemented the process of post-sorting as an initiative to reduce waste that is combusted in incinerators in order to maximise the recycling potential of the waste they collect. On top of their core activities aligning with the principles of a CE itself, the example of post-sorting is an additional measure to further enhance the circularity.

Recalu

Recalu is a national environmental service provider that consists of several divisions, among them a metal division, a paper and cardboard division, and a plastic division. The metal that is collected is a mix of different types, where they sort into magnetic and non-magnetic metals, separating the aluminium. Thereafter, the aluminium scrap is either fragmented in a large press, or if it is too thick it is cut into smaller pieces. Then the scrap is sold directly to aluminium production facilities, unless the scrap is not approved for production yet, in which case it is sold to treatment facilities that have more advanced equipment than what Recalu has. Their customers are mainly located in Europe, including Norway, but some are in Asia as well. However, they cannot sell to just anyone as they have a compliance program where the customers have to be approved before sold to. Yearly, Recalu collects approximately

20,000 tonnes of aluminium, where over 90 percent of it is recycled. On the company website, it is described how sustainability is a priority for Recalu, and how they work every day towards a CE. However, they have not set any specific goals yet, besides to continuously reduce waste and their emissions.

In the subsequent section, we introduce the time horizon of the thesis.

3.6 Time Horizons

When designing a research project, it is important to identify the time horizon appropriate for the thesis. Depending on the research question, the time horizon will be either cross-sectional studies or longitudinal studies. Cross-sectional studies examine a specific phenomenon at a certain period of time. The majority of research projects completed for academic courses are most likely time-constrained, therefore the study will presumably only be able to look at the subject of matter for a particular time (Saunders, Lewis, and Thornhill 2019). Cross-sectional studies may be attempting to describe the prevalence of a phenomenon or to clarify how various organisational aspects relate to one another. Using a qualitative or mixed methods are both widely used strategies within the time horizon, and several studies rely on collecting data from interviews carried out over a shorter period. When a research study changes and progresses, it is called a longitudinal study. By utilising this type of time horizon, it might be possible to partially manage some of the variables being researched. Despite given timeframe limits, a longitudinal component can be introduced to a study, for instance by reanalysing published data accumulated over time. Finding applicable surveys is the first step in obtaining useful secondary data (Saunders, Lewis, and Thornhill 2019).

The time horizon for this research project is cross-sectional due to the brief period that the master thesis spans. This explains why the interviews were conducted over a short period, and moreover there is limited access to existing secondary data on the subject. Data collection and analysis is covered in the next section.

Next, we describe the data collection and analysis of this research.

3.7 Data Collection and Analysis

The data collected to answer the research questions can be divided into two categories: primary and secondary data. Primary data is the collection of new data, while secondary data is data that already have been collected for another purpose, but is reanalysed to meet the objectives of a new research (Saunders, Lewis, and Thornhill 2007). Kumar (2011) explain how the method of collecting primary data depend on the purpose of the study, the resources available and the skills of the researcher, and distinguish between three types of collecting primary data: Through observation, interview, or questionnaire.

For this research, the primary data was collected through interviews as is allows for more freedom in terms of the format and content of the questions, the wording, and the order they are asked (Kumar 2011). In terms of secondary data, this was collected through a literature review for this research, or retrieved from documents as Kumar (2011) describes. The documents that are collected and analysed in this thesis consist mainly of scientific papers, books, official websites, and reports. These data collection techniques are described next.

3.7.1 Interviews

According to Yin (2018), interviews are one of the most important sources of evidence in a case study, as they provide explanations as well as personal views, in addition to enabling direct focus on the case study topic. An interview is defined as a conversation between two or more people, where the purpose is to gather valid and reliable data that are relevant to the research questions and objectives of your study (Saunders, Lewis, and Thornhill 2007). Conducting an interview can be done in a flexible or inflexible manner depending on whether the questions are formulated beforehand or if they are thought up consecutively as the topic is investigated (Kumar 2011). The level of flexibility in the interviews decides if it is categorised as a structured, semi-structured or unstructured interview (Saunders, Lewis, and Thornhill 2012). Furthermore, Saunders, Lewis, and Thornhill (2012) explain how a semi-structured or unstructured interview is suitable to collect qualitative data in an exploratory study with an inductive approach to collect contextual material for the study, whereas a structured interview is appropriate for a descriptive study to identify general patterns.

For this research, a semi-structured interview was conducted with some influence of a structured interview. An interview guide comprising a short description of the study and a set of main questions were given to the interview participants beforehand so they could prepare themselves to answer the questions in the best possible manner (see Appendix 1 to 4). This covered the fundamental topics that the participants were questioned about in the interview, while additional questions that came to mind were added in the interview process. This was evaluated as the best approach as this study is about a topic with a lack of research, making it essential to conduct a thorough data collection process to be able to answer the research questions sufficiently.

The interviews were conducted virtually on the communication platform Microsoft Teams, between the two researchers and either one or two participants from the case company. By conducting the interviews online, it opened up for a wider selection of case companies as the location would not become a restriction. The informants were informed in advance that the interview would take about one hour, and the scheduling of the interview was planned according to their schedule. Before the interview, the participants were also asked for permission to record the meeting, as this would provide a more accurate interpretation than taking own notes (Yin 2018). This also contributed to staying present in the interview rather than focusing on writing down the participant's answers. Further communication through E-mail was also conducted with follow-up questions from the interview. In total, seven interviews were conducted with the six companies (see Table 3.2).

Table 3.2: Overview of Interviews

Case company	Interviewees	Date	Interview duration
Hydro	Finance- and purchase manager.	22.02.2023	70 minutes
Aluroco	Production Manager.	28.02.2023	45 minutes
Glamox	HES-/Quality Manager. Responsible for sustainable products & production.	01.03.2023	65 minutes
	Technical Director and Sustainability Team lead.	11.04.2023	30 minutes
Marine Aluminium	Head of HSEQ & Lean Processes.	03.03.2023	75 minutes
RIR	Operations Manager	03.03.2023	55 minutes
Recalu	CCO/Marketing manager	22.02.2023	45 minutes
		21.04.2023	30 minutes

3.7.2 Literature Review

The main goal of conducting a literature review, according to Bryman (2012), is to know what is already known about the topic being researched. A literature review can be described as a method of gathering and summarising already existing research, where the purpose is to create a foundation for advancing knowledge and facilitating theory development (Snyder 2019). When conducting a literature review it demands one to make reasoned judgements about the value of the different literature and to organise the ideas and finding that have value for the review, which is both difficult and time-consuming (Saunders, Lewis, and Thornhill 2012). For the present study, a preliminary search was conducted first to generate some research ideas, thereafter, a critical literature review was carried out to obtain up-to-date knowledge about CE and its position in the aluminium industry. This revealed a research gap, which established what the research problem and questions would be composed of. Furthermore, as this is an inductive approach study, the literature review also created the foundation for the discussion of the thesis, where the findings from the interviews were be linked with the theoretical findings (Saunders, Lewis, and Thornhill 2012).

As mentioned, the secondary data that was collected for this thesis consisted mainly of scientific papers, books, official websites, and reports. These were accessed through search monitors such as “Google Scholar”, “Science Direct” and “Research Gate”. The literature search can be divided into three parts, as the literature review is structured this way. The first part of the literature search consisted of keywords as “CE”, “CSCM”, “CE strategies” and “CE barriers”, as the aim of the first section was to introduce the concept of CE and its position in the manufacturing industry. The subsequent section consisted of search words as “aluminium industry”, “aluminium production” and “aluminium recycling”, to establish fundamental knowledge about aluminium manufacturing. The last part of the literature search consisted of search words as “circular aluminium”, “recycling post-consumer aluminium scrap” and “CE in the aluminium industry”. However, the results of this literature search were limited, hence the research gap this thesis is aiming to fill. Figure 3.2 illustrates how the literature review was conducted in this study.

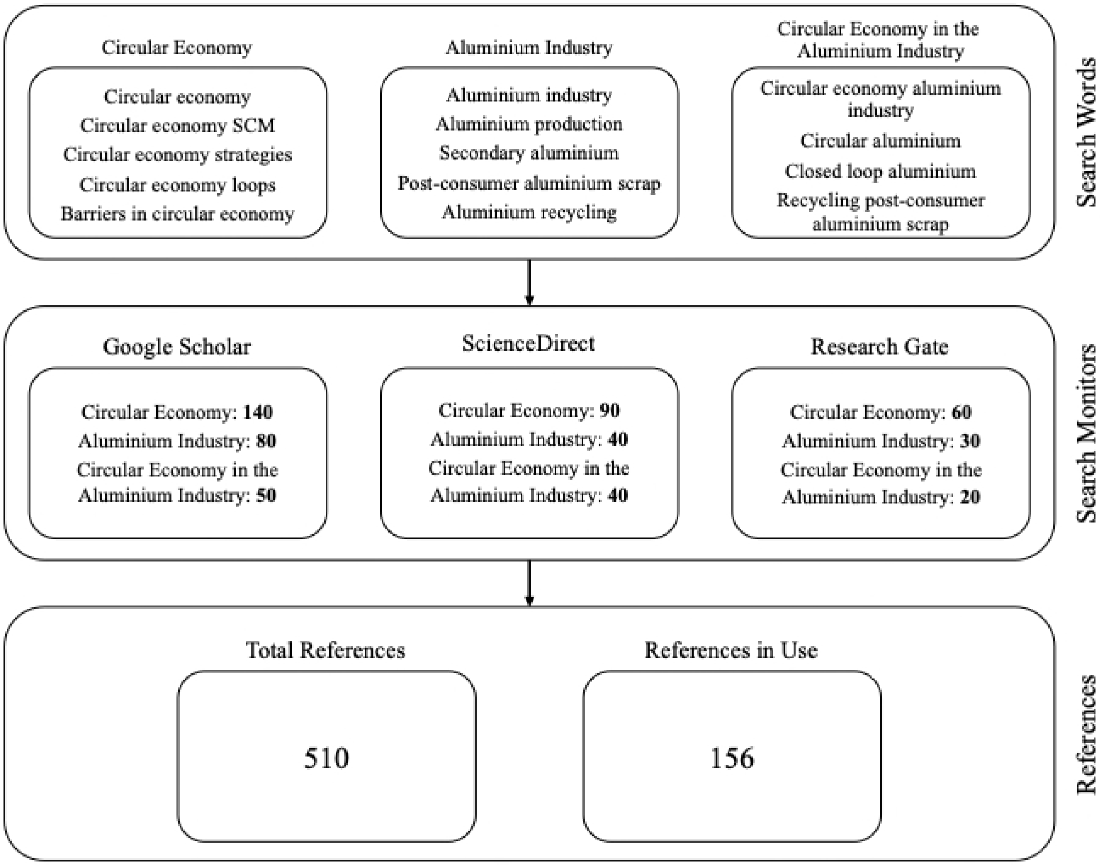

Figure 3.2: Overview of Literature Review

3.7.3 Data Analysis

One of the main difficulties of qualitative research is that it generates a large and comprehensive set of data that the researcher must find an analytic path through, which is not an easy matter (Bryman 2012). Unlike quantitative data where one analyses numeric data, qualitative data needs to be classified into categories and analysed through the use of conceptualisation (Saunders, Lewis, and Thornhill 2007). Furthermore, Saunders, Lewis, and Thornhill (2012) explain how qualitative data analysis can be approached from a deductive or inductive perspective, similarly as the research approach. When conducting a deductive approach, one uses existing theory in the research process and in the data analysis. On the contrary, if conducting an inductive approach, one builds their own theory based on the gathered data. In this exploratory study, an inductive approach is conducted as the data is analysed as it is collected (Saunders, Lewis, and Thornhill 2012).

Qualitative data can be found in many different forms, such as documents and emails, which are in written form, or audio- and video-recordings, which are non-written. When conducting an interview, it is recommended to audio-record and transcribe the recording afterwards (Saunders, Lewis, and Thornhill 2012). As the interviews for this research was conducted on Microsoft Teams, it was easy access to video-recording and automatic transcription, which saved a lot of time. By saving time on transcribing, it allowed to focus more on data cleaning, which is the correction of transcription errors (Saunders, Lewis, and Thornhill 2012). By recording and transcribing, it also ensured reliable data which simplified the analysis process. Furthermore, as the informants from the case companies were all Norwegian speaking, the interviews were conducted in Norwegian. This way, the informants could feel comfortable speaking in their native tongue, ultimately benefitting the data collection.

Saunders, Lewis, and Thornhill (2012) explain how there is no standardised approach to analyse qualitative data, but that the approach will mainly depend on whether the research is deductive or inductive. When selecting a data analysis approach, one must be observant that the approach is consistent with the research philosophy, research strategy and nature of the data collection method, in order to justify the selected approach. Some approaches to analysing qualitative data may be highly structured, whereas some adopt a lower level of structure. Further, some approaches to analysing qualitative data may be highly formalised and procedural, while some rely more on the interpretation of the researcher. These ways of differentiating qualitative analysis procedures, paired with the distinction between a deductive or inductive approach, form the criteria to achieve an approach that is consistent with the rest of the methodology (Saunders, Lewis, and Thornhill 2012). Figure 3.3 illustrates these dimensions, where this research identifies with the left side of the figure.

Figure 3.3: Dimensions of Qualitative Analysis (Saunders, Lewis, and Thornhill 2007)

The approaches that are specific to an inductive approach are: data display and analysis, template analysis, analytic induction, grounded theory, discourse analysis, and narrative analysis (Saunders, Lewis, and Thornhill 2007). The approach for this study is a data display and analysis, which is based on the work of Miles and Huberman (1994). This approach consists of three processes: data reduction, data display, and drawing and verifying conclusions. The first process is about summarising and simplifying the data collected and/or focusing on selected parts of the data (Saunders, Lewis, and Thornhill 2007). As the interview for this research had been transcribed, it was simple to select out the most important answers for our thesis. Thereafter, the data that was evaluated as relevant was put in a table in order to categorise and systemise the answers according to the research questions, which included key points and direct quotes. This way, it was easier to analyse and compare the answers from the informants, as well as drawing conclusions and verifying them.

To ensure reliable data from this method, the quality criteria is important to revise, which is described in the subsequent section.

3.8 Quality Criteria in Qualitative Research

There are several philosophical and methodological stances on whether the results of qualitative research can be recognised. Qualitative techniques continue to be important in research processes, despite the widely held opinion that quantitative research is better to qualitative research in terms of the credibility of its findings (Steinke 2004). The subjectively formed ideas and theories as a result of qualitative method, need to be quality verified because the findings of qualitative studies tend to depend only on a limited amount of cases, frequently following an unorganised process (Steinke 2004). Despite their differences, qualitative and quantitative methods can be considered to have equivalent methodological worth when applied correctly (Steinke 2004).

Regardless of whether a qualitative or quantitative method is applied, good research is characterised by documentation that is reliable, relevant to real-world situations, constant, and impartial (Halldórsson and Aastrup 2003). Although qualitative and quantitative research share similar requirements for solid data, these quality factors are conceptualised and applied differently in each case. The classical quality criteria for quantitative data are divided into measures of objectivity, which is the separation of study findings from the researcher's persona, reliability, which is the stability, accuracy, and consistency of the measurement circumstances, and lastly validity, which deals with the query regarding if what is being measured is what is supposed to be measured (Mayring 2014). The necessity for developing an inter-subjective comprehensibility of the method of study, on the basis of which results can be evaluated, is suitable in qualitative research (Steinke 2004). However, as this field of subject does not have numerous research findings, the evaluation of the integrity of research literature rather than research result is significantly important in this thesis (Snyder 2019).

The present study is based on qualitative data, and the procedures on how to achieve quality in this type of data was by checking its credibility, transferability, dependability, and confirmability (Halldórsson and Aastrup 2003).

3.8.1 Credibility

Credibility is the degree of confidence in the veracity of study findings. Credibility determines if the study findings are a valid interpretation of the participants' original perspectives and represent trustworthy information derived from the participants' original information. It concerns how reliable and credible the study's results are to other people (Korstjens and Moser 2018). In order to ensure that the depictions of the socially created reality of the research participants really reflect what the individuals intended there are several procedures that can be utilised, by for example using multiple data sources, methods, researchers and theories (Frambach, van der Vleuten, and Durning 2013). However, there is a recognised method that is characterised by achieving credibility by following four strategies, which are prolonged engagement, triangulation, persistent observation and member check (Korstjens and Moser 2018). When researchers design their study, they will be able to establish which of the four strategies they will use to achieve credibility, as it is not possible to use them all together in all contexts (Korstjens and Moser 2018). This thesis has used the strategy of triangulation in order to achieve credibility.

Through the use of methodological, investigative, and data-driven approaches, triangulation seeks to improve the qualitative research process. The methodological triangulation is when the researchers use several data collection methods to process their data. This research involves a search of the literature in addition to interviewing experts within the subject, which makes it achieve this part of the triangulation. The investigator triangulation takes into account the importance of having several researchers on the same study, as the data can be analysed by two or more parties, both separately and together, which will lead to the data being interpreted in the most appropriate way. Due to the fact that this thesis was produced by two students, it has undergone much reflection and discussion. Having a supportive supervisor who has provided advice and comments to ensure that the assignment has been comprehended correctly has also been beneficial. Lastly, data triangulation is the usage of numerous data sets that are discovered throughout the analytical process is known as data triangulation (Korstjens and Moser 2018). This thesis mostly depends on in-depth interviews with the collaborative companies, and the requirements for the approaches within triangulation is therefore not met.

3.8.2 Transferability

Concerning the element of application is transferability, where the degree to which the results may be used or transferred to other contexts is viewed (Frambach, van der Vleuten, and Durning 2013). To be able to assess the transferability of the study's findings, it is important that the researcher provides thorough and explanatory information on who the study involves and what processes it has undergone to arrive at these results. For the purpose of providing the readers with sufficient background information about the cooperative enterprises, this thesis includes case descriptions of each of them. In addition, the transcripts from the interviews and the interview guide are attached so that the readers can see how the information was obtained and which individuals it includes.

The reader's opinion of how applicable the results are to their own context is something known as the transferability judgement. Therefore, transferability is not unilateral due to each individual's perception of the research conduction and processes and the end result (Korstjens and Moser 2018). The results of a survey must thus be useful to others by giving adequate context and background information if they are to be transferrable (Frambach, van der Vleuten, and Durning 2013). By providing fundamental information, reasons for the importance of the task and how it was able to contribute to build theory, this thesis will be able to contribute to a more positive transferability judgment.

If research is very specific and its content cannot easily be transferred, it is possible through developing generalisable theoretical understandings of individuals and systems that may be used outside of their original context is the goal for a researcher (Amin et al. 2020). Therefore, the choice of the thesis was important for the readers to understand, in order for them to relate to the content more easily. This thesis deals with research questions that may appear specific but actually address a number of more general issues that can apply to a much wider range of individual's needs. Because it demonstrates how the research questions and problem spread from this, it was necessary to argue the need for filling the research gap on this topic. This information was important for the reader's comprehension of the thesis transferability (Korstjens and Moser 2018).

3.8.3 Dependability

Consistency is part of what makes anything dependable, and it is related to the consistency of data throughout time (Korstjens and Moser 2018; Halldórsson and Aastrup 2003). Dependability measures how well the results are compatible with the context in which they were produced (Frambach, van der Vleuten, and Durning 2013). This thesis has been developed over a longer period of time, as the research process started by writing a proposal, which then was assessed by the supervisor who gave feedback and further recommendations. This provided a good basis for which topics the thesis will cover and made it able to source out the literature and find the right collaborative companies to best support the thesis.

It's critical to continue gathering data and information until no new themes, objectives, or contents emerge in order to produce research that is dependable. When the same or similar tools are used to measure the same phenomena again in addition to describing the reasoning behind the choices made regarding processes and methods during a dependability audit, dependability is achieved (Halldórsson and Aastrup 2003). The connections between the organisations were identified during the analysis of the in-depth interviews, as they were compared, and the information was sorted. We contacted the interviewees again if there was a topic they raised that interested us further, or if there was something that was unclear. This good contact with the companies helped the task to cover all the areas it should have dealt with until no more topics arose.

In order to be prepared for potential changes to occur, it is crucial for the researcher to be flexible and open-minded regarding the research (Frambach, van der Vleuten, and Durning 2013). The thesis started without hypotheses about what the outcome and conclusion would be. Thus, the task has changed in line with new information that has been obtained, because as researchers one can learn even more about the field written about along the way. Also due to the fact that it was prepared for methodology changes, adjustments in hypotheses, or changes in conceptions. In order for the research problem and questions to remain at the forefront, it was also important to adapt them continuously to the information provided. Changes in the research design are signs of a mature and meaningful study because naturalistic inquiry, as opposed to a priori inquiry, relies on an emerging research strategy

(Halldórsson and Aastrup 2003). Early interviewing allowed for the discovery of further objectives and information which led to both extend and advance the thesis content. As the information and data that have been brought in was analysed, it then was carefully assessed whether it was necessary to include additional information.

3.8.4 Confirmability

Confirmability is concerned with the idea of impartiality (Korstjens and Moser 2018). Confirmability measures how much the results are supported by the subjects of the research and circumstances rather than the researcher's biases (Frambach, van der Vleuten, and Durning 2013). It is to the thesis's advantage that it has been written by two students. By having multiple people investigating, it gives the opportunity for better reflections and discussions regarding the research, and it will be more difficult to create specific or fixed opinions on the thesis processes.

The inter-subjectivity of the data must be protected, and the interpretation has to be supported by the evidence rather than your personal preferences and worldview. Here, the emphasis is on the interpretation process integrated into the analysis process (Korstjens and Moser 2018). All information gathering was in the form of in-depth interviews, which means that the data gathered was already influenced by the company and/or the employees. Good communication with the interviewees, and the advantage that two companies of those involved in the production, consumption and recycling of aluminium gave the task better confirmability by being able to compare the information given from the companies in the same sector.

By discussing the research process with others and reflecting on different point of views, it helped the researchers to keep open-minded on the study. This is often accomplished through a confirmability audit, which contains the procedure being employed and enables an outside actor to affirm the study's findings (Halldórsson and Aastrup 2003). It was crucial that the interviewees observed the information that they had provided, both to give them the chance to change it if something was thought to be incorrect and to give them the chance to send it to a department within the company in order to remove sensitive information that could harm their competition. The supervisor read and confirmed the thesis content by receiving multiple drafts throughout the semester.

3.9 Chapter Summary

The goal of the methodology is to present the approach conducted for this thesis to assure trustworthy and legitimate findings. The “Research Onion” concept created by Saunders, Lewis, and Thornhill (2012) was utilised, where each layer has been described and the suitable solutions for this thesis are presented. First, we address the research philosophy where it was determined that the study will use interpretivism. Thereafter, the reasons for an inductive approach, qualitative design and exploratory study were given. Next, a multiple-case study is selected as the research strategy, and interviews are identified as the primary data, followed by a detailed representation of the case companies. The final topic we covered was the quality criteria that were used for this thesis to ensure credibility, transferability, dependability, and confirmability. The next chapter will present the thesis findings.

4.0 Findings

4.1 Chapter Introduction

This chapter presents the findings of the study. Following the study's research questions, this chapter is divided into three parts. The first section presents the findings for the first research question about the potentials of recycling post-consumer aluminium scrap within the economic, environmental, and social dimension. The second section addresses the second research question about how to achieve a circular aluminium system with the four strategies of transitioning to a CE. The last section presents the findings for the third research question about the barriers of recycling post-consumer aluminium scrap to achieve a CE.

4.2 Potentials of Recycling Post-consumer Aluminium Scrap

This section presents the findings related to the first research question: "*What is the environmental, economic, and social potential of recycling post-consumer aluminium scrap?*". It is structured according to the three dimensions of CE, where the case companies' perceived potentials of recycling post-consumer aluminium scrap are presented. Lastly, a section summary summarises the findings and addresses them in relation to the research question.

4.2.1 Environmental Dimension

All of the case companies agree that there is an obvious environmental benefit of recycling post-consumer aluminium scrap. Hydro explained how they are able to reduce their energy input when producing with post-consumer aluminium scrap, and that the CO_2 reduction is the most important environmental benefit of it.

> *"The use of post-consumer scrap is a prerequisite to be able to produce carbon-neutral… It only requires five percent remelting versus primary production."* Hydro

Marine Aluminium also highlights this and explained how post-consumer aluminium scrap contributes to reducing the environmental footprint of their products when considering scope

1, 2, and 3[3], which is a way of categorising the different kinds of carbon emissions they create in their own operations, and in their wider value chain.

> *"We work closely with our aluminium supplier to map the CO_2 footprint. Even if we do not produce aluminium ourselves, we have to include its emissions as a scope 3."* Marine Aluminium

This is because the primary production of aluminium is the largest contributor to the environmental effects, which Aluroco also described.

> *"So, it is clear that if you look at the CO_2 equivalents on our products, there is a large environmental dimension when using scrap. But for our internal processes, it does not have an environmental effect… It's the source of aluminium that have the largest effect on how large the CO_2 emissions are."* Aluroco

However, these perceptions only consider the emissions from the upstream SC, excluding the environmental impacts from the recycling process. Discussing the recycling processes, RIR explained how the quality of the sorting affects the environmental potential. This is because not sorted aluminium scrap ends in combustion processes, reducing its volumes and quality.

> *"One of the reasons we do post-sorting is to reduce non-magnetic metals that end in combustion processes. When collecting aluminium from combustion remains, the aluminium scrap volume is reduced with 20 percent. The quality is also reduced compared to before the combustion."* RIR

Recalu also described how high impurity levels is more difficult for them to handle, hence potentially reducing the environmental potentials.

> *"There are some special alloying elements we receive high levels of, which can be more difficult to handle, but we just have to find the correct foundry or smelter."* Recalu

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[3] Scope 1 includes direct emission from the company, scope 2 covers indirect emissions from the company, and scope 3 includes all indirect emissions related to the company that occur in the value chain (National-Grid 2023).

Furthermore, the aluminium producers described what role their energy input has. Norwegian aluminium already has a competitive advantage in terms of environmental impact because the production is powered by renewable energy. As the energy source also plays a large role in the CO_2 footprint of aluminium, it creates a dilemma for primary aluminium producers, as the market of post-consumer aluminium scrap is still premature.

"What is the customer looking for? The share of post-consumer aluminium scrap in the aluminium or the CO_2 emissions from it?" Hydro

Glamox experiences a similar dilemma as Hydro, as they have to evaluate what circular initiatives to prioritise when considering the long-term CO_2 emissions. This is a particular challenge for Glamox as they produce products that consume energy in the use phase in addition to the production phase.

"The challenge of this is that the positive of one principle can become negative for another. For example, if we decide on component A instead of component B, it may be positive for the energy efficiency but bad for the material efficiency, or vice versa. We have to continuously evaluate this and always look at the facts." Glamox

Glamox explained how post-consumer aluminium scrap increases their material efficiency but reduces their energy efficiency as it does not perform well enough in the use process because of the impurities reducing its quality, hence reducing the environmental potential. Marine Aluminium described this as well, as they are dependent on the quality of the products to meet the specifications in order for them to achieve a long lifespan.

"It is the quality that matters. We have to guarantee that our products achieve the required characteristics." Marine Aluminium

Although the case companies described great environmental potentials of recycling post-consumer aluminium scrap, several of the companies give the impression of how the environmental gains are secondary to the economic aspect.

"The environment factor is a driver, but the cost picture will always be the main driver for us." Marine Aluminium

4.2.2 Economic Dimension

As revealed, the case companies suggest a focus on the economic potentials of recycling post-consumer aluminium scrap. The aluminium producers discuss how the market is not mature enough yet, which largely affects the economic aspect of recycling post-consumer aluminium scrap. However, Hydro believes they can reduce their production costs by producing with post-consumer aluminium scrap, in addition to increasing the price they sell it for, which also Aluroco expects.

> *"Now that there is little access to post-consumer aluminium scrap on the market, it's possible to get a higher price for products containing it."* Aluroco

The customers of aluminium also explained how they are controlled by the market, whereas Glamox described how they are dependent on a demand for post-consumer aluminium scrap in their products for it to be profitable for them. However, they already experience an increased demand for sustainable products, indicating that they can achieve the same with post-consumer aluminium scrap, which Marine Aluminium describes as well.

> *"The customer most often selects the cheapest option, but now, as it is a worldwide transition that is currently happening, customers are willing to pay more for sustainable products, in which recycled aluminium is a part of."* Marine Aluminium

While it is obvious that the case companies are dependent on a functional market for it to be profitable for them to implement post-consumer aluminium scrap, what they imply is that it is still too soon for them to obtain the economic potentials of this circular measure.

Moreover, the recyclers explained how the selling price of aluminium scrap is determined by the global aluminium price. Where Recalu also explain how the price is determined by how clean they can sell their scrap as well.

> *"… For example, we can sell clean aluminium scrap for a higher percentage of LME[4], and less clean scrap for a lower percentage of LME."* Recalu

[4] LME stands for «London Metal Exchange" and is the "trading and price-formation venue of choice for industrial metals globally" (LME 2023).

Recalu also described how their cost is affected by the level of impurities in the aluminium scrap, in which there are higher costs if there is a high content of alloying elements. Whereas Aluroco explained the impurities as a potential cost saving, as it can reduce their costs related to purchase separate alloy metal. However, they described potential cost additions of it as well, in which the state of the aluminium is a variable in the cost of post-consumer aluminium scrap, explaining how the location of the source and how well it is sorted affects the purchase price. They also described how the impurities affect the economic potential.

> *"It is more difficult to have control of what you purchase with scrap, as a mix of different alloys can be more difficult to handle… At the same time, an advantage is that the alloy is already in the aluminium, which may reduce our need to purchase it ourselves."* Aluroco

Furthermore, Hydro explains how the additional costs cannot be considered isolated, but the profit margin must be evaluated.

> *"But the question is what it will cost us internally compared to the premium we get. Why I'm describing it as an immature market is because I believe customers will be willing to pay a higher premium for green products, and then we don't have to look at the costs alone but the margin."* Hydro

Hydro is currently not experiencing any additional costs of producing with post-consumer aluminium scrap, as the small volumes allow them to implement it in their primary production. The parent company is planning to establish a hub with facilities for processing post-consumer aluminium scrap, allowing them to outsource the processing of the scrap and avoid large investment costs in own facilities with future scrap growth.

> *"With large investments in such facilities, there can't be many of them. One is dependent on having facilities that can achieve economies of scale."* Hydro

The aluminium customers also experience an increased cost of recycled post-consumer aluminium scrap, corresponding with the additional premium that Hydro described.

> *"It's more expensive with recycled aluminium. It costs approximately 2.5 percent more."* Glamox

Lastly, Aluroco described that the European authorities can influence the economic dimension by implementing taxes and policies.

> *"I believe it will depend on what the European authorities will decide on in the future, what policies and taxes they implement on different products... If they for example add CO_2-taxes on product level, it might be an economic incentive for the aluminium industry to push usage of post-consumer scrap."* Aluroco

Implying that it is cheaper to produce with post-consumer aluminium scrap, encouraging non-sustainable businesses to implement circular initiatives.

4.2.3 Social Dimension

The social dimension is where the case companies had the least input. However, two main social potentials of recycling post-consumer aluminium scrap were revealed. The first potential that was discussed by all three case company categories, was how the reduction of waste will benefit the society at large.

> *"I think that the whole world benefits of recycling metal. There are some places in the world where you see these huge mountains of rubbish that flows into rivers, and I think everyone wishes it wasn't really like that."* Aluroco

Glamox also explained with similar examples, describing how large amounts of waste cause problematic social consequences. Furthermore, Aluroco also described how there is not an unlimited reservoir of raw materials, and we eventually can run out of it, which Recalu also highlights.

> *"In 10 to 20 years when there is more post-consumer aluminium scrap in the market, it will have an effect of reducing the raw material extrusion."* Recalu

As the raw material access is limited, this increases the value of aluminium scrap itself. Therefore, it is beneficial to keep the scrap within our society, as the scrap attains great value due to its limited volumes and great qualities, which RIR explained as a social potential.

> *"It's beneficial with local recycling and local exploitation of resources."* RIR

Hydro described similar social potential, explaining how keeping the post-consumer aluminium scrap within the society is beneficial.

"The social benefit is that the scrap is kept within the society with the benefits of it." Hydro

4.2.4 Section Summary

This section has presented the results to the first research question: "*What is the environmental, economic, and social potential of recycling post-consumer aluminium scrap?*". The case companies described several potentials of recycling post-consumer aluminium scrap, where the overall impression is that they have positive perceptions of this CE measure. However, it becomes evident how the dimensions are not equally emphasised, where a following ranking is revealed, from most to least important: First the economic dimension, then the environmental dimension, and lastly the social dimension. The case companies also give the impression of how the potentials are not beneficial enough yet, indicating how the described potentials are small-scale now, but potentially bigger in the future when the market is more mature. Moreover, the findings did not reveal any specific distinctions between the case company categories. Table 4.1 summarises the potentials of recycling post-consumer aluminium scrap towards a CE.

Table 4.1: Summary of Potentials of Recycling Post-consumer Aluminium Scrap

	Environmental	**Economic**	**Social**
Hydro	CO_2 reduction Competitive advantage dilemma	Increased sales price Production cost reduction	Scrap value is kept within society
Aluroco	CO_2 reduction	Increased sales price Higher handling costs Government affects potentials	Waste reduction Reduced pressure on raw material extraction
Glamox	Emission reduction Decreased energy efficiency	Increased sales price Higher material cost	Waste reduction
Marine Aluminium	CO_2 reduction Decreased lifespan	Increased sales price Higher material cost	
RIR	Sorting effort affects potential		Scrap value is kept within society
Recalu	Impurities affect potential	Contaminations affect potential Impurities affect potential	Reduced pressure on raw material extraction

In the following section, the findings of the second research question are presented.

4.3 How to Achieve a more Circular Aluminium System

This part of the findings addresses the second research question: *"How can the Norwegian aluminium industry achieve a more circular economy by recycling post-consumer aluminium scrap?".* To answer this research question, it has been divided according to the four strategies for achieving a CE in a manufacturing business: narrow, slow, regenerate, and cycle. Each case company has been questioned regarding whether they employ or have the chance to influence the strategies that might lead to the development of a more circular aluminium system. The last section summarises the findings in relation to the research question.

4.3.1 Narrow Strategies

In the interviews, the case companies were asked how they can contribute to achieving a more circular aluminium system by reducing material and/or energy consumption.

The interviews made it quite evident that energy conservation was a top priority for all the case companies. The necessity of consuming less energy for their businesses was emphasised most by the aluminium producers and recyclers.

> *"Energy consumption is something we work on internally, which can be anything from streamlining our processes for better logistics to switching from diesel to electric operation of machines."* RIR

The recyclers have initiated a process whereby several of their machines and sorting machines will switch from using fossil fuel to being electric. Therefore, they will focus more on making their processes more efficient, as there will be an increased consumption of energy in the future. RIR addressed how an increased efficiency will benefit the business's profitability in addition to the environmental savings it will create. Both RIR and Recalu described how sorting thoroughly can reduce energy consumption by ensuring that all provided fractions are as clean as possible.

> "*Nothing beats sorting at the source*." RIR

According to RIR doing so will help them save resources on post-sorting. Recalu added that the first step in accomplishing this is to raise awareness of sorting so that it is easier to continue processing it.

> *"An improvement would be to create greater awareness of the importance of private individual's recycling. The better waste is recycled from the source, the easier it is for us as recyclers to recycle it."* Recalu

Aluroco believed that their biggest contribution to this strategy was their focus on reducing process scrap. The informant explained that some scrap is generated internally which is circulated in their processes, and that up to 20 percent of what they produce ends up as pre-consumer aluminium scrap. A full utilisation of pre-consumer aluminium scrap will be able to reduce the company's material consumption, which will lead to a reduction of post-consumer aluminium scrap.

> *"For us, it would probably be best to try to reduce the proportion of process scrap as much as possible. The more process scrap you have, the more you have to remelt and further process… Letting this circulate internally is unnecessary energy use."* Aluroco

Further, Aluroco also described the large energy consumption that exists within aluminium production, and that any reduction in process scrap helps to reduce energy use. In order to derive more value from the material, the informant believes that there must be an increase of the resource and process efficiency. Aluroco concluded by stating that in order for them to reduce their share of pre-consumer aluminium scrap, they rely on their aluminium customers to make the best use of their products.

> *"Beyond that, reducing material use, it's a bit more down to the customers after us then. How they design their products to make the most of it."* Aluroco

Glamox referred to its development department, which is responsible for further developing and optimising the products they sell. They referred to an example where the body of fluorescent light fittings is still in good condition, but that the customers want to replace the old technology and replace it with LED. As a result, Glamox created a solution where they only changed the inside of the fittings.

> *"In relation to the reduction of the material, you can start with the fact that it is related to the construction of the fixtures, so many of these decisions are within the development*

department. However, we can also make changes after we have manufactured products." Glamox

The informant believes that there should be a greater focus on changing the production processes of each sub-product. Glamox gave an example where they avoid conjoining their parts together with glue so that the user can easily take it apart and thus replace individual parts. This will help to reduce their customers' material consumption as well as their own.

"Instructions on how to take apart the product are available online or it is supplied with the product." Glamox

Marine Aluminium referenced to their innovative cutting method for aluminium, which has reduced the amount of material required. The informant described how employing a water cutting machine instead of manually cutting the aluminium sheets has improved material utilisation.

"We achieve increased material utilisation by using water cutting machine and CNC[5] *machine in order to get all of the pieces into a kind of puzzle and get the lowest possible scrap back."* Marine Aluminium

The plates they cut have predefined measurements, so that the amount of aluminium scrap they generate is reduced. Despite wanting to use aluminium as efficiently as possible, Marine Aluminium claims that their share of process waste is still too high.

4.3.2 Slow Strategies

The case companies were questioned how they might contribute to the development of a more circular aluminium system by prolonging the lifespan of the products.

Glamox connected the use-less strategy (i.e., narrow strategy) with the strategy of using longer, also referred to as the slowing loops. The informant referred to the link between the extended lifetime of products and the reduction of material consumption. Glamox explained that advances in technology, material selection, and effective customer interaction to optimise products, all lead to an extended lifespan. They employ sensor control as an

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[5] CNC stands for computer numerical control, and it is often used to create a custom-design item (Mamadjanov, Yusupov, and Sadirov 2021)

example, which helps ensure that products are utilised only when they are required, offering advantages like energy savings while also extending their lifespan.

> *"… then it is about our responsibility of increasing the lifespan of the fixtures. The less they need to be in use the longer they will be able to last, which will also reduce material consumption."* Glamox

Hydro also referred to working closely with clients to design the alloy that would meet their demands for the aluminium's durability and strength. The informant emphasised that they only produce according to demand, so that they do not have a high level of stock or aluminium that is not in demand.

> *"The customer orders from us, and we will deliver it to them, but at the same time we work on developing the alloy in collaboration with the customer to optimise it. This result in the aluminium having both the strength, longevity, and corrosion resistance and so on."* Hydro

The informant emphasises the collaboration between the customer and the research department as an important factor in achieving the optimal alloy composition. According to Hydro, by providing each customer with a product that is specifically tailored to attain the qualities they desire, they are assisting in the longevity of their goods.

Recalu and RIR were unable to provide a straight response to the query on extending the life of products. The informant from Recalu described how they do not handle goods intended for re-use as recyclers.

> *"If something can be reused, it will not be recycled. Basically, we don't want that, otherwise we won't get scrap anymore."* Recalu

Recalu claims that although there is no activity within aluminium, they have an entirely separate department that deals with reuse. Recalu also expressed that re-use is not something they want, because they are dependent on EOS for it to be profitable for them. RIR adds that because their purpose is to recycle items, recyclers have no influence over this tactic.

> *"As our job is sorting and reloading, we are not that involved in the reuse process itself."* RIR

4.3.3 Regenerate Strategies

During the interviews, the case companies were questioned regarding how they could contribute to create a more circular aluminium system by phasing out dangerous and/or toxic material in their business processes.

This revealed itself as a strategy the case companies placed little emphasis on, and there was an agreement among all companies that they do not handle many hazardous or toxic materials. It is explained by Glamox that if one uses hazardous or toxic materials, it is strongly regulated by law, and that the materials they take in and use are therefore pre-approved.

> *"There is a list of content in the product and there is a list of prohibited substances, among other things. And we approve our suppliers based on that. What we check is that they meet those requirements, and we use a lot of European suppliers, and then it's reasonably safe, because there are stricter rules."* Glamox

Recalu emphasised that they personally do not use dangerous or toxic materials, and that the facilities are checked for them. If they receive scrap that contains dangerous substances, they have routines on how these are to be removed, as they cannot deliver anything on to foundries or works if it has not been cleaned.

> *"It is our task to take it out and ensure that it is further processed in an environmentally sound manner."* Recalu

Hydro explained that the significant energy requirements of the aluminium sector, makes energy a central part of the company's operations. Aluminium production in Norway is produced with hydropower, which is a sustainable energy.

> *"It is important that the aluminium consumers are informed whether the aluminium they buy is based on coal production in South Africa, China or India, or if its production is based on hydropower from Norway."* Hydro

Hydro says that they work within the regulations around "Reach[6]", and that they have their own working groups that qualify all materials before they enter the factory, led by people from the HSE department and the laboratory to ensure that they do not take in materials that are in breach of the guidelines.

> *"We have our own department that checks new types of material, regardless of what it is, it has to go through them to be approved in the factory."* Hydro

4.3.4 Cycle Strategies

How the case companies could contribute with material circulation and reuse was the final issue presented to them. Considering all the firms can participate in the recycling of post-consumer aluminium scrap, it was their role in this process that received the most attention.

Recalu's core activity is recycling, which they then resell and keep in the SC as a result. The informant estimated that they are able to successfully recycle approximately 90 percent of the aluminium they receive, and they have already taken measures to ensure that they can recycle all aluminium scrap in the future.

> *"This means that we have to buy machines in order to recycle the last 10 percent, and before going in the machines the aluminium has to possibly be washed or de-varnished."* Recalu

They have already implemented this further automation of production, and within the next 5-10 years it should be implemented. The informant points out that it will be a lot of extra work for them to recover the last 10 percent, both in the form of purchasing new machines and the process the materials must go through before it can be further processed. However, it will strengthen the company's ability of recycling post-consumer aluminium scrap.

Glamox explains that they focus on having a good dialogue with those who receive their waste to ensure that it is delivered safely and that nothing ends up astray. They specify that

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[6] The government's chemical regulations is called Reach, which has the main objective to achieve better protection of health and the environment by gaining better control over the production, import, use and release of chemicals (Regjeringen 2007).

they pay for a membership in order for another business to take care of the sorting and recycling, and that they are obliged to be a member in the type of business.

> *"... and then the product will be taken apart. Everything we supply of electrical products go into a system that we are associated with. They then handle the product further and take the components apart. Plastic there, aluminium there, steel there, wires, really, everything will be sorted."* Glamox

Glamox emphasised that once a product reaches its EOL, it should be simple for customers to take the product apart in order to properly recycle it. They have set requirements for their products to be detachable, hence making them easy to disassemble and recycle.

> *"Since the internal parts of many of our products are replaceable, you can purchase individual components. It is a selling point because you actually save money and the environment, in addition to making the product last even longer."* Glamox

In the case of Hydro, using pre- and post-consumer aluminium scrap in its manufacturing promotes material circulation and reuse. They circulate all process scrap from their own manufacturing, and they also anticipate that around 20 percent of the scrap from their customers is returned and recycled.

> *"Aluminium is, after all, an eternal metal which is continually recyclable. The value of the material is so great that it comes back again in the loop."* Hydro

Furthermore, Hydro added approximately 2,000 tonnes of post-consumer aluminium scrap in 2022 in their production, and that they have a goal of doubling that to 4,000 tonnes in 2023. Hydro has also taken measures to capture by-products, such as sulfur dioxide and fluorides from production, which are goods with value that they partially manage to recover in their own loop. However, they make it clear that large parts still end up in landfills.

> *"Hydro has an ambitious program to reduce waste and we look into possibilities to further utilise our own by-products."* Hydro

Hydro has plans to set up a hub in Høyanger for post-consumer aluminium scrap, which will be able to handle aluminium from the Scandinavian market. It is said that it will act as a recycling centre of post-consumer aluminium scrap.

"We are helping to remove what exists in Norway and Scandinavia and have set up our own system for that." Hydro

4.3.5 Section Summary

This section has presented the result to the second research question: *"How can the Norwegian aluminium industry achieve a more circular economy by recycling post-consumer aluminium scrap?".* The case companies offer information on responding to the four inquiries on how to achieve a CE. The companies provide numerous examples of their current contributions as well as their plans for the future towards advancing CE in the aluminium industry. The findings make reference to CE strategies that are already documented in the literature, but new discoveries are also found. Given that the research problem refers to the recycling of post-consumer aluminium scrap, it's logical that the case companies are most involved in the final strategy cycle. The companies appear to be aware of the need to implement additional measures to become more circular, but few strategies have yet been put into practise to achieve this. The findings indicate that the companies have employed CE promotional strategies that are additionally advantageous to them, though measures that require greater resources and/or are not as beneficial for them have not been started. In table 4.2 the findings from the CE strategies by recycling post-consumer aluminium scrap is summarised.

Table 4.2: Summary of CE Strategies by Recycling Post-consumer Aluminium Scrap

	Narrow	Slow	Regenerate	Cycle
Aluroco	Reducing material Reduce energy		Follow regulations	Recycle post-consumer aluminium scrap
Glamox	Reduce material Reduce energy	New technology Increase lifespan of products Maintenance	Follow regulations	Design for easy disassembly at the end of the product lives
Hydro	Reduce energy	Increase lifespan of products On-demand manufacturing	Renewable energy Follow regulations	Recycle post-consumer aluminium scrap

Marine Aluminium	Reduce process scrap Reduce energy		Follow regulations	
Recalu	Improve sorting Reduce energy		Clean toxins from materials Follow regulations	Sort post-consumer aluminium scrap
RIR	Increase sorting awareness Reduce energy		Clean toxins from materials Follow regulations	Sort post-consumer aluminium scrap

In the next section the findings of the final research question will be presented.

4.4 Barriers of Achieving Circular Aluminium System

This section presents the findings related to the third research question: "*What are the barriers of recycling post-consumer aluminium scrap in achieving a circular economy?*". These barriers are divided into four categories, which are viewed as the most fitting to present the finding for this research question following extant literature. The section concludes with a section summary where the findings are summarised into Table 4.3.

4.4.1 Market Barriers

The case companies experienced several similar barriers within the market category. For this research, market barriers include obstacles due to non-existing or ill-functioning markets (Grafström and Aasma 2021). Both of the aluminium producers and aluminium customers described imposed costs as a barrier. For example, the aluminium producers described high investment costs as a barrier as they will have to invest in facilities to process the scrap, whereas the aluminium customers described high material costs as a barrier due to recycled materials being more expensive than virgin materials.

> *"… of course, but unfortunately, the costs control everything… It is a cost for us to be sustainable."* Marine Aluminium

RIR also described how they are dependent on large volumes of aluminium scrap to invest in a separate aluminium recycling facility, but the volumes of scrap are still scarce. The lack of post-consumer aluminium scrap is also described as a barrier by the aluminium producers, hence hindering them from covering the demand for aluminium with secondary aluminium with post-consumer aluminium scrap.

> *"As the demand for aluminium is still much higher than the access to scrap, it is not possible to supply the demand only using scrap."* Aluroco

Glamox also described how the access to post-consumer aluminium scrap is a barrier.

> *"I know our suppliers are worried that they might not be able to cover the increasing demand for recirculated aluminium."* Glamox

From the recyclers' point of view, this is confirmed, where the recyclers described how there is not much aluminium scrap to collect in Norway today.

> *"I'm actually unsure if there is any more scrap to collect in Norway."* Recalu

The overall impression the case companies give is that the market is still immature, hence, slowing down the emergence of secondary aluminium with post-consumer aluminium scrap.

4.4.2 Technological Barriers

The technological barriers are related to the quality of the scrap and the processes related to it. The aluminium producers explained how the impurities that are present in the aluminium scrap hinder them from achieving the requested aluminium quality by the customers, and how there is a need for good sorting processes to map the impurities in the scrap.

> *"We cannot produce poor alloying compositions just because it is green aluminium. The customer will not accept this, so we need to map the alloying elements to fit the customer needs."* Hydro

The aluminium customers also described the problem of the impurities affecting the quality of their products, where both Glamox and Marine Aluminium have strict product requirements they have to satisfy.

> *"As of today, the quality is a barrier because it negatively affects the use phase of our lighting solutions where the largest environmental impacts are."* Glamox

Marine Aluminium also described how they are required to document the alloy composition in their products, which the impurities in post-consumer aluminium scrap make challenging, unless a system is created to track the aluminium scrap. Furthermore, the recyclers also described barriers regarding the impurities in the scrap in terms of who they can sell their scrap to, in addition to contaminations that make it difficult to clean it. Recalu described this by using the automobile industry as an example.

> *"Some car manufacturers require an alloy composition which is impossible to produce with post-consumer aluminium scrap, which is a barrier."* Recalu

RIR also highlighted poor product design as a barrier, explaining with the example of how contaminated aluminium products are difficult to recycle.

> *"It is a challenge with the product design, where the products are not designed to be recirculated… For example, laminated products are difficult to recycle."* RIR

4.4.3 Social Barriers

The social category consists of barriers related to lack of awareness, lack of knowledge, and resistant company culture. Aluroco described how there is a lack of awareness in the industry, where customers request secondary aluminium, not distinguishing between pre- and post-consumer aluminium scrap. Marine Aluminium also described this.

> *"I don't think the customers care if it is pre- or post-consumer aluminium scrap, as long as they can put a green label on it."* Marine Aluminium

As Aluroco described, the barrier can be a pure lack of knowledge, whereas the scenario described by Marine Aluminium indicate how companies also intentionally do not distinguish between the types of scrap, with the sole purpose of marketing themselves as sustainable. Glamox also described how they experience different levels of maturity in the industry due to the complexity of CE, resulting in greenwashing[7].

> *"We experience large variations in terms of matureness in the industry, as it is as complex. Therefore, it is very important for us to avoid greenwashing, in which we are concerned with transparency in our actions and to be able to document our effects."* Glamox

[7] Greenwashing is "to make people believe that your company is doing more to protect the environment than it really is." (Cambridge-Dictionary 2023)

Similarly is described by Aluroco, in which they explained how few companies actually implement circular measures due to lack of knowledge and awareness, but also pointing out some large companies are setting exceptions, highlighting a distinction between small and large companies.

> *"Many talk about implementing circular measures, but do not actually initiate it. However, we see large car manufacturers starting to implement stricter requirements in terms of future expectations."* Aluroco

Marine Aluminium explained how they are still in the start-phase of shifting to a sustainability focus, where they are still spreading awareness in the company. It was also revealed during the interview how they have not focused on distinguishing between pre- and post-consumer aluminium scrap themselves and are only focusing on simple circular measures for now, such as electrification of facility vehicles and reusing of process waste.

> *"We are working on it, but we are working with the "low hanging fruits" in the first place, meaning the things that are clear in our daily work."* Marine Aluminium

4.4.4 Regulatory Barriers

Only one case company identified regulatory barriers of recycling post-consumer aluminium scrap. Recalu exemplified the automobile industry again, explaining how some of them have set requirements to use as much post-consumer aluminium scrap as possible, and reflects how this should be applied for all industries.

> *"If things are required by law, it has to be done, so this can be identified as a barrier."* Recalu

They described this as a barrier in terms of the Norwegian aluminium industry lacking stricter regulations that encourage companies to recycle post-consumer aluminium scrap.

4.4.5 Section Summary

This section has presented the results to the third research question: "*What are the barriers of recycling post-consumer aluminium scrap in achieving a circular economy?"*. Multiple barriers are identified by the case companies, revealing differences between the case company categories. It also becomes evident which barriers that are emphasised more than others, in terms of which barriers that are identified by most of the case companies. The market category reveals the lack of scrap and the cost element as the most prominent barriers, the technological category identifies barriers related to the impurities and sorting processes as the most reoccurring, the social category reveals most barriers related to lack of knowledge and awareness, and only lack of regulations is identified as a regulatory barrier. However, the number of barriers identified by the companies does not dictate their significance, which will be further elaborated in the discussion. Table 4.3 summarises the barriers presented in the findings.

Table 4.3: Summary of Barriers of Recycling Post-consumer Scrap to achieve CE

	Market	Technological	Social	Regulatory
Hydro	Investment cost Lack of scrap	Impurities Lack of sorting processes		
Aluroco	Investment cost Lack of scrap	Impurities Lack of sorting processes	Lack of industry awareness Lack of industry knowledge Varying levels of industry maturity	
Glamox	Cheaper virgin material Lack of scrap	Quality	Varying levels of industry maturity Greenwashing	
Marine Aluminium	Cost driven Cheaper virgin material	Quality Lack of alloy mapping	Lack of industry awareness Resistant company culture Lack of company knowledge	
RIR	Lack of scrap	Impurities Poor product design Contaminations		
Recalu	Lack of scrap	Impurities Contaminations		Lack of regulations

Next, a discussion of the study's findings is presented.

5.0 Discussion

5.1 Chapter Introduction

The previous chapter presents the findings related to each of the research questions for this thesis, forming the basis for the upcoming discussion. The findings are discussed in relation to the theoretical background, as introduced in Chapter 2, to evaluate if they fit with the existing knowledge. The discussion is structured according to the research questions, forming three sections. The first section discusses the potentials of recycling post-consumer aluminium scrap, the second section discusses how to achieve a more circular aluminium system, and the third section discusses the barriers of recycling post-consumer aluminium scrap to achieve a CE. The final section of the discussion presents a conceptual framework as an outline of the research to support aluminium actors in a transition to a circular aluminium system by recycling post-consumer aluminium scrap.

5.2 Potentials of Recycling Post-consumer Aluminium Scrap

The findings reveal positive potentials of recycling post-consumer aluminium scrap within the environmental, economic, and social dimensions. However, while the case companies describe their perceived benefits of recycling post-consumer aluminium scrap, they also maintain a critical view of it, debating its outcomes and comparing it to other circular initiatives. Their perceptions and critical views are further discussed in relation to the theoretical concepts of recycling post-consumer aluminium scrap.

The findings within the environmental dimension reveal two main potentials of recycling post-consumer aluminium scrap, including the reduction of CO_2 emissions and reduced waste. Although reduced waste was only identified as a social potential in the findings, it can also be considered as an environmental potential. The reduction of waste is a prominent result of recycling post-consumer aluminium scrap as it is reintroduced into the SC instead of ending up in a landfill, reflecting the first characteristic of a CE of waste being designed out (Ellen-MacArthur-Foundation 2015b). Moreover, the reduction of CO_2 emissions is described as a consequence of energy savings in the primary production of aluminium, requiring only five percent of the energy consumption compared to primary production. However, as revealed in the study by Soo et al. (2019), it is crucial to also consider the recyclers of aluminium scrap when considering the environmental potentials, where the impurity level of the aluminium scrap is a crucial factor. This also becomes evident in the findings as the recyclers explain difficulties of processing the aluminium scrap due to poor sorting and/or high content of impurities, diluting the environmental benefits. However, Recalu solve this by targeting customers according to their alloy requirements, which is discussed by Soo et al. (2019) where they explain how recyclers can target customers if they have an indication of the alloy composition. While this may be solvable with the current scrap levels, increased scrap flows and higher demand may increase the pressure this has on the environmental potentials.

The impurities in the aluminium scrap also diffuses the environmental potential for the aluminium customers. This was revealed in the findings as the aluminium customers are dependent on a specific alloying composition in their products to meet their product requirements, but for two separate reasons. Marine Aluminium depends on a specific alloy mix for their products to be resistant in outdoor conditions and to achieve long lifespan, whereas Glamox requires as pure aluminium as possible to maximise the energy efficiency in their products. Therefore, unless the aluminium scrap can meet the alloy requirements, the use of post-consumer aluminium scrap will damage the potentials of other circular measures with potentially larger environmental effects. Maximising product lifetime and energy efficiency are circular measures themselves (Kirchherr, Reike, and Hekkert 2017), hence the importance to still obtain these while implementing post-consumer aluminium scrap.

Furthermore, Hydro also expresses a dilemma in terms of prioritising circular measures, questioning whether a high share of post-consumer aluminium scrap is better than a lower CO_2 footprint. This topic is brought up as the aluminium scrap flows in Norway are still small-scaled, in which importing scrap from Europe is an alternative. This is discussed by Sevigné-Itoiz et al. (2014) regarding exportation of aluminium scrap to regions with a high energy emission impact, hence substituting pollutant primary production and increasing the environmental benefits. Whereas in the case of Hydro, it will have the opposite effect as the scrap that is produced in Europe has a higher emission impact compared to primary aluminium produced with sustainable energy in Norway. Highlighting the importance of maximising the national aluminium scrap potential and keeping the aluminium scrap within society to achieve a circular aluminium system in Norway.

An overall impression from the findings is how the environmental potential is only a bonus of the economic benefits of recycling post-consumer aluminium scrap as the market for circular products and services is still maturing. Especially for smaller companies, such as Marine Aluminium, rely on having the funds to sustain a circular production. This was also revealed in the study by Soo et al. (2019), explaining how there is a trade-off between the environmental and economic aspects of recycling, as the market is largely driven by profits. The importance of the market dynamics was further emphasised in the findings within the economic dimension, revealing potential gains as well as costs. The aluminium producers explained how they are able to increase the price of their products as there is little access to aluminium with post-consumer aluminium scrap in the market, whereas the aluminium customers explained how they are dependent on a demand for post-consumer aluminium scrap for them to initiate this circular measure. The aluminium customers continue to explain how they already experience an increased demand for sustainable products, which post-consumer aluminium scrap can be categorised as. However, as explained in the study by Rombach (2013), and revealed in the findings, it may be difficult to cover the demand for circular aluminium in current time due to its long lifespan resulting in low volumes of post-consumer aluminium scrap streams. This will affect the current economic benefits of recycling post-consumer aluminium scrap, but by maintaining a long-term perspective, it can induce economic gains in the future.

Although the low levels of post-consumer aluminium scrap limits the current environmental and social potentials as well, the issue is emphasised in the economic dimension. The findings and the study by Han et al. (2017) describe a significant energy reduction of producing with post-consumer aluminium scrap, resulting in reduced production costs. However, due to the low stocks of post-consumer aluminium scrap, this economic potential cannot be fully obtained yet, but will increase with the growth of scrap. Moreover, Hydro also describes how their current production with post-consumer aluminium scrap does not induce any additional costs, but as their goal is to increase their production with it, they might be forced to invest in additional scrap processing facilities. This proves to show how the increase of scrap flows will induce economic gains as well as losses. Ultimately, the key is to consider the profit margin, as Hydro explains. As the scrap levels increase, the cost savings will increase and the demand can be covered, foreseeably surpassing the incurred costs, thus highlighting the importance of considering the long-term effects of a CE. This logic also applies to the aluminium customers, as they expect higher material costs of utilising post-consumer aluminium scrap, but also to be able to sell it with an added premium, expectantly creating a positive profit margin.

The actors of the aluminium SC that seem to get the least economic potential of this circular transition are the recyclers. The findings reveal that their selling price is determined by the global aluminium price, in addition to how clean the scrap is and its purity level, as Soo et al. (2019) also describes. Aluroco describes how the impurities in the scrap can induce additional costs for them in terms of mapping the alloy elements, but it can also reduce their purchasing costs as they will not have to purchase as much alloy metal themselves, if they are able to identify the alloy mix. While the impurities induce additional costs, it can potentially be solved with government policies. The findings and the studies by dos Santos Gonçalves et al. (2021) and Soo et al. (2019) describe how the implementation of policies can have an effect on the supply and demand for secondary aluminium with post-consumer aluminium scrap, ultimately increasing the economic potentials for companies that produce with or recycle post-consumer aluminium scrap. This can for example be a primary aluminium production tax, which will benefit the aluminium producers and customers that produce with post-consumer aluminium scrap, and/or it can be setting targets on impurity levels in the aluminium scrap which can increase the economic potential for the aluminium recyclers.

As with a large share of literature within the CE, the findings reveal a lack of potentials within the social dimension (Mies and Gold 2021). The findings reveal two main social potentials of recycling post-consumer aluminium scrap, related to reducing negative environmental impacts and boosting local industry. First, the reduction of waste benefits the global societies' wellbeing, as it contributes to eliminating large landfills across the globe that negatively impact the nature and the living. Han et al. (2017) describe this as an environmental potential but can be interpreted as a social benefit as well. Furthermore, although not specifically expressed as a social benefit in the findings, the emission reduction can also be understood as a benefit for society, applying the same logic for the reduction of waste. Also, the findings reveal how reintroducing the scrap back into the SC contributes to reducing raw material extraction as the bauxite reservoirs are limited. Lastly, the findings also reveal it as a social benefit to keep the valuable aluminium scrap within our society, as it possesses great qualities and is critical to achieve a Norwegian circular aluminium system. Sevigné-Itoiz et al. (2014) also describe this in their research, in addition to how exporting scrap can create a loss of local industry. However, while the local industries are maintained, the findings reveal how the implementation of post-consumer aluminium scrap can introduce a set of new jobs and replace workforce related to the primary industry, which can be perceived as a social loss for parts of the society but a gain for others.

The subsequent section discusses how to achieve a more circular aluminium system by recycling post-consumer aluminium scrap.

5.3 How to Achieve a more Circular Aluminium System

The findings reveal that each case company has taken measures towards encouraging circularity within their organisations. However, there were variations in both what strategies and the degree to which each case company use them. It becomes evident that aluminium producers, aluminium customers, and recyclers can all contribute in different ways to the growth of a circular aluminium industry. As this research is based on a research gap, there is not much literature linking the CE strategies to the recycling of post-consumer aluminium scrap and how they can aid the aluminium industry to adopt a CE. Therefore, some of the strategies revealed in the findings are new additions to the academic literature, while others can be connected to previous research.

According to the findings, all of the businesses concentrated on utilising less energy in their operations. Bocken and Ritala (2021) demonstrate that this is a strategy that many businesses employ, whether they are linear or circular, as it is a simple approach to conserve resources. The literature agrees with what companies have done, and it is often one of the first steps companies can take to become more circular, as it will also provide benefits such as resource savings. Given that producing and recycling aluminium requires a lot of energy, it becomes natural that these businesses adopt this strategy (Bocken and Ritala 2021). Additionally, it is conceivable that one of the factors contributing to their desire to apply this strategy is the significant increase in power rates, which makes energy conservation an important strategy to implement.

As an aluminium producer, Aluroco can influence the reduction of materials by reducing its own process scrap. As Bocken and Ritala (2021) explain, it is valuable to utilise all the materials by reusing them within the company's boundaries. However, Hydro sees it as a waste of energy to allow excess process scrap to be constantly reintroduced into the primary aluminium mixture. Although it is beneficial to use all materials, remelting aluminium requires additional energy consumption, which is an unnecessary use of resources if it can be avoided. As Aluroco accepts process scrap from customers as well, they are dependent on the customers maximising the material efficiency in order to reduce pre-consumer aluminium scrap. Both parts benefit from this given that Aluroco will have less process scrap and consumers will experience greater resource utilisation (Brändström and Saidani 2022).

Glamox reveals that they embrace the slow strategies through designing products for easy disassembly and reassembly. By making it easier for customers to take apart the products for maintenance, upgrades, or recycling, shows that the company understands the value of circular product design for extending the product lifespan. By keeping up to date with the customers' needs and by being innovative in terms of technologies that contribute to longer life cycles of their products. They are also establishing themselves within a new market by selling parts of their products, which means that they will be competitive on durable products which Konietzko, Bocken, and Hultink (2020) explain as an essential component of slow strategies. This is also closely related to the cycle strategy's "design for easy disassembly at the end of the products' lives", which makes it easier for consumers to disassemble and recycle the components after a product's life cycle (Patala, Salmi, and Bocken 2020). The recyclers acknowledged that poor sorting was a role in lowering their contribution; as a result, easily disassembled products can boost the fractions that are properly sorted, aiding in the recycling of post-consumer aluminium scrap.

Another crucial element of the slowing strategy reveal that Hydro produce on demand, which increases the lifespan of their products. On-demand production, according to Moreno et al. (2019), results in material savings as a consequence of more precise production, energy-efficient production methods, and decreased warehouse waste. They contribute to the make-to-order market, which means that each of the customers can tailor the aluminium to the properties they want. Consequently, every aluminium product that Hydro sells to their customers will be optimised according to the area of use, which in turn means that the product will be able to be used for as long as possible.

RIR and Recalu have a different approach to interpreting the slow strategy. They believe that they as recyclers do not contribute to this part of the CE of the aluminium industry as they do not promote to the reuse of products. Here it emerges that the case company categories found it difficult to apply all strategies to achieve a CE within the aluminium industry. As the recyclers have neither control over the production nor the maintenance of products, they will not be able to have much influence on extending the life of products either. On the other hand, it is mentioned that there are departments within Recalu that deal with the reuse of materials, where they do not have to go through the recycling process in order to be sold. Therefore, reuse can become more relevant in the future to be a larger part of the activities RIR and Recalu engage in, as they will be able to reintroduce resources back into the system (Çetin, De Wolf, and Bocken 2021). Reuse is an important part of slowing the loops, and according to Çetin, De Wolf, and Bocken (2021), it will create great value without requiring significant change or resource consumption.

Given that Norwegian energy is generally sustainable has a significant impact on the Norwegian aluminium sector (Rauter 2022). The fact that Hydro produces the aluminium by utilising hydropower is a major component within regenerate strategy, where employing renewable energy is a high-minded business model fundamental. Maitre-Ekern and Dalhammar (2019) explain the importance of informed consumer in order to achieve a CE, and as Hydro is producing using renewable energy it gives them a competitive advantage in terms of brand reputation compared to cheap aluminium produced in other regions. As one can assume in Norway that the cooperative companies mainly rely on water or wind power, they also help to exploit the regenerate strategy. Consumers must be educated regarding the manufacturing of aluminium, as informed by Maitre-Ekern and Dalhammar (2019), in order for them to be willing to pay more for sustainable production, given that aluminium prices are higher in Norway.

However, it turned out that the case companies did not contribute to the other key regenerate concepts. Very few companies responded to the query about eliminating or lowering hazardous and/or toxic components in manufacturing. Hydro follows the government's chemical regulations called Reach, and the other companies also attested to following government regulations on which materials are acceptable for use and how to properly dispose of them when necessary. There are extensive regulations for the production, use and recycling of dangerous chemicals, and the interviewees believed that these regulations are strict within Norway and the EU/EEA (Lovdata 2002). However, none of the businesses had made the decision to reduce toxic or hazardous materials beyond what was required by law. Although it has not been mentioned, it is possible that a further reduction will be difficult within the aluminium industry, as they have stated, production changes have an impact on the aluminium production and that it may be at the expense of the quality of the products.

Furthermore, the planned recycling hub of Hydro fall under the narrow and the cycle strategies. Thus, what they want to achieve with this hub is to streamline and have a collection point for all post-consumer aluminium scrap that will contribute to the circulation of aluminium, and which CE effects fall under the narrow strategy. An important factor within narrow strategy is the concept of sharing, which is when the same product is accessible to numerous user groups which can result in fewer products overall in an ecosystem (Brändström and Saidani 2022). Therefore, Hydro's future plans do not correspond to the literature on the narrow strategy, as it will increase the number of recycling facilities in Norway, in addition to reducing the use per machine. As there are reputable recyclers who are able to undertake this function for them, and Hydro states that they lack EOS, it will be challenging to make operations profitable. The new hub in Høyanger set out to be able to receive post-consumer aluminium scrap from all over Scandinavia. Neither RIR nor Recalu collects aluminium scrap from abroad, and this will therefore bring greater value of aluminium to the country. However, this would contradict Sevigné-Itoiz et al. (2014) claim that export flows are against CE goals, as well as the reality that exporting aluminium results in the loss of a valuable resource and that shifting primary production might result in the decline of local industry.

The cycle strategy is evidently the most significant to this thesis considering that it deals with the recycling of post-consumer aluminium scrap and how this can assist the Norwegian aluminium industry in achieving a CE. The aluminium producers and recyclers recognised their role in enhancing circularity in the aluminium industry by contributing to the recycling of post-consumer aluminium scrap. Recalu emphasised their ability to recycle the remaining 10 percent of the aluminium they receive and how they have invested in new equipment that will allow them to recycle 100 percentage of the aluminium they receive in the future. This is an initiative that would not have been done if it were not for external promoters who demand this from them. This points to the importance of legislation from the authorities to initiate the CE, which is validated from Kyriakopoulos (2021) stating that legislations are an important approach to achieve CE. As it requires greater investment funds and it will also take a long time before it will create value for the companies, it is difficult to find motivation to initiate such a transition. This is related to Glamox as well because they outsource their recycling, and if they had not been required by law to participate in such a programme, it is possible that this would not have been high on their list of priorities.

The subsequent section discusses the barriers of achieving a more circular aluminium system by recycling post-consumer aluminium scrap.

5.4 Barriers of Achieving a Circular Aluminium System

The findings reveal multiple barriers of recycling post-consumer aluminium scrap to achieve a circular aluminium system, where the case companies agree upon several barriers, but one can also distinguish some differences between the case company categories. The following discussion links the barriers from the findings with existing literature, but also identifies barriers that has not been revealed in the literature. Interrelationships between the barrier categories are also investigated and discussed.

The findings reveal that the case companies experienced similar barriers within the market category. Both of the aluminium producers and the aluminium customers describe imposed costs as a barrier. The aluminium producers describe high investment costs related to processing facilities as a barrier, similarly revealed by Jaeger and Upadhyay (2020) where a "world leading aluminium manufacturer" describes the challenge of balancing the trade-off between investments and earnings. Distinguishing between large and small companies, Jaeger and Upadhyay (2020) also reveal a small company that describes costs as a barrier as they do not implement solutions unless they can profit from it. Marine Aluminium, which can be categorised as a small company, also expresses this, explaining how the costs is the main driver for them and how they experience sustainable solutions as too costly. Furthermore, Glamox describes costs as a barrier as well in terms of primary aluminium being cheaper than secondary, corresponding with Kumar et al. (2019) and Badhotiya et al. (2022) who identifies low virgin material prices as a barrier.

Moreover, a notable market barrier revealed in the findings is the lack of access to post-consumer aluminium scrap in Norway. The aluminium producers describe it as impossible to cover the high demand for aluminium with production of secondary aluminium with post-consumer aluminium scrap, where only a small of share can be covered. The aluminium recyclers also describe this, explaining how they do not believe there is more aluminium scrap to collect in Norway than the volumes that are being collected today. This is not revealed as a barrier in the literature, but is described by Rombach (2013) and is discussed in Section 5.2 as an element that reduces the potentials of recycling post-consumer aluminium scrap.

While the long lifespan of aluminium is a large contributor in the lack of post-consumer aluminium scrap, other factors potentially amplify this barrier as well, revealing an interrelationship between the market and technological barrier category, which (Badhotiya et al. 2022) describes as a phenomenon in barrier identification. As the aluminium producers reveal in the findings, the Norwegian aluminium industry lacks a sufficient system for processing and mapping post-consumer aluminium scrap. In addition, Marine Aluminium highlight the lack of a system that maps the alloy composition in the post-consumer aluminium scrap. This can be linked to the barrier identified by Kashyap, Kumar, and Shukla (2022) about the lack of technology in waste collection systems. If an improved and innovated aluminium waste system was established, it could potentially improve the scrap utilisation, hence reduce the significance of the barrier related to the lack of scrap. Also, RIR explained the lack of attention to the EOL phase in the product design as a barrier, which can be viewed as interrelated to the lack of scrap volumes as it reduces the ability of recycling post-consumer aluminium scrap. An example of poor product design can be contaminations present in the post-consumer aluminium scrap that is difficult to remove, as the recyclers described as barriers. Kumar et al. (2019) describe the lack of attention to the EOL phase as a technological barrier in their study, however contaminations in itself is not identified as a barrier in the literature.

One can also identify interrelationships within the technological category, again related to the lack of technology in waste collection systems (Kashyap, Kumar, and Shukla 2022). All of the case companies reveal how the impurities in post-consumer aluminium scrap is a barrier for them in some way. The aluminium producers explain how they cannot produce secondary aluminium with post-consumer aluminium scrap that has an unknown or incorrect alloy composition, potentially not fulfilling customer requirements, where the aluminium customers explain how they are dependent on fulfilling strict product specifications in terms of alloy mix for their products to achieve specified quality. The aluminium recyclers also express this barrier from their point of view, describing impurities as a barrier in terms of what customers they can sell it to due to their product specifications. If a sufficient waste collection system existed to map impurities of post-consumer aluminium scrap, the impurities in itself would not be a barrier. Impurities as a barrier can be linked to the barrier identified by Jaeger and Upadhyay (2020), where companies describe virgin materials as better quality than recycled materials. However, due to the case specificity, the literature does not identify impurities or alloy elements as barriers in themselves.

The findings within the social barrier category reveal differences between the sizes of the case companies, as Jaeger and Upadhyay (2020) also show in their study. Aluroco explained how few companies implement circular measures, but they experienced some large car manufacturing companies who have started to initiate a CE transition. This also becomes evident within the case companies in this study. The overall impression from the findings is that the smaller companies do not have as great knowledge about the concept of CE as the large companies do, which also has to do with them not having a circular strategy in their organisation as well. Marine Aluminium reveals during the interview how they have not distinguished between pre- and post-consumer aluminium scrap in their operations, indicating that they have a low level of knowledge about circular aluminium, which also Badhotiya et al. (2022) point out as a barrier in their study. They continue to describe how they are still working with the "low hanging fruits", highlighting how they are still in the start phase of a circular transition. Jaeger and Upadhyay (2020) describe this as barrier in their study as well, explaining how manufacturers are only focusing on the low impact strategies and less on the high impact strategies. It is not only due to a lack of knowledge that Marine Aluminium are in the start phase of a circular transition, but also due to a resistant company culture where an older generation is still unfamiliar with the concept of CE, which is a barrier that is identified by Kumar et al. (2019) as well.

Furthermore, Marine Aluminium describes how they do not perceive their customers as concerned with differentiating between pre- and post-consumer aluminium scrap, and that they only are interested in marketing their products as green, i.e. greenwashing. This has a negative effect on the industry, as it does the opposite of spreading awareness about post-consumer aluminium scrap and its potentials, which Aluroco explains as a barrier in itself. Kumar et al. (2019) and Kashyap, Kumar, and Shukla (2022) highlight the lack of public awareness about the CE concept, but the literature does not identify greenwashing as a barrier, which may be due to its recent relevance. The findings also reveal varying maturity levels in the industry as a barrier, which can be linked to lack of public awareness about the concept of CE and to the barrier identified by Badhotiya et al. (2022) about low demand and acceptance of remanufactured goods.

Government support and legislation could combat the barrier related to greenwashing, forcing companies to document circular initiatives and potentials, but the lack of government policies is identified as a regulatory barrier in itself by Recalu and Badhotiya et al. (2022). While this is only identified by Recalu in the findings, it is evaluated as a barrier of high importance by Badhotiya et al. (2022). This becomes apparent for other barriers as well, where the literature identifies critical barriers, but it is not emphasised in the findings as a key barrier. For example, Badhotiya et al. (2022) evaluate social barriers as the most critical, whereas the finding do not reveal this barrier category as more emphasised than the other categories, in terms of the number of barriers identified. This proves to show how Kashyap, Kumar, and Shukla (2022) have ranked the barrier based on cause and consequence, thereby providing a more precise picture of the actual importance of the barriers.

Next, we present a conceptual framework, which is developed for CE adoption in the Norwegian aluminium industry by recycling post-consumer aluminium scrap.

5.5 Conceptual Framework

Figure 5.1 illustrates a conceptual framework for how aluminium industry actors can transition to a CE by recycling post-consumer aluminium scrap. The framework serves as an outline for the entire research, aiming to create knowledge on how recycling of post-consumer aluminium scrap can enhance CE adoption in the Norwegian aluminium industry.

A description of Figure 5.1 will be given to better understand how the conceptual framework is organised. The CE and the aluminium industry are the two circles on each side of the research objective, representing the fundamental concept and the case industry for this research, as the thesis' research problem and questions are all related and based on these two factors. The intersection of the CE and the aluminium industry illustrates the focus of the thesis: recycling of post-consumer aluminium scrap. Next, the three coloured circles represent the contributing factors – potentials, barriers, and CE strategies – demonstrates how a CE is attained in the aluminium industry by recycling post-consumer aluminium scrap. They are structured as a Venn diagram to demonstrate their interrelationships, where the overlap reveals the connection between the contributing factors. Outside the Venn diagram, the findings within each contributing factor are summarised.

The conceptual framework reveal how the research questions can be viewed as connected to each other, thus highlighting the importance of considering all three contributing factors of the conceptual framework together, and not each in isolation. The relationship can be explained as follows: By implementing CE strategies, the aluminium industry can achieve economic, environmental, and social potentials, but barriers may occur on the pathway that slow down the process. Further, to illustrate the relationships in the conceptual framework, some examples from the findings will be highlighted and discussed in relation to each other.

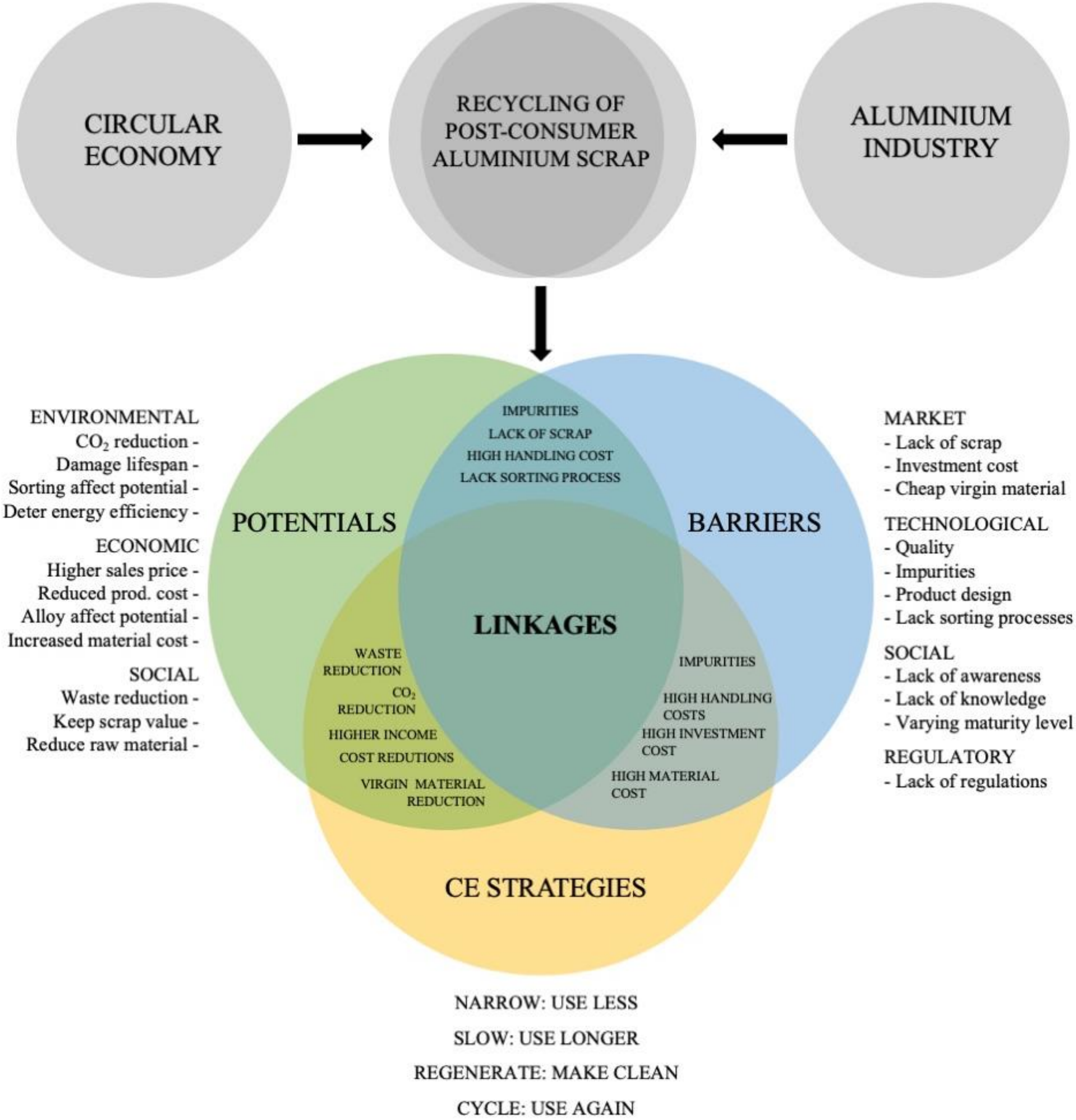

Figure 5.1: Conceptual Framework

Out of the three dimensions of the first research question, the economic dimension was revealed as the most emphasised by the case companies, and it becomes evident how this dimension is present within the other contributing factors of the thesis as well. Viewing the potentials and strategies in relation to each other, one can detect several of the strategies that induce economic gains. For example, for the narrow strategy, cost reductions are generated through reducing material and energy consumption, which Hydro and Aluroco reveal in the findings. Furthermore, the cycle strategy can generate higher income, which was described by the aluminium producers and aluminium customers as an additional premium they can add to their products by labelling them as green. However, economic losses are revealed as well, such as higher handling costs related to the cycle strategy as Aluroco describes. These incurred costs are also revealed as barriers in the findings, where the different case company categories are financially burdened in different ways. The aluminium producers explained high investment costs as a barrier, and the aluminium customers described high material costs as a barrier. However, investments are necessary to be able to implement the CE strategies, and in the long run a positive profit margin is expected when the demand and access to post-consumer aluminium scrap increases.

Another barrier that becomes evident within the other contributing factors of the thesis is the impurities that is present in the post-consumer aluminium scrap. This is identified as a barrier by the aluminium customers as it reduces the quality of their products, and by the aluminium producers as they have to meet customer requirements of the alloy mix. This is linked to the slow strategy, as a specific alloy composition is required to achieve a long lifespan of the products, as described by the aluminium customers. The economic and environmental potentials are also affected by the impurities. Aluroco explained how the impurities increases their handling costs, while Recalu explained how some special alloy elements increase the difficulty of recycling the scrap, potentially reducing their recycling rate, thus reducing the volumes of post-consumer aluminium scrap that is reintroduced back into the SC.

Several linkages between the environmental dimension and the CE strategies can identified as well. By implementing the cycle strategy of recycling post-consumer aluminium scrap, one achieves environmental potentials such as CO_2 reduction, as described by the aluminium producers and aluminium customer. It also reduces waste generation and the pressure on raw material extraction, which are described as environmental and social potentials in the findings. However, due to the low levels of post-consumer aluminium scrap in Norway today, it hinders to fully implement the cycle strategy, hence achieve the potentials that come of it. Also, the aluminium industry is deprived of the potentials of recycling post-consumer aluminium scrap and achieving a CE due to a lack of awareness and knowledge that is present in the industry today.

The next chapter will present the conclusion of this thesis.

6.0 Conclusions

6.1 Chapter Introduction

This final chapter presents the conclusion, including a research summary and the theoretical and practical contributions of this thesis. The limitations of the thesis are also presented, as well as suggestions for future research.

6.2 Research Summary

The main aim of this thesis is to increase the understanding and knowledge on how recycling of post-consumer aluminium scrap can enhance CE adoption in the Norwegian aluminium industry. Three research questions were proposed in order to further investigate the research problem, and the results are summarised in this section.

Exploring the first research question, *"What is the environmental, economic, and social potential of recycling post-consumer aluminium scrap?"*, the case companies were asked what they perceive as the potential benefits or losses within each of the CE dimensions of recycling post-consumer aluminium scrap. The findings reveal how the case companies do not prioritise the dimensions equally, thus, the economic potential is prioritised as the most significant, followed by the environmental and then the social dimensions. While it is revealed of the great potentials that recycling of post-consumer aluminium scrap has, it also comes to light how the potentials are not possible to fully obtain yet, due to an unmature market and low levels of post-consumer aluminium scrap. However, as the post-consumer aluminium scrap flows are expected to increase, it is expected that the potentials will become more substantial.

In the second research question "*How can the Norwegian aluminium industry achieve a more circular economy by recycling post-consumer aluminium scrap?*" the companies were asked about the four strategies to achieve a CE in the aluminium industry. The findings indicated that although there is need for development in the recycling of post-consumer aluminium scrap, the case companies are aware of the strategies and the effects it will have on their circular transition. It was revealed that the cycle strategy is the most practised, which is beneficial as the recycling of post-consumer aluminium scrap is considered as upcycling as the value of the scrap increases when reintroduced back into the SC. However, not many initiatives outside the cycle strategy have been made. Therefore, there is still greater potential for improvement within the narrow, slow, and regenerate strategies, which is lacking in initiatives from the case companies.

Lastly, the third research question, "*What are the barriers of recycling post-consumer aluminium scrap in achieving a circular economy?"*, aims to explore the barriers of recycling post-consumer aluminium scrap within the different case company categories, thus gaining a broad perspective of why a circular aluminium system has not been obtained yet. While the findings reveal some barriers that are more emphasised than others, it does not determine the level of importance, only highlighting similarities between the aluminium SC actors. Furthermore, it also comes to light in the discussion how some barriers are not identified in the literature, which is due to the literature covering barriers for all manufacturers, while the thesis findings are industry specific to aluminium and recycling of post-consumer aluminium scrap. By categorising the barriers, interrelationships are revealed between the barrier categories as well as between individual barriers within a category, where the market category and the technological category can be perceived as intertwined, in addition to individual barriers within the technological barrier category.

6.3 Contributions

This section discusses how the thesis and its results contribute to the literature about CE in the aluminium industry, and how post-consumer aluminium scrap can aid this transition, attempting to fill the identified research gap.

6.3.1 Theoretical Contributions

The first contribution of the thesis is that it builds theory by linking the CE with the aluminium industry with the role of recycling post-consumer aluminium scrap, as there is limited research on this topic. The thesis examines what potentials companies can obtain when transitioning from a linear economy to a CE, contributing to increase knowledge about CE in relation to post-consumer aluminium scrap and provides an outline of the sector's efforts to attain circular aluminium system.

Second, the thesis contributes by examining how to utilise the four CE strategies to achieve a CE within the aluminium industry, as this also lacks research. By linking the strategies, narrow, slow, regenerate, and cycle, to aluminium producers, aluminium customers, and recyclers in the aluminium industry, the study establishes an increased understanding of how different aluminium SC actors interpret and use CE strategies in their business operations. As a result, it is possible to determine the extent to which the aluminium industry has progressed in implementing CE, which loops have potential for development, and which areas they are restricted. This information will be instructive and aid the development of CE in the aluminium industry.

Third, the identified barriers of recycling post-consumer aluminium scrap in achieving a CE contributes to an increased understanding on the complexity of transitioning to a CE in the aluminium industry. In contrast to the literature on barriers within the manufacturing industry, this thesis provides industry-specific barriers. Thus, the emphasis on barriers in this thesis improves the knowledge on how the barriers inflict the aluminium industry in the implementation of CE and constitutes an important theoretical advancement.

Fourth, the thesis combines insights on CE potential, strategies, and barriers in order to create a conceptual framework. It aims to create knowledge on how recycling of post-consumer aluminium scrap can enhance CE adoption in the Norwegian aluminium industry. This framework takes a step toward revealing the potentials, strategies, and barriers of recycling post-consumer aluminium scrap, which can help researchers further expand the literature on CE in the aluminium industry in relation to recycling post-consumer aluminium scrap.

6.3.2 Practical Contributions

The thesis has also contributed to practical implications that managers and companies in the aluminium sector can find useful. This can provide important insights into creating realistic strategies and directives for enhancing CE adoption in the Norwegian aluminium industry. The thesis can assist companies in the aluminium industry in making the transition from a linear to a CE by recycling post-consumer aluminium scrap. It contributes with practical implications in which companies in the aluminium sector can gain insights into how to apply strategies to achieve a CE by recycling post-consumer aluminium scrap, and what potentials and barriers they can obtain.

The identification of the CE strategies can help companies in the aluminium industry become more circular. By introducing the strategies from the perspective of the aluminium industry, it increases the knowledge on how practitioners can assess its current performance and strategies to become more circular. The present study contains findings within three stages in a value chain that the case companies represent, which enable companies in the aluminium industry to review and compare the findings of the companies that are most comparable.

The identified barriers in the findings will help companies become aware of what hinders the aluminium industry from transitioning to a CE. This will make practitioners aware of what they should expect to encounter in terms of market, technological, social, and regulatory barriers, which will make them more resilient in a CE implementation. The identified barriers of recycling post-consumer aluminium scrap will aid companies in gaining knowledge that will assist them in organising and outlining a strategy that enables them to overcome the obstacles in the best way feasible.

The proposed conceptual framework increases the understanding of how post-consumer aluminium scrap can contribute to the CE adoption. The framework can aid practitioners in developing the right set of expectations and preparedness when transitioning from a linear model to a CE. It presents the thesis contributing factors and connects its findings to each of them, which can increase the practitioners' competence and chances of achieving a CE.

6.4 Limitations of the Study

In this section, the limitations of the thesis are presented. As the thesis is based on obtaining information from both interviews and existing literature, it was discovered that there is a lack of research about CE in the aluminium industry and the role of post-consumer aluminium scrap, hence the research gap. There was little and, in some cases, no existing literature with which could compare the thesis' findings with, and this may have influenced how the thesis' discussion is spread.

As the field of the thesis had limited existing literature, the thesis was dependent on obtaining sufficient information from the interviews with the case companies. Moreover, another limitation when collecting data was not getting in contact with the key people in some of the companies, meaning informants did not have enough competence about CE. As a result of this, not all necessary data was collected, and the same company had to be reinterviewed with other informants to fill in the gaps from the previous interviews. The research could possibly have uncovered additional information if the communication had been with the right individuals in some the case companies.

The thesis could also have benefited from collecting data from more companies. However, the task had to be limited to a certain number of companies, in addition to only relating to the Norwegian market, in order for the information to be obtained, sorted, and analysed in the limited time frame. This limits the study's relevance to mainly Norwegian companies producing, using and/or recycling aluminium. By expanding the number of companies, and including a larger geographical area, it would potentially be possible to identify more factors that increase the knowledge on how recycling of post-consumer aluminium scrap can enhance CE adoption in the aluminium industry.

6.5 Suggestions for Further Research

The findings and limitations of this thesis refer to areas that require more research in order to better understand how the recycling of post-consumer aluminium scrap can enhance CE adoption in the aluminium industry. First, investigating approaches to overcome the identified barriers is a suggestion for further research. This thesis emphasised the barriers to a CE transition in the aluminium industry, thus, it would be highly relevant to suggest how to solve these obstacles. This would make it easier to assist future companies in the aluminium industry given that they would be more aware of the challenges they can encounter in the transition, as well as understanding how to solve them.

Secondly, the findings revealed a lack of potentials within the social dimension, as is the case with a significant portion of CE literature. It will therefore be beneficial to identify additional potentials within the social dimension, as it is an important part of the CE that needs to be covered.

Finally, this thesis is limited to the Norwegian aluminium industry, and it is suggested that future studies examine a variety of nations, paying particular attention to those with bauxite reserves as most likely additional potentials and barriers will be uncovered, in addition to identifying new advances within the CE strategies. This would broaden the research's applicability to a global scale and also be able to strengthen the thesis' contributing factors.

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Appendices

Appendix 1: Front Page and Preface of Interview Guide

Molde University College
Specialized University in Logistics

Intervjuguide - Circular Economy in the Norwegian Aluminium manufacturing industry: The role of Recycling Post-Consumer Aluminium Scrap

Datainnsamling som en del av Masteroppgave i Master of Science in Logistics

2023

Introduksjon

I denne masteroppgaven skal vi undersøke hvordan oppnå sirkulær økonomi i den norske aluminiumsindustrien, hvor fokuset vil være på post-forbruker aluminium skrap og dens rolle i dette skiftet. Det er tre forskningsspørsmål vi skal svare på i oppgaven, og som er utgangspunktet for intervjuguiden: Hva er potensialet ved å resirkulere post-forbruker aluminium skrap? Hvordan kan norsk aluminiumsindustri oppnå et sirkulært system? Og til slutt: Hva er barrierene som hindrer et sirkulært skifte i aluminiumsindustrien? For å samle inn data og svare på disse spørsmålene har vi valgt å ha intervju med produsenter, brukere og gjenvinnere av aluminium. Dette er fordi det er kritisk at alle i forsyningskjeden samarbeider i en sirkulær økonomi, og derfor vil det være nødvendig å samle data fra flere faser av livssyklusen til aluminium. Derfor er vi interesserte å få deres standpunkt som produsent/bruker/gjenvinner av aluminium i vår oppgaveløsning.

For å kunne svare på noen av spørsmålene, vil vi gi litt bakgrunnsinformasjon om strategiene for å oppnå en sirkulær økonomi. For å oppnå en sirkulær økonomi så er vi avhengig av å utføre fire aktiviteter: Snevre, sakte ned, regenerere og sirkulere. Den første strategien (snevre) handler om å redusere material- og energiforbruk, da det er et kjerneelement i en sirkulær økonomi å bruke mindre. Dagens materialforbruk er ineffektiv ettersom vi har muligheten til å produsere samme sosiale gevinst ved å bruke mindre og ved å utnytte bærekraftig energi. Den andre strategien (sakte ned) handler om å beholde materialene i bruk så lenge som mulig. Dette kan bli gjort gjennom ved å designe for holdbarhet og reparasjonsevne. Dette vil bidra med å redusere material etterspørsel i det lange løpet. Den tredje strategien (regenerere) handler om å fase ut farlige og giftige materialer og prosesser, og erstatte dem med bærekraftige ressurser. Dette kan bli utført på systemnivå hvor en kan designe regenerative prosesser, eller på produktnivå hvor en kan gå over til biotiske produkter for eksempel. Den siste strategien (sirkulere) handler om å sirkulere og gjenbruke materialer. Målet er å maksimere volumet av sekundære materialer som tilføres inn i økonomien igjen, som vil minimere behovet for råmaterialer.

Appendix 2: Interview Guide Aluminium Producers

A: Introduksjonsspørsmål

A.1: Bedriftsrelaterte Spørsmål

1. Kan dere beskrive hvordan deres supply chain ser ut?
   a. Hvilke prosesser har dere?
   b. Hvem er kundene deres? Hvor er de lokalisert?
   c. Hvor mange leverandører har dere? Hvor er de lokalisert?
2. Hva produserer dere?
   a. Kan dere beskrive prosessen ved å produsere aluminium?
3. Hvor langt har dere kommet i overgangen til resirkulert og/eller sirkulær aluminiumsproduksjon?
   a. Har dere startet?
   b. Har dere planer for hva dere vil oppnå?

A.2: Aluminium Relaterte Spørsmål

1. Hvor mange tonn primær aluminium produserer dere årlig?
2. Hvor mange tonn sekundær aluminium med pre-forbruker skrap produserer dere årlig?
3. Opplever dere økt etterspørsel av sekundær aluminium med pre-forbruker skrap?

B: Potensial for Resirkulering av Post-Forbruker Aluminium Skrap

1. Hva er potensialet til å resirkulere post-forbruker aluminium skrap?
   a. Innenfor den økonomiske dimensjonen?
   b. Innenfor miljø dimensjonen?
   c. Innenfor den sosiale dimensjonen?
2. Produserer dere sekundær aluminium med post-forbruker skrap?
   a. Er det en etterspørsel etter sekundær aluminium med post-forbruker skrap
3. Hvor mye post-forbruker aluminium skrap behøves for å iverksette overgangen til en sirkulær aluminiumsproduksjon?
   a. Hvorfor?
4. Hvor stor andel av deres produksjon vil være sekundær aluminium av post-forbruker aluminium skrap?

5. Hvordan vil deres supply chain endre seg ved å introdusere post-forbruker aluminium skrap i deres produksjon?
    a. Hvor vil dere forsyne dette fra?
6. Hva tror dere er kostnadsforskjellen ved å produsere sekundær aluminium med post-forbruker skrap sammenlignet med primær aluminiumsproduksjon?
7. Vil dere tro det er prisforskjell ved salg av sekundær aluminium med post-forbruker skrap sammenlignet med primær aluminiumsproduksjon

C: Hvordan oppnå et Sirkulært Aluminium System

1. Hvordan kan dere bidra til å oppnå et sirkulært aluminium system?
    a. Hvordan kan dere redusere material- og energiforbruk?
    b. Hvordan kan dere bidra til å forlenge levetiden til materialene?
    c. Hvordan kan dere fase ut farlig og/eller giftig materiale og prosessen?
    d. Hvordan kan dere bidra til å sirkulere og redusere materialer?

D: Barrierer ved å oppnå et Sirkulært Aluminium System

1. Hvilke barrierer opplever dere ved å produsere sekundær aluminium med post-consumer skrap?
2. Er det manglende regelverk som tilsier hvor stor mengde produksjon som må være sirkulær?

Takk for deres bidrag!

Appendix 3: Interview Guide Aluminium Customers

A: Introduksjonsspørsmål

A.1: Bedriftsrelaterte Spørsmål

1. Kan dere beskrive hvordan deres supply chain ser ut?
    a. Hvilke prosesser har dere?
    b. Hvem er kundene deres? Hvor er de lokalisert?
    c. Hvor mange leverandører har dere? Hvor er de lokalisert?
        i. Hvem er deres leverandører av aluminium?
2. Hva produserer dere?
    a. Hvilke produkter er laget av/med aluminium?
    b. Kan dere beskrive prosessen for aluminiumsbehandling?
3. Hvor langt har dere kommet i overgangen til resirkulert og/eller sirkulær produksjon?
    a. Har dere startet?
    b. Har dere planer for hva dere vil oppnå?

A.2: Aluminium Relaterte Spørsmål

1. Prosesserer dere både primær- og sekundær aluminium?
2. Hvor mange tonn primær aluminium prosesseres årlig?
3. Hvor mange tonn sekundær aluminium med pre-forbruker skrap prosesserer dere årlig?
4. Opplever dere et økt tilbud fra leverandører eller en etterspørsel fra deres kunder etter sekundær aluminium?

B: Potensial for Resirkulering av Post-Forbruker Aluminium Skrap

1. Hva er potensialet til å resirkulere post-forbruker aluminium skrap?
    a. Innenfor den økonomiske dimensjonen?
    b. Innenfor miljø dimensjonen?
    c. Innenfor den sosiale dimensjonen?
2. Prosesserer dere sekundær aluminium med post-forbruker skrap?
    a. Har dere etterspurt og/eller forutser dere en etterspørsel av sekundær aluminium med post-forbruker skrap fra leverandør?

3. Hvor stor andel av deres produksjon vil inkludere sekundær aluminium av post-forbruker aluminium skrap?
4. Vil deres supply chain endre seg ved å introdusere post-forbruker aluminium skrap i deres produksjon?
5. Tror dere det vil bli en differansen i kostnadene ved innkjøp av sekundær aluminium med post-forbruker skrap sammenlignet med primær aluminium?
6. Vil dere selge produktene deres til en annen pris dersom det er produsert med post-forbruker aluminium skrap sammenlignet med primær aluminium?

C: Hvordan oppnå et Sirkulært Aluminium System

1. Hvordan kan dere bidra til å oppnå et sirkulært aluminium system?
   a. Hvordan kan dere redusere material- og energiforbruk?
   b. Hvordan kan dere bidra til å forlenge levetiden til materialene?
   c. Hvordan kan dere fase ut farlig og/eller giftig materiale og prosessen?
   d. Hvordan kan dere bidra til å sirkulere og redusere materialer?

D: Barrierer ved å oppnå et Sirkulært Aluminium System

1. Hvilke barrierer opplever dere ved å produsere med sekundær aluminium av post-consumer skrap?
2. Er det manglende regelverk som tilsier hvor stor mengde produksjon som må være sirkulær?

Takk for deres bidrag!

Appendix 4: Interview Guide Recyclers

A: Introduksjonsspørsmål

A.1: Bedriftsrelaterte Spørsmål

1. Hvordan ser deres organisasjonsstruktur ut?
2. Kan dere beskrive hvordan deres supply chain ser ut?
   a. Hvilke prosesser har dere?
   b. Hvem er kundene deres? Hvor er de lokalisert?
3. Hvor mange tonn avfall mottar dere årlig?
   a. Hvor stor andel av dette klarer dere å gjenvinne?
4. Hvor langt har dere kommet i overgangen til resirkulert og/eller sirkulær produksjon?
   a. Har dere startet?
   b. Har dere planer for hva dere vil oppnå?

A.2: Aluminium Relaterte Spørsmål

1. Hvor mange tonn aluminium skrap mottar dere årlig?
   a. Og hvor mye av dette klarer dere å sortere og gjenvinne?
2. Hvilke produkter av aluminium mottar dere mest av?
   a. Og er det noen typer aluminium skrap som er vanskeligere å gjenvinne enn andre?
3. Hva er deres kostnader knyttet til gjenvinning av aluminium skrap?
4. Hvem er deres største kunder av aluminium skrap?
5. Hva er prisen dere selger aluminium skrap for?
6. Opplever dere (økt) etterspørsel av sekundær aluminium?

B: Potensial for Resirkulering av Post-Forbruker Aluminium Skrap

1. Hva er potensialet til å resirkulere post-forbruker aluminium skrap?
   a. Innenfor den økonomiske dimensjonen?
   b. Innenfor miljø dimensjonen?
   c. Innenfor den sosiale dimensjonen?
2. Vil deres supply chain endre seg i overgangen til et sirkulært aluminium system?

C: Hvordan oppnå et Sirkulært Aluminium System

1. Hvordan kan dere bidra til å oppnå et sirkulært aluminium system?
    a. Hvordan kan dere redusere material- og energiforbruk?
    b. Hvordan kan dere bidra til å forlenge levetiden til materialene?
    c. Hvordan kan dere fase ut farlig og/eller giftig materiale og prosessen?
    d. Hvordan kan dere bidra til å sirkulere og redusere materialer?
2. Hvilke forbedringer mener dere kan gjøres for å øke resirkulering av aluminium skrap?

D: Barrierer ved å oppnå et Sirkulært Aluminium System

1. Hvilke barrierer opplever dere å resirkulere med aluminium?
2. Er det manglende regelverk på resirkulering av aluminium?

Takk for deres bidrag!