Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Mechanical and Industrial Engineering

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Developing circular logistics solutions

A case study of the Norwegian plastic pipe industry

Master's thesis in Global Manufacturing Management
Supervisor: Jan Ola Strandhagen
June 2023

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Preface

This master's thesis is submitted as the final work of the Master of Science program in Global Manufacturing Management at the Department of Mechanical and Industrial Engineering at the Norwegian University of Science and Technology (NTNU). It has been a learningful experience and I have gained knowledged that I will take with me after submission of my master's thesis.

I would like to thank my supervisor from NTNU, Jan Ola Strandhagen for his guidance, advice and encouragement throughout the semester. His feedback has provided me with valuable insights and I am grateful for his help.

I am also grateful for the guidance I have received from the case company, Pipelife Norge AS, especially Stian Thorsen and Sigmund Aandstad. They have always been available for my questions, provided me with feedback and encouraged me through my work. I would also like to express my gratitude to Peter Sundt from Sundt Consulting and Jørn Sundby from INOVYN Norge AS, whom I came in contact with through the case company. They have also been available to all my questions and provided very useful insights.

I must also express my gratitude towards the respondents to the surveys conducted in my master's thesis. Their responses and insights provided a good data foundation for the thesis. In addition, I would like to thank Roger Viken from Trym AS, who organized a site visit for my master's thesis.

Lastly, I want to thank my fellow students, and especially my friends whom I shared an office with for the past year. Their company has made the final year of my studies very enjoyable and I must thank them for the encouragement and fun times they have contributed with.

Hedda Oppedal Olsen
Trondheim, June 2023

Abstract

Research concerning the end-of-life (EOL) options for plastic waste is significantly less explored than other options, and the research in the area of sustainable logistics systems is predominantly focused on the forward flows in the supply chain without sufficient focus on the reverse flows. An approach to waste management strategies that incorporate the reverse flows is the circular economy, where waste is reduced to a minimum and the life cycle of the product is extended. There is no comprehensive framework supporting companies in designing a circular business model, and there is a lack of discussion on the topic. It is essential to make informed decisions on how to manage the reverse flows and these research gaps establishes a need for research in the area.

The process for recycling plastic waste in Norway depends on the type of product and the origin of the plastic waste, there are for instance different processes for plastic pipes and packaging. Recycling is generally perceived as an environmentally friendly practice, because it saves energy, reduces raw material extraction and combats climate change. Producers in the Norwegian plastic pipe industry use a minimal fraction of recycled materials in their production and there is therefore a need to develop optimal reverse flows. The goal of this project was to identify there is potential for utilizing recycled plastic pipes in the production of new pipes. The objectives were to identify take back schemes in other countries and industries to outline a logistics system for the Norwegian plastic pipe industry to enable a transition to a circular industry. The following research questions were developed to reach this objective:

RQ1: *What are the obstacles that hinder the implementation of a take back scheme that would increase the circularity of the Norwegian plastic pipe industry?*
RQ2: *What are the potentials for increasing the circularity in the Norwegian plastic pipe industry?*
RQ3: *How might the process for the recycling of plastic waste in the Norwegian plastic pipe industry look to overcome the obstacles and exploit the potential for increased circularity?*

The methodology used to answer the research questions were a literature study, a case study and surveys. The literature study was used to gain an overview of the status of research in the field, support the findings of the case study and surveys and build a stronger foundation for the thesis. The case study was chosen to investigate the case company, the Norwegian plastic pipe industry and solutions in other countries. The surveys were chosen to gather first-hand information from actors in the plastic pipe industry. The findings from all these methods were used to develop a suggestion for a take back scheme in the Norwegian plastic pipe industry.

The study performed for this thesis revealed that there are obstacles hindering the implementation of a take back scheme in the Norwegian plastic pipe industry. These obstacles are related to the nature of the projects that arise, strict quality requirement in the industry, economical factors and financing of the scheme and the inherent linear thinking. Even though there are obstacles, there is also potential for implementing a take back scheme. Based on

the survey responses, the actors of the industry are positive to such a change. They see many benefits of the scheme, however, they are dependent on economical factors to ensure participation. If solutions are found for the economical challenges of the scheme, there will be great potential. The obstacles must be overcome and linear attitudes must be changed. There needs to be focus on long-term effects of the scheme, joint support of stakeholders and circular business models.

The suggestion for a take back scheme in the Norwegian plastic pipe industry is within four categories: materials and products collected, collection options, costs and cost distribution, and actors and responsibilities. Pipes produced in all three materials are included in the scheme and there are four collection options: container rental, collection points, big bags and self-delivery. The costs of the scheme are distributed between the actors, however, the pipe producers are expected to take on more of the financial liability for establishing the scheme. The pipe producers are also suggested to be responsible for the establishment and administration of the scheme in collaboration with the industry organization, while the remaining actors will be part of an association for the scheme. All the solutions are developed to meet the demands of the actors, while facilitating optimal material flows.

The objectives of the thesis can be said to be be reached and the research questions are answered. To conclude, there are obstacles hindering the implementation of a take back scheme in the Norwegian industry. However, if certain enablers are present there is also great potential for successful implementation. The suggested take back scheme is a good start for a transition in the industry, that must be further developed.

The main limitations of this study are connected to the qualitative nature of the study and the data collection. Quantitative considerations will strengthen the validity of the study, and the data foundation would have been strengthened by broadening the scope of the survey sent to actors in the Norwegian industry. There is also further research to be done. This is three-folded: the findings must be quantified to strengthen the suggestion, the remaining links of the logistics network must be developed and the solutions must be verified with actors in the industry.

Sammendrag

Forskning som omhandler håndtering av plastavfall ved materialens sluttfase er vesentlig mindre utforsket enn andre alternativer for avfallshåndtering, og gjennomført forskning som omhandler bærekraftige logistikkløsninger omhandler hovedsakelig materialflyt til sluttkunde, og mangler fokus på materialflyten etter endt bruk. En tilnærming til avfallshåndtering som inkluderer materialflyt etter bruk er den sirkulære økonomien, hvor avfall reduseres til et minimum og livssyklusen til produktene utvides. I dag finnes det ingen omfattende rammeverk som støtter bedrifter i utviklingen av sirkulære forretningsmodeller, og det er mangel på diskusjon av temaet. Det er vesentlig å ta godt informerte beslutninger på hvordan man styrer materialflyten ved endt bruk, og disse manglene i forskningen skaper et behov for mer fokus på området.

Resirkuleringsprosessene for plastavfall i Norge avhenger av typen produkt og opphavet til avfallet go det er eksempelvis ulike prosesser for plastrør og emballasje. Resirkulering oppfattes generlet som den mest miljøvennlige praksisen, fordi det reduserer energibruk, reduserer utvinning av råmaterialer og bidrar til å motkjempe klimaendringer. Produsenter i den norske plastrørindustrien bruker minimalt med resirkulerte materialer i sin produksjon, noe som er nødt til å utvikles. Det overordnede målet for dette prosjektet var derfor å identifisere om det finnes potensiale for bedre utnyttelse av resirkulerte plastrør i produksjonen av nye rør. Objektivene med oppgaven var å identifisere returordninger i andre land og industries for å foreslå logistikkløsninger for den norske plastrørindustrien for å fasilitere en overgang til den sirkulære økonomien. Følgende forskningsspørsmål ble utviklet for å nå disse målene:

RQ1: *Hvilke barrierer hindrer implementeringen av returordninger for å øke sirkulariteten i den norske plastrørindustrien?*
RQ2: *Finnes det potensiale for å øke sirkulariteten i den norske plastrørindustrien?*
RQ3: *Hvordan kan prosessen for gjenvinning av plastavfall i den norske plastrørindustrien utformes for å overkomme hindringene og utnytte potensialet for økt sirkularitet?*

Metodikken som er brukt for å besvare forskningsspørsmålene består av literaturstudie, casestudie og spørreundersøkelser. Literaturstudien ble brukt for å få oversikt over forskningen på området, støtte opp under funnene i casestudien og spørreundersøkelsene, samt legge et bedre grunnlag for masteroppgaven. Casestudien ble brukt for å få kunnskap om casebedriften, den norske plastrørindustrien og løsninger i andre land. Spørreundersøkelsene ble brukt for å samle innsikt fra aktørene i plastrørindustrien. Funnene fra dette ble brukt for å utvikle de foreslåtte logistikkløsningene.

Dette avdekket at det er barrierer som hindrer implementeringen av en returordning i den norske plastrørindustrien. Disse barrierene er knyttet til karakteristikker ved bygningsprosjektene, strenge kvalitetskrav i industrien og lineære tankesett. Selv om det er barrierer tilstede, er det også potensiale for å implementere en slik løsning. Basert på svarene på spørreundersøkelsen er aktørene i industrien positive til en slik endring. De vurderer at det er mange fordeler med en slik ordning, men dette avhenger av de økonomiske faktorene. Dersom gode løsninger finnes for de økonomiske utfordringene med ordningen vil det være godt

potensiale. Barrierene må motkjempes of lineære tankesett må endres. Det må være fokus på langsiktige effekter, samarbeid mellom interessenter og sirkulære forretningsmodeller.

Forslaget for en returordning i den norske plastrørindustrien omfatter fire kategorier: materialer og produkter som samles inn, alternativer for innsamling, kostnader og kostnadsfordeling og ansvarlige aktører. Rør produsert i alle tre materialene er inkludert i returordningen og det finnes fire alternativer for innsamling: containerleie, innsamlingpunkter, storsekker og innlevering til miljøstasjoner. Kostnadene for returordningen fordeles mellom aktørene, men det forventes at produsentene påtar seg mer av det økonomiske ansvaret for etabliringen av ordningen. Rørprodusente er også ansvarlige for etablering og administrasjon av ordning i samarbeid med industriorganisasjonen, imens de resterende aktøreene tar del i en organisasjon for returordningen. Disse forslagene er utviklet for å møte kravene fra aktørene i industrien, samtidig som det fasiliteter optimal materialflyt.

Målene for denne masteroppgaven vurderes som nådd og forskningsspørsmålene er besvart. For å konkludere finnes det barrierer som hindrer implementeringen av en returordning i den norske industrien. Dersom visse tilretteleggere er tilstede vil det allikevel være stort potensiale for vellykket implementering. Den foreslåtte returordningen er et godt sted å starte for den norske plastrørindustrien, men den er nødt til å videreutvikles.

De mest vesentlige begrensningene knyttet til denne oppgaven er at den hovedsakelig er basert på kvalitativ data og utfordringer med datainnsamlingen. Kvantitative vurderinger ville styrket troverdigheten av studien, og datagrunnlaget ville blitt styrket av bredere avgrensninger for spørreundersøkelsen sendt til aktører i den norske industrien. Det er også behov for videre arbeid, noe som er tredelt: funnene må kvantifiseres for å styrke den foreslåtte returordningen, de gjenværende kategoriene i forretningsmodellen må utvikles og ordningen må verifiseres med aktører i industrien.

Contents

List of Tables

List of Figures

Acronyms

CBM circular business models. 13, 30–32, 65, 68, 76, 77, 82

CBMI Circular Business Model Innovation. vii, 31, 65, 76

EOL End-of-life. 1, 5, 21, 29, 33, 46, 49, 50, 54, 64

EPR Extended Producer Responsibility. 18, 28, 29, 39, 48, 67, 72–74, 78

EU the European Union. 4, 21, 23, 29, 38, 39, 49, 64, 66, 67, 69, 73, 78

PE Polyethylene. 3, 24, 25, 34–36, 38, 43–45, 47–49, 53, 58, 59, 61, 64, 69

PP Polypropylene. 3, 24, 25, 34, 35, 38, 43–45, 47–49, 53, 59, 61, 64, 69

PVC Polyvinyl chloride. 3, 24–26, 34, 38, 39, 43–49, 53, 59, 61, 64, 69, 74

S1 Survey 1. 10–12, 44, 52, 53, 65, 66

S2 Survey 2. 10–12, 52, 55, 64, 65, 67–71, 73, 74, 77, 80

1 Introduction

This section will provide an introduction to the background and motivation of conducting this study, the problem statement, objectives to be reached and the research questions to be answered throughout the study. Lastly, the structure of the report will be presented.

1.1 Background and motivation

The demand for resources is rising rapidly and the challenge of global resource scarcity is critical. Manufacturing companies therefore find themselves in uncertain situations when it comes to resource supplies.(Lieder & Rashid, 2016) In addition, environmental impact is one of the most pressing issues facing logistics and transport managers today (Wong, 2010).

Research concerning the End-of-life (EOL) options for plastic waste is significantly less explored than other options, and the conventional waste management strategies for plastics are suited for linear models. (Payne et al., 2019) Research in the area of sustainable logistics systems is predominantly focused on the forward supply chain, without sufficient focus on the reverse flows. The reverse flows will also contribute to emissions and understanding the environmental impacts of reverse flows is crucial to make better decisions on product design, choice of materials and the design of logistics systems. It is essential to understand the impacts of various logistics systems for managing EOL products and make informed decisions on how to manage the reverse flows. (Wong, 2010) At some point there will be a cut-off point where the recycling processes are too complicated or resource-demanding to provide a net-benefit (Andersen, 2007), which establishes a need for new solutions.

These research gaps create a clear incentive for industries to develop alternative waste management strategies (Payne et al., 2019). The plastic industry must shift towards a circular economic model to reduce plastic waste, while retaining material value.

An approach to waste management strategies that incorporate the reverse flows is the circular economy. In a circular economy, waste is reduced to a minimum and the life cycle of the product is extended, which can also lessen the impact of resource scarcity (European Parliament, 2023). There is no comprehensive framework supporting companies in designing a circular business model, and there is lack of discussion on the topic (Lieder & Rashid, 2016; Lewandowski, 2016). The field of circular economy has many split approaches, which hinders effective implementation of it (Kalmykova et al., 2018).

There are many benefits to increasing the circularity of an industry, such as significant reductions in emissions related to the production and consumption of plastic and creating new business opportunities, cutting the costs of products and enhancing supply security with minimized environmental consequences (Deloitte, 2020; Andooz et al., 2023; Kalmykova et al., 2018; Golinska-Dawson, 2020).

Plastic materials are particularly long-lived when they are discarded, and additives that are used to prolong the working life of plastics slow deterioration of plastic waste even further (Chamas et al., 2020). This creates problems, as it is estimated that 60% of all plastics ever produced were discarded, collecting either in landfill or in the environment (Payne et al., 2019). Incineration is also a used method, which is particularly sensitive to waste stream contamination. To mitigate environmental concerns, while facilitating increase in plastic demand, it is essential to shift focus from single-use plastic to a model focused on recapturing product value, namely the circular economy. A "one-method-treats-all" strategy for the plastics industry is unrealistic, and there is a necessity to develop and diversify the recycling technologies to realize a truly green future (Payne et al., 2019).

During the fall semester of 2022, I wrote a specialization project on the topic of circularity of high-quality plastics in manufacturing companies in the Norwegian plastic pipe industry. The objective of this project was to identify the barriers for using recycled materials that are present in the Norwegian plastic pipe industry and establishing an overview of the Norwegian plastic industry and its recycling processes. The outcome of this project was an overview of the industry and a list of the barriers in the supply chain. The reason for conducting this project was to establish an understanding of how to proceed in the work of increasing the circularity of the industry, which this master's thesis is a continuation of.

1.2 Problem statement and objectives

There is a vision for the plastic pipe industry to become circular long-term, therefore it is a need for developing solutions to facilitate this. There are barriers present that makes this development more challenging. The barriers found in the specialization project were divided into the categories quality, costs, capacity and volume, supply chain coordination and market communication, and systemic change. Quality of the recyclates and a systemic change to make the transition feasible were found to be of greatest important. These barriers complicate the transition to a circular economy, which makes it even more important to prioritize. A summary of the findings are presented in section 3.

The process for recycling plastic waste in Norway depends on the type of product and the origin of the plastic waste, there are for instance different processes for plastic pipes and packaging. The waste goes into one of three categories: material recycling, incineration or landfill. Recycling is generally perceived as an environmentally friendly practice because it saves energy, reduces raw material extraction and combats climate change (Wong, 2010). According to Statistisk Sentralbyrå (SSB, 2021), 61% of plastic waste generated in 2021 went to material recycling, 32% to incineration and 5% to landfill. The percentage for material recycling is quite high, however, this accounts for all types of plastic waste. The recyclates do not go into the production of pipes. There is no clear overview of whether the pipes are recycled, incinerated or end up elsewhere. For the plastic pipe industry to become circular where recyclates are used in the production of pipes, a systemic change where the whole industry is involved is necessary.

There is a need for changes to be made with a focus on long-term system change (Mishra et al., 2022; van Buren et al., 2016). van Buren et al.(2016) discuss how circular systems are not always better than linear systems, which needs clear guidance and monitoring. Wong(2010) also discusses how recycling of metal, paper, wood, glass and plastic is generally perceived as an environmentally friendly practice because it saves energy, reduces raw material extraction and combats climate change. However, some previous studies discovered that plastic recycling supply chains are logistically inefficient, expensive, fragile and even environmentally harmful (Wong, 2010)

The goal of this project is thus to identify if there is potential for utilizing recycled plastic pipes in the production of new pipes. The objectives are to identify take back schemes in other countries and industries to outline a logistics system for the Norwegian plastic pipes industry to enable a transition to a circular industry. This will be a step further to implement the practices in the industry.

1.3 Research scope

To reach the objectives described, limitations have been made to the scope of the thesis. This has been done to make it feasible to reach the objectives within the set limits for time and resources.

There are many parts of a business and a value chain that are affected and need to be designed when implementing changes in an industry. The parts of the value chain and business model that is part of the scope for this thesis is:

- Materials: which materials to include and not include in the take back scheme
- Collection: which solutions that will be available for collection of waste
- Costs: how to distribute the costs across the value chain
- Actors: which actors are part of the solution and which responsibilities do they have

1.3.1 Plastic materials

There are many different types and qualities of plastic materials. The Norwegian plastic pipe industry use three types of plastic materials: Polyvinyl chloride (PVC), Polyethylene (PE) and Polypropylene (PP). The scope of this project is therefore limited to plastic waste of these types, which will be introduced in subsection 4.3. These materials are applicable in the industry due to their properties.

1.3.2 The plastic pipe industry

The three materials have many application areas and are used to manufacture all kinds of products. The scope of this project is limited to the plastic pipe industry, and includes plastic pipes and accessories such as fittings. This industry is relevant for the study as there is potential to make changes in it. There are examples of industries that have successful take back schemes, such as the fishing industry and fish farming industry. The Norwegian plastic pipe industry currently have no circular take back schemes. The characteristics of the industry, such as quality demands, degradation of plastic materials and a well-established linear model, creates challenges in the industry.

Other industries use materials of the same qualities as the plastic pipe industry, for instance window profiles. However, the European Union (EU) is adopting legislation for closed loop production, where for instance window profiles can not be used as a source for materials for pipe production. The scope of this project is therefore limited to plastic waste directly from the pipe industry.

The thesis is also limited to the Norwegian plastic pipe industry for several reasons. First, there are differences between the waste handling practices and legislation across borders which would make it challenging to develop a solution that would satisfy demands and function properly. Second, the actors in the Norwegian industry operate in the same market with similar customers and processes, which will enable generalization of a solution that fits the actors. Lastly, geographically it is beneficial for the collaborators to be located in the same areas. Some of the actors have production outside of Norway, but these are still included in the scope.

The scope is further limited to waste from the plastic pipe industry in the construction industry. The construction industry includes construction of buildings, road construction and demolition projects. This also includes temporary installations, excavated pipes and pipes that are damaged during transportation or storage. This limitation is done as it is an area that can generate large volumes for the industry.

1.3.3 Post-consumer waste

During the production there is waste generation, for instance due to products that do not meet specification or that are damaged during production or storage. This waste falls under a different category than the waste from the construction industry and there are separate waste handling systems for this type of waste.

Plastic waste can be separated into four different categories:

1. Offcuts and leftover products from plastic production
2. Production failure
3. Production waste
4. Post-consumer waste

The scope is limited to post-consumer waste, that is when the material is normally at its End-of-life (EOL) stage. The processes from the pipes leave the finished goods inventory until they are raw materials again is thus the scope of this thesis.

1.4 Research questions

To reach the objectives of the thesis, the following research questions have been formulated to be answered through the study:

RQ1: *What are the obstacles that hinder the implementation of a take back scheme that would increase the circularity of the Norwegian plastic pipe industry?*

This study aims to identify if there are certain obstacles that hinder the implementation of a take back scheme in the Norwegian industry. This builds upon the findings of the specialization project, as well as a literature study and a case study of the industry.

RQ2: *What are the potentials for increasing the circularity in the Norwegian plastic pipe industry?*

This study aims to uncover if there is potential in the industry to transition to a circular economy, as long as the identified obstacles are overcome. This build upon the findings of the specialization project, as well as a literature study and a case study of the industry.

RQ3: *How might the process for the recycling of plastic waste in the Norwegian plastic pipe industry look to overcome the obstacles and exploit the potential for increased circularity?*

This study aims to suggest the outline of a take back scheme for the Norwegian plastic pipe industry, within the limitations of the scope as presented previously. It builds upon the findings of RQ1 and RQ2, as well as the case study and literature study conducted.

The methodology used to answer the research questions are presented in section 2.

1.5 Thesis structure

A short description of the content of each section is presented in Table 1 below.

Table 1: Thesis structure

Section	Description
Section 1 Introduction	The introduction presents the background and motivation of the thesis, the research objectives and questions, research scope and the thesis structure.
Section 2 Methodology	The methodology chapter presents the research approach chosen and describes the research methods utilized, which are literature study, case study and surveys.
Section 3 Main findings of specialization project	This section summarizes the specialization project conducted as a foundation for this master's thesis, as it is used as foundation for the problem formulation of this thesis.This is done by presenting the background of the project, the case description and main findings.
Section 4 Theoretical background	This section presents the key theoretical perspectives that are relevant to answer the formulated research questions.
Section 5 A case study: The Norwegian plastic pipe industry	The case study section introduces the case company, the customer segment and construction industry, and provides an example of waste handling at a construction site.
Section 6 Solutions for circular waste handling	This section presents descriptions of four existing take back schemes in the plastic pipe industry, as well as an example of a take back scheme outside the plastic pipe industry.
Section 7 Findings	This section is separated into two main parts: survey results and suggestion for take back scheme in the Norwegian plastic pipe industry.
Section 8 Discussion	The discussion section is used to elaborate on the findings from section 7, as well as discussing the findings, the validity of them and seeing them in conjunction with the theoretical background. Lastly, the limitations of the study and further work needed is discussed.
Section 9 Conclusion	The conclusion summarizes the key points of section 7 and section 8, to conclude and answer the research questions. In this section, an assessment of the objectives, contribution to knowledge, main limitations and further work is also presented.

2 Methodology

To efficiently investigate a topic, one needs a clear definition of the chosen topic and the methods to be employed. A challenge with this is to choose the appropriate methods for investigation of the research questions. (Karlsson, 2008) There is an important distinction between research methods and research methodology. Research methods can be described as all the techniques that are used to conduct research, while research methodology is a way to systematically solve the research problem (Kothari, 2004).

The chosen research methods thus constitutes parts of the research methodology, where each method is carefully selected to contribute towards finding answers to a given research problem. In this chapter, the developed methodology for this thesis is presented. This consists of a literature study, a case study and surveys.

2.1 Literature study

A literature review is extensive reference to related research and theory in the field, and connections are made between the references found and the position chosen in the research. This can be used to support the identification of a problem or to illustrate that there are research gaps that need to be filled. (Ridley, 2012) A literature review of the field you are studying must be performed to gain thorough understanding of the current work in the area to position one's research, and examined before defining the research problem (Ridley, 2012; Kothari, 2004).

A thorough literature study was previously conducted in the specialization project, which founded the formulation of the specific problem to be researched in this thesis. The problem statement was formulated based on the current status of research and the scope was narrowed down as the literature study endured. The formulated research questions for the specialization project can be found in section 3. The search words for this literature study was divided into two main categories, with adjacent search words. These are presented in Table 2 below.

Table 2: Search words: literature study

Focus of research	Main search words	Additional search words
Circular economy	Circular economy	Barriers
	Closed loop	Benefits
	Cradle to cradle	Challenges
		Concepts
		Definitions
		Enablers
Plastic recycling	Plastic recovery	Challenges
	Plastic recycling	Nordics
	Waste handling	Norway
	Waste management	Plastic types
		Plastic volumes

The work performed in this literature study directed the results found in the project conducted. The research questions for this master's thesis were formulated with the results of the specialization project as the foundation. A literature study was then performed with the scope of the research foundation, to strengthen this master's thesis. The main focus of this study was the current status for similar solutions as the one to be developed in this thesis, the circular economy and its concepts and tools, plastic materials, circular business models and circular logistics network design.

The relevant literature was mostly found by searching for relevant articles and books in Google Scholar, Science Direct and NTNU's library search engine Oria. The articles with relevant titles were selected, then keywords and abstracts were read through. Sources that were found to be relevant were then read through thoroughly to extract relevant insights and key points. The snowball technique was also used to find relevant articles, which means following up references from the bibliographies of articles that you have already read (Ridley, 2012). For the searches that acquired an extensive number of results, year of publication was considered to elect the most relevant sources. To manage the references, the built in reference tool in Overleaf was used by downloading formatted citations from Google Scholar and Oria.

A literature study is an ongoing process that starts when you read the first article or book and ends when you finish the final draft (Ridley, 2012). The study was thus performed throughout the whole master's thesis, and developed as the direction of the thesis developed. The case study and surveys, which is described in the next sections, were important parts of this thesis. The literature study was used to support the findings of the case study and surveys, find key theoretical perspectives and develop the foundation for the thesis.

2.2 Case study

The case study approach was chosen to investigate the case company, the Norwegian industry and similar companies and industries in other countries. A case can be defined as a detailed description of an organization, incident or phenomenon (Karlsson, 2008). There is no one definition of case study research, but it can generally be described as an intensive study of a person, a group of people or a unit, with the purpose of generalizing for a larger group of cases or units (Heale & Twycross, 2018; Gerring, 2004, 2007; Flyvbjerg, 2011) This method allows researchers to take a complex and broad topic and narrow it down into a manageable research question, as well as gaining more in-depth insight into the topic (Heale & Twycross, 2018). Case studies can be performed for many purposes, but they are usually carried out as a research method to generate findings or relevance beyond the individual cases. Case studies are not rigorously planned, and the conduct of the study is guided by what they see in the field to deal with unexpected findings (Fidel, 1984).

The two main steps when performing a case-study are as follows (Heale & Twycross, 2018):

1. Defining the case
2. A search to determine what is known about the case through a review of literature, reports and so one. Data in case studies are often qualitative

For this thesis, the case to be explored was defined in collaboration with the case company to ensure a mutual understanding of the topic to be researched. Next, a search for literature on the topic was performed to uncover what was already known. Then, similar cases in other countries were explored. This was supported by the execution of surveys, as described in the next section.

The case study was performed with a qualitative approach, which is usually concerned with constructivism, interpretation and perception, rather than with identification of a rational and objective truth (Karlsson, 2008). This was beneficial to create an understanding of the situation and interpret the understanding to develop the results of the thesis. The interpretations and uncertainties were discussed with company representatives during the work to avoid misinterpretations.

A benefit of the case study approach is that theory developed for the case is well-suited for new research areas or research areas where existing theory is inadequate (Eisenhardt, 1989). This is well-suited for the case in question, as existing theory does not cover what is necessary to easily develop new solutions, and the area of circular economy is still quite young.

Another of the benefits of a case study is that you gain in-depth understanding of a topic, which will involve collecting several different types of data (Heale & Twycross, 2018). The technique for data collection is determined by the nature of the subject and you usually look for a variety of sources to supply the collected data (Fidel, 1984). The data for this thesis was collected through sources found online, emails and meetings, and surveys to collect first-hand data from the industry. The online sources for the case study to a large extent consisted of material from a conference for waste in the construction industry, Byggavfallskonferansen, which was held in February where companies from the construction industry participated to discuss construction waste. Meetings and discussions with representatives from the case company were used to collect insights from them and to provide new approaches to strengthen the work. Lastly, how the surveys were used is described in the next section.

2.3 Surveys

Surveys are most often used to describe a method of gathering information from a sample of individuals, where the sample is a fraction of the population being studied (Scheuren, 2004). There are many ways to conduct a survey, but the basic steps in the survey process are the same for all types of surveys (Sue & Ritter, 2007). The process of conducting a survey is broadly:

1. Defining the study's goals and objectives
2. Deciding on the type of survey to employ
3. Developing the survey questionnaire and choosing participants
4. Monitoring data before the deadline
5. Analyzing and presenting the results

For this thesis, two surveys were used. The first survey, from now on referred to as S1, was used to gather information about existing solutions from other countries. The purpose of this was to get more details on the design process, the resulting scheme and challenges they experienced. Five respondents were contacted to participate in this survey and four of them participated. These respondents were provided by Jørn Sundbø and Peter Sundt. Jørn Sundbø is a representative from the raw material producer INOVYN Norge AS and therefore has many contacts in the plastic industry. Peter Sundt is a consultant hired by Pipelife Norge AS, that has long experience in various roles in the plastic industry. They provided contacts that were seen as very relevant for the study. The survey consisted of 15 questions in total and can be found in Appendix A.

The second survey, from now on referred to as S2, was used to gather demands from the different actors affected by the proposed solutions. It is crucial to consider the opinions of the user, as the proposed solution will not work without their support. 21 respondents were contacted to participate in the survey and 14 of them participated. These respondents were provided by the case company. The respondents were divided into different groups based on their roles, the categories were: entrepreneur, distributor, renovator, recycler and others. The questions uncovered demands, ranking of important criteria and opinions on how the solution should be organized. The survey consisted of 13 questions in total and can be found in Appendix B.

An important decision in the survey process is choosing how to conduct the survey, which can be done in many different ways, such as by phone, by email or in person (Scheuren, 2004; Sue & Ritter, 2007). Both surveys were sent by email, meaning that the survey is accessed through a link in an email invitation (Sue & Ritter, 2007). Online surveys are fast and efficient and allows direct data entry. By using phone or in person surveys it is easier to ask complex questions, as misunderstandings can be solved (Sue & Ritter, 2007). The information must be collected by standardized means, so that every respondent is asked the same question (Scheuren, 2004). Online surveys do not provide the opportunity of explaining the questions or giving additional information, but all participants are asked the same questions without interviewer's bias. The questions were in a Microsoft Office Form, where it is easy to sort the questions, it offers different options for how to ask questions, such as text, ranking, multiple choice and so on, and it is easy to gather all questions in one place.

The survey process started by defining objectives for the survey. For S1 this was to gather information about existing solutions and for S2 this was to gather opinions from the actors in the supply chain. Next, the work on narrowing down participants began. Sampling is the process of selecting items from a larger population to include in the study, where items can be individuals, groups or what you wish to collect information on or about. The degree of generalizability and representativeness and the validity of the findings are related to the sampling. If the items know little about the topic, the data will not be very informative. (Guest, 2014; Sue & Ritter, 2007)

For S1 it was not important that the results could be used to generalize or that the answers were representative for the opinions of a group of individuals. The focus was rather the validity of the answers and first-hand knowledge on the topic. The size of the population depends on the purpose of the study (Scheuren, 2004) and the five participants were specifically elected based on their knowledge. For S2, it was important to get different perspectives on the topic. If the topic is complex and involves multiple stakeholders, and you collect data from only one group, the findings will be limited in scope and relevance (Guest, 2014). The respondents were therefore elected from four categories, with "Others" as an additional option. The actor that will be affected the most in their day-to-day activities by the solution is entrepreneurs, and a high number of entrepreneurs was thus included. S2 was dependent on more respondents than S1, to uncover as much information and opinions as possible. This also allows generalizing the answers to a larger extent, to consider if there is consensus among the actors.

Next, the survey questionnaire was developed. The best questionnaire items are short, unambiguous and meaningful to the respondent (Sue & Ritter, 2007). To ensure that the questions were unambiguous and meaningful, the questionnaires were sent to the internal supervisor at NTNU and the case company. They gave feedback on clarifications that would make the questions easier to understand for someone outside the project. For the more complex questions, descriptions were added with additional information or examples to make it easier to understand. Questions can be open-ended or closed and the manner of how the questions are asked will affect the results of a survey (Scheuren, 2004). Both surveys consist of a combination of open-ended and closed questions. The open-ended questions are used to allow the respondent to express their opinions and prioritize what they see as relevant. The closed questions to compare answers and uncover consensus, through choosing between or ranking predefined alternatives.

The questionnaire must be considered as a whole (Scheuren, 2004). The surveys were introduced with a description of the project, the survey and why the respondents were elected to ensure connection to the topic. Another aspect is that the questions flow well from one to the next, as earlier questions provide information and context to the respondents thay may influence the answers (Scheuren, 2004). The questions were asked in a logical manner, where they are affected by previous considerations.

There is a recurrent problem encountered by nearly all surveys: people who are asked may not respond. This is called non-response and refers to discrepancy between the group approached to complete a survey and those who provide data. Most often, the gap of information is filled by assuming that their data approximates the data provided by respondents. (Burkell, 2003) This would not work for these surveys, especially in S1. The wanted output was specific experiences and knowledge, which cannot be uncovered by filling in the gap. In S2, filling in the gap would not give an accurate representation of the answers. The surveys had a deadline of one week, and a reminder was sent before the deadline, as well as after to gather more responses. For S1, four out of five respondents answered the survey. For S2, 14 out of 21 respondents answered the survey. According to Burkell(2003), you need a 75% response rate to accurately ensure generalization. However, the response rates are considered as sufficient, due to the objectives of the surveys.

After the responses were collected, the data was downloaded and grouped, before they were gone through thoroughly. Fro S1, it was necessary with clarifications and elaborations, where the respondents were contacted by email. For S2, the responses were systematically sorted and interpreted.

3 Main findings of specialization project: Barriers for increased circularity in the Norwegian plastic pipe industry

As mentioned previously, I have written a specialization project on the topic of circularity of high-quality plastics in manufacturing companies in the Norwegian plastic pipe industry in collaboration with Pipelife Norge AS, which laid the foundation for this master's thesis. In this chapter, the background of the specialization project and the main findings that are deemed relevant for the master's thesis are summarized.

3.1 Background

Over the past years, the number of studies on the circular economy has increased rapidly, but studies on logistics and supply chain management is still underrepresented (Golinska-Dawson, 2020). Establishing well-functioning business models for distribution and securing optimal utilization of resources is crucial for the profitability of circular business models (CBM) (Deloitte, 2020). Some challenges that are highlighted in the literature are fragmented supply chains and limited awareness across the supply chain (Adams et al., 2017).

There is low utilization of plastic waste in the Nordic region and a fraction of plastic materials go back into production processes through reuse and recycling practices (Milios et al., 2018). The Nordic markets are characterized by low volume, demand for a relatively high quality of the material for input and output and fluctuating supply of input materials to recyclers (Hennlock et al., 2015). Plastics have the potential to be recycled many times (Milios et al., 2018), however, there are challenges hindering the transition to a circular plastic industry in Norway. The objective of the specialization project was therefore to identify the barriers for using recycled materials in the Norwegian plastic pipe industry. The outcome of the project was thus a list of barriers present in the supply chain, as well as an overview of the Norwegian plastic industry and its recycling processes.

The scope of the project was limited to the Norwegian actors and market, as the vision is to mobilize the Norwegian industry. Next, the scope was limited to recycling in a circular economic perspective, to exclude other approaches such as manufacturing of products with longer lifespans. Lastly, the scope was limited to include high-quality plastics from industrial applications and for instance excludes packaging.

To meet the objectives of the project, three research questions were formulated and answered. These are listed below, where SP represents specialization project.

SP-RQ1: *How is the Norwegian plastic pipe industry and its recycling processes organized?*

SP-RQ2: *Which barriers are present in the Norwegian plastic pipe industry that hinder circular recycling of the materials?*

SP-RQ3: *Which of the categories of barriers are of greatest importance and to what extent do they require cooperation between several actors to be handled?*

3.2 Case study

Demands from customers and the industry requires that products are manufactured in accordance with high quality standards. Pipelife Norge AS processes around 40 000 tons of material annually and almost exclusively use virgin plastic. The case company expressed that there are barriers in the supply chain that hinder the implementation of circular economic concepts, which must be tackled to facilitate a transition. It must also be acknowledged that at some stage there will be a cut-off point where recycling will become too difficult and burdensome to provide a net-benefit;a circular economy cannot promote recycling in perpetuity (Andersen, 2007). The first step of the process was to identify the barriers, which creates an understanding of how to facilitate the transition.

3.3 Findings

In this section, the main findings of the specialization project are presented. The findings are summarized and not explained thoroughly, to provide the necessary background for the master's thesis.

3.3.1 The Norwegian plastic pipe industry

To answer SP-RQ1, the characteristics of the Norwegian plastic industry, its actors and recycling processes were identified. An interesting characteristic of the industry is that the will to change is generally higher for the industries that are consumer related, for instance packaging producers are under higher pressure from the public than pipe producers (Grønt Punkt Norge, 2019). It requires more of the actors to make the necessary changes if there is no pressure from the outside, which makes an efficient argument not to invest in new solutions.

The Norwegian plastic pipe industry has an organization that represents the industry to the government and other organizations, called NPG Norge. Practically all actors of the Norwegian plastic pipe industry are part of the organization. (NPG Norge, 2023)

The process for recycling plastic waste in Norway depends on the type of product and the origin of the plastic waste. For instance, there are differences between the recycling flows of plastic pipes and the recycling flows of plastic packaging. In figure 1 below, a visualization of the material flows in the plastic pipe industry in Norway is presented.

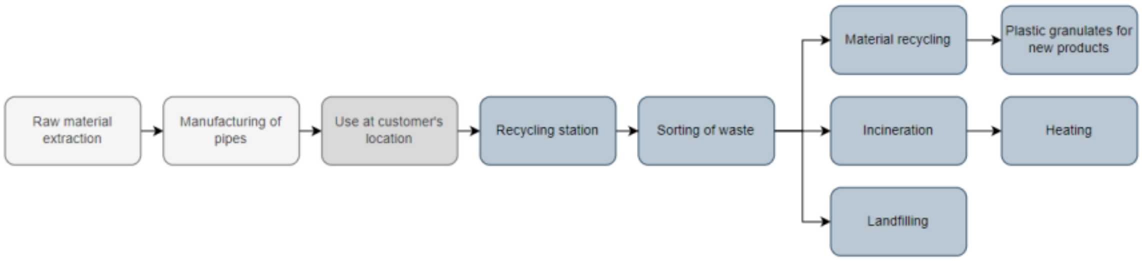

Figure 1: Material flows in the plastic pipe industry

There are three main stages: manufacturing, use and waste handling. Raw material extraction consists of extraction of material, processing and polymerization. Manufacturing consists of the main steps granulate melting, extrusion and cutting. After use, the materials are distributed to a recycling station or waste company. After sorting, there are three alternatives for further processing: material recycling, incineration and landfilling. In material recycling, the plastic is melted to plastic granulates that can be used for new products. Due to the quality and impurity the plastic granulates are not used for new pipes, but rather other products such as packaging. In incineration, the material is burned for heat, which typically happens for products such as pipes and not packaging. The last alternative is landfilling, which in general does not happen in Norway.

For generated waste of all fractions of plastic in 2021, 61% went to material recycling, 32% to incineration and 5% to landfill. Of the waste that is sent to recycling, a large percentage of it is sent abroad (Deloitte, 2020). There are many actors offering recycling services and knowledge of increasing the circularity of the plastics industry in Norway. Resources are therefore available to enable a transition, but it increases the need for cooperation and communication.

The Norwegian Directorate of Environment, Miljødirektoratet, has set strict rules for the producers' responsibility in the handling of waste. The responsibility is regulated through waste regulations, which say that manufacturers must be members of a publicly approved waste return company. Return companies are approved by Miljødirektoratet, and the manufacturers must pay a fee to be members. Return companies are then responsible for the manufacturer's responsibilities on behalf of them. (Avfall Norge, 2023)

3.3.2 Barriers

Through the work of the specialization project, several barriers were identified. These barriers were divided into five main categories: quality, costs, capacity and volume, supply chain coordination and market communication, and systemic changes.

Table 3: Barriers for increased circularity in the Norwegian plastic pipe industry

Category	Barriers
Quality	The recycled plastics fail to meet the high-quality standards that characterizes the demand.
	The quality of recycled plastics is lower than for virgin materials due to the degradation of the material.
	Separation steps and recycling in fractions is not performed, which impurifies the quality of the plastic material.
Costs	It is more costly to recycle the plastic in fractions of different waste streams to ensure high purity.
	The cost of virgin raw materials will in many cases be lower than the price of recycled materials.
	The economic benefits of the circular economy is harder to grasp than the environmental benefits.
	There is a lack of investment power for the considerable amount of upfront investments.
	Costs and revenues are unevenly distributed in the supply chain.
	Taxes and charges specified by governments do not promote the implementation of circular economy.
Capacity and volume	The Nordic market for recycled plastic is characterized by low volumes of input material and a fluctuating supply.
	The low volume and lack of supply act as a barrier for investing in the necessary capacity for recycling.
	The supply of input material must be stable and not fluctuating for manufacturers to depend on it for production.
Supply chain coordination and market communication	Awareness and sence of urgency among companies is still too limited to trigger a large-scale shift towards circular actions
	The promotion of consumer responsibility is crucial, but it is challenging to define who has which responsibilities.
	The plastic value chain is very fragmented, and there is in general a lack of coordination and communication between the supply and demand actors.
	Single links are able to optimize their own production processes, but the individual optimization will not result in optimal closed-loop supply chains.
Systemic change	The transition to a circular economy requires comprehensive changes in several subsystems.
	The linear economic view is very embedded in our society.
	There will at some point be a cut-off point where the circular economy is not better than a linear one.
	There is no comprehensive framework supporting companies in the development of circular business models.

All the barriers presented in the table will be of importance in the transition to increasing circularity, however, they will affect the transition to different extents. Out of the five defined categories, quality and systematic change was considered as most important. The quality of recycled materials is crucial, as they can not be used in the industry if they are not of high enough quality. The price of recycled materials can be significantly lower than the price of virgin materials, but if the quality is not high enough the manufacturers will still use virgin materials. The barrier of systemic change will also be important, as the solutions found will not be possible to implement unless there is a fundamental change in how the industry conducts business.

Even though some barriers are deemed to be of greater importance than others, all effect each other. For instance, costs and volume are closely related to quality and systemic change. The industry will not transition unless it is economically sustainable, economic prosperity is even mentioned before environmental quality when the aim of the circular economy is defined.

Pipelife will depend on cooperation with other actors to find solutions for the barriers. Cooperation is a prerequisite for success and several actors in the supply chain are involved and will be affected. The barriers affect the potential for a well established solution to a great extent, and it will be beneficial for all actors to continue the work on this.

4 Theoretical background

The findings presented in subsection 3.3 laid the foundation for the development of the objectives of this master's thesis. After finalizing the specialization project, it was necessary to move beyond the barriers and further develop the theoretical foundation of the thesis.

The further theoretical background that is relevant for answering the research questions is presented in this chapter. First, the circular economy is presented alongside definitions, some of the key concepts and benefits of the circular economy. Second, a comparison of the linear and circular economy is made. Next, the concept of Extended Producer Responsibility (EPR) is presented, before different types of plastic materials and processes for recycling plastics is presented. Lastly, developing circular business models and designing logistics networks is presented.

There are many theoretical perspectives that can be relevant for this master's thesis. For instance, the concept of supply chain management in circular business models could be elaborated on. However, exclusions must be made. The theoretical perspectives that are presented are therefore chosen as they can provide substance to the thesis.

The sections on the circular economy, comparison of linear economy and circular economy and plastics are based on the literature study performed in the specialization project.

4.1 Circular economy: the basics

There are many definitions of the circular economy, but there is not one that is broadly agreed upon. Kirchherr et al.(2017) conducted a study on 114 definitions of the circular economy, and found that along with the lack of an agreed upon definition there is also conceptual confusion of what the circular economy is.

The various definitions indicate that the circular economy is frequently portrayed as a combination of reuse, reduce and recycle activities, often excluding that it necessitates a systemic shift. The study concluded on the following definition: *"An economic system that replaces the "end-of-life" concept with reducing, alternatively reusing, recycling and recovering materials in production, distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond) with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations"* (Kirchherr et al., 2017, p. 229).

The circular economy can also be understood as the realization of a closed-loop material flow in the economic system (Geng & Doberstein, 2008). To ensure impact, the circular economy must be understood as a fundamental systemic change and not a bit of twisting of the current status (Kirchherr et al., 2017). According to Payne et al.(2019) the circular economy is based on three key principles: reduce plastic waste and pollution through product design, retain resources and products in use and regenerate and preserve natural systems.

The focus on resource efficiency and waste reduction opens up for new business opportunities through closing the material loops in the economy (Golinska-Dawson, 2020). The circular economy is to an increasing extent treated as a solution to a series of challenges, such as waste generation and resource scarcity (Lieder & Rashid, 2016). At some point there will be a cut-off point where the recycling processes are too complicated or resource-demanding to provide a net benefit (Andersen, 2007). It is crucial that the transition is economically beneficial to be sustained over time, which must be considered in the activities of the circular economy.

There are various approaches and concepts that can be implemented to transition to a circular economy. The circular economy can have various gradations, which are frequently referred to as the 9 Rs (van Buren et al., 2016). The 9 Rs are:

1. Refuse: preventing the use of raw materials
2. Reduce: reducing the use of raw materials
3. Reuse: product reuse; second-hand and sharing of products
4. Repair: maintenance and repair
5. Refurbish: restoring a product
6. Remanufacture: creating new products from old products
7. Repurpose: product reuse for a different purpose
8. Recycle: processing and reuse of materials
9. Recover energy: incineration of residual flows

These can be combined in different ways, with the most common combinations being 3R (reduce, reuse and recycle), 4R (reduce, reuse, recycle and recover) and 6R (reduce, reuse, recycle, remanufacture, repair and refurbish) (Golinska-Dawson, 2020; Kirchherr et al., 2017; van Buren et al., 2016). Many view the R framework as the "how-to" of circular economy.

Another key concept is the waste hierarchy, which considers the order of priority in waste handling from the most preferred option to the lease preferred one (Zhang et al., 2022). Energy efficiency and effective utilization of natural resources is prioritized (Manickam & Duraisamy, 2019). The five steps in the waste hierarchy, ranging from most to least preferable, are:

1. Reduce and avoid creation of waste
2. Reuse
3. Recycle
4. Energy recovery
5. Disposal

(Manickam & Duraisamy, 2019)

The hierarchy gives top priority to preventing the creation of waste. Once waste is created, it gives priority to recover it in an order of environmental preference (Nelles et al., 2016). The main driving force of the waste hierarchy is environmentally sound disposal of waste, as well as ensuring that the value of resources is preserved (Zhang et al., 2022).

The waste hierarchy and R framework build upon the same principles. Both consider the whole life cycle of a product, emphasize the design and use of a product before it turns into waste and managing waste in the perspective of resource effectiveness. The main difference between the concepts is that the waste hierarchy allows disposal, which the R framework does not. (Zhang et al., 2022). There are also many circular economic concepts dedicated to the design process of products, however, the concepts of waste handling are more relevant for this thesis.

The main aim of the the circular economy is economic prosperity followed by environmental quality. Societal benefits are often not considered in definitions. (Kirchherr et al., 2017) Several researchers have proved that the introduction of circular economic principles provide a superior solution towards societal and environmental impact (Manickam & Duraisamy, 2019). Economic analyses show the benefits of circular resource management, which can coincide well with societal and environmental value creation (van Buren et al., 2016)

The economic benefits are what attract the participation of stakeholders (Golinska-Dawson, 2020), which makes it essential to the transition. The circular economy contributes to enhancing profitability through reducing materials costs and providing larger profit pools (Kumar et al., 2019; Lieder & Rashid, 2016; Ellen MacArthur Foundation, 2013), reduces the impact of increasing prices of virgin raw materials due to resource scarcity (Kumar et al., 2019; van Buren et al., 2016) and provide competitive advantage (Kumar et al., 2019; Lieder & Rashid, 2016)

The environmental benefits of the circular economy is often more apparent than economic prosperity (Kumar et al., 2019). It contributes to less product of virgin raw materials, extending life cycles of materials, increasing availability of materials and reduction of environmental deterioration (Kumar et al., 2019; van Buren et al., 2016; Manickam & Duraisamy, 2019; Lieder & Rashid, 2016).

The circular economy will also strengthen the connection between the society and the industry as it requires extended collaboration (Kumar et al., 2019). It also has the potential to create employment opportunities. Some sectors may diminish, but there is still a projection of a net creation of jobs (Kumar et al., 2019; van Buren et al., 2016; Reichel, De Schoenmakere, & Gillabel, 2016)

There are many benefits to the circular economy and increasing pressure from EU, making a transition eventually inevitable. For this to be achievable, certain enablers must be present. One of these is business models, which some claim to be seen as the core of the circular economy (Lewandowski, 2016). This topic can be read more about in subsection 4.6. Other enablers that are important include joint support of all stakeholders (Lieder & Rashid, 2016; van Buren et al., 2016), promoting consumer responsibility (Gallaud & Laperche, 2016), cooperation with the logistics industry (van Buren et al., 2016; Ellen MacArthur Foundation, 2013) and a systemic shift (Kirchherr et al., 2017)

4.2 A comparison of the linear economy and the circular economy

There are fundamental differences between the linear economic model and the circular economic model. In this section, a brief description of the linear economy is presented. Thereafter, a comparison of the two models is presented based on the description of the circular economy in the previous section.

4.2.1 The linear economy

The linear economy is the model that is most widespread and how the system in place today would be described. Manickam and Duraisamy (2019) describes it as a linear model of consumption, where companies extract materials, add labor and energy and sell it to consumers who dispose it after use, when it no longer serves its purpose. This stems from a mindset of products having the purpose of beind discarded after use, which can be seen as planned obsolescence (Lieder & Rashid, 2016). There are many terms used to describe the linear model, for instance "source-use-waste", "take-make-waste" or "take-make-dispose" (Manickam & Duraisamy, 2019; van Buren et al., 2016). Social and environmental interests are undervalued and mistreated in this model, as it is dominated by short-term profit (van Buren et al., 2016).

According to Payne et al. (2019), the linear economy is a significant contributor to the plastic waste challenges. There are different waste management strategies that offer alternative EOL alternatives for plastic, but they often stem from a linear economic model. To mitigate growing environmental concerns it is essential that the plastic industry evolves, shifting its focus to a model focused on retaining product value and reducing waste, namely the circular economy. (Payne et al., 2019)

4.2.2 The differences of the linear economy and the circular economy

The linear and circular economy are based on fundamentally different perspectives. In the linear economy, materials are extracted to make products and eventually thrown away as waste. In contrast, the circular economy stops waste from being created in the first place. (Ellen MacArthur Foundation, 2013) There is increasing awareness that the linear take-make-waste system is unsustainable and should be replaced with a circular system where waste is transformed to useful resources (Manickam & Duraisamy, 2019). This would offer alternatives that entail better business cases and added value (van Buren et al., 2016).

In the circular economy, the value of the product is defined by focusing on value retention (Manickam & Duraisamy, 2019). "Waste" and "resources" are not differentiated in the circular economy, which stands in contrast to the conventional waste management system (Lieder & Rashid, 2016). One of the challenges with the linear economy is that it turns well-functioning materials into waste and the environment into its waste reservoir (Kumar et al., 2019). The circular economy not only focuses on reducing waste through recycling, but also reducing the consumption of raw materials, which separates it from the take-make-waste thinking (Kumar et al., 2019; van Buren et al., 2016; Yuan, Bi, & Moriguichi, 2006)

The linear economy can be seen as an open system with the assumption of unlimited resources, while the circular one is a closed system with limited resource supply (Lieder & Rashid, 2016). Hence, the circular economy will help fight the resource scarcity, while the linear economy contributes to it. In a circular economy, the speed of resource depletion and waste generation are reduced. If one assumes that the population is rapidly growing, the speed of resource depletion will be greater in a linear economy than a circular one. (Lieder & Rashid, 2016)

The concept of circular economy is developed based on insight in the current economy, as it is seen as necessary to make fundamental changes in the business models (Lieder & Rashid, 2016; Manickam & Duraisamy, 2019). There are many ways to define the transition, such as "cradle to grave" to "cradle to cradle" or "make-use-dispose" to closed-loop cycles (Lieder & Rashid, 2016; Manickam & Duraisamy, 2019). The transition can be achieved through reduce, reuse and recycle activities.

The transition can reduce costs and impact through reducing sourcing of raw materials and waste processing (van Buren et al., 2016). Both models focus on economically sustainable development, but only the circular considers environmental and social development (Kumar et al., 2019).

The differences between the linear economy and the circular economy is presented in Figure 2 below.

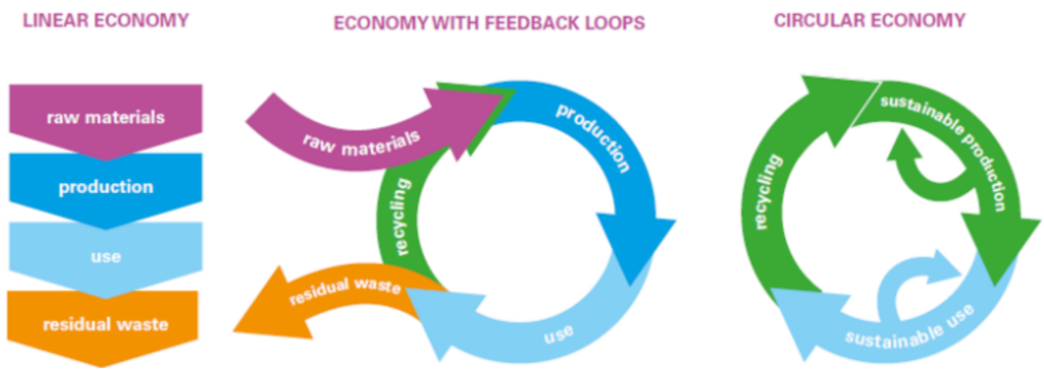

Figure 2: Comparison of the linear and circular economy
(van Buren et al., 2016)

The linear economy stands out the most from the other two models. The economy with feedback loops, also referred to as the recycling economy, and a fully circular economy differ in the way that the recycling economy requires input of raw materials and allows the generation of waste. In addition, the circular economy has the reuse of materials as an integrated factor in the model. The circular economy differs from both models by the fact that it also entails the production and use of renewable energy as one of the constituent principles. (van Buren et al., 2016)

The preceding comparison of the linear model and the circular one illustrates the limitations of a linear economy, and how the circular one can be considered as a solution for harmonizing economic growth and environmental protection (Lieder & Rashid, 2016). However, at some point there will be a cut-off point where the circular economy is no longer beneficial, and it therefore requires clear guidance and monitoring (van Buren et al., 2016). The circular model can not be said to be better than the linear one under all circumstances.

4.3 An introduction to plastic materials

Plastic materials have widespread use in the manufacture of products, such as packaging, textiles, floor coverings and pipes (Aguado, 1999). Plastics have played an important role in the development of society, being used in a variety of sectors (Payne et al., 2019). In the EU, the use of plastic is dominated by packaging, followed by building and construction (Shen & Worrell, 2014). The many qualities, such as being lightweight, resilient and highly durable, are what makes the materials desirable and superior in many applications (Aguado, 1999; Shen & Worrell, 2014; Shrivastava, 2018).

It is not easy to define the term "plastic", which is usually considered as equivalent to the term polymer. The term "resin" is usually used to describe virgin polymeric material without added components, while commercial plastics includes other components such as additives, fillers and compounds to improve their properties (Aguado, 1999)

Polymers are usually classified according to two main criteria: thermal behavior and polymerization mechanism, which is important for deciding the most suitable methods for recycling (Aguado, 1999). The classification depends on the behavior when heated. The most common category is called thermoplastics, which all three types used in the plastic pipe industry fall under. Thermoplastics undergo a softening when heated to a particular temperature and can easily be reprocessed by heating and formed into a new shape. (Aguado, 1999; Shen & Worrell, 2014)

4.3.1 The three types of plastics: PVC, PE and PP

There are three types of plastic used in the Norwegian plastic pipe industry: Polyvinyl chloride (PVC), Polyethylene (PE) and Polypropylene (PP). There are many qualities within the different main types, but the industry is dependent on qualities suited for pipe production due to strict quality demands.

Polyvinyl chloride (PVC)
PVC is a widely used polymer, and in terms of revenue generated it is one of the most valuable products of the chemical industry. As of 2018, over 50% of the manufactured PVC is used in construction for house siding, piping and so on (Koerner & Koerner, 2018).

There are two main grades of PVC: rigid and flexible. The rigid PVC is directly obtained from polymerization, and is stiff, hard and often brittle. Flexible PVC is obtained by blending with a variety of plasticizers and is a soft and pliable material. Rigid PVC is used in the manufacture of sheets, pipes, window profiles and so on, and flexible PVC is used for wire coating, toys, floor coverings and so on. (Aguado, 1999)

PVC is a very versatile material and is inexpensive, hard, easy to assemble and highly processable (Koerner & Koerner, 2018; La Mantia, 1996). Additives are used to improve the performance of the material for use in specific applications and the additives are chosen based on application, tradition of the marked and local legislation (La Mantia, 1996).

Polyethylene (PE)
PE is the most common and most widely used plastic (Agboola et al., 2017; Basmage & Hashmi, 2020; La Mantia, 1993). As of 2017, over 100 million tons of PE resins were produced annually, accounting for 34% of the total plastic market (Basmage & Hashmi, 2020). The material is found nearly everywhere today, from grocery bags, plastic wrap, drainpipes, milk cartons to trash cans. It is common and extremely useful and cost-effective (Dhakal & Ismail, 2021).

PE is easily processed and can be made into a variety of shapes and forms (Dhakal & Ismail, 2021). The mechanical properties of the material depend on variables such as branching, crystal structure and molecular weight (Basmage & Hashmi, 2020). One of the favorable qualities PE has is its ability to tailored for a variety of uses (Dhakal & Ismail, 2021).

PE can be made into different types depending on the reaction conditions (Aguado, 1999).

The three basic types of PE that are most frequently used and sold most are HDPE, LDPE and LLDPE (Agboola et al., 2017; Basmage & Hashmi, 2020):

- High-density polyethylene (HDPE): has a high and specific gravity and a high degree of crystallinity. The main applications are for the manufacture of films, food containers, crates and pipes.
- Low-density polyethylene (LDPE): is a highly branched polymer characterized by lower crystallinity and specific gravity than HDPE but with greater flexibility. The main applications are use in films for bags and food packaging, greenhouses, bottles, cable insulation and injection molded parts.
- Linear low-density polyethylene (LLDPE): is a polymer with intermediate properties with respect to LDPE and HDPE. The main applications are films, injection molded parts and wire insulation.

(Aguado, 1999)

Polypropylene (PP)

PP is produced in lower volumes than PE and PVC. For instance, it was expected to be produced 35 million tons of PP in 2020 , compared to 100 million tons of PE in 2017 globally. Even though PP is produced in lower volumes, it is important industrially and used in a number of industrial applications. (Greene, 2021)

There are many reasons for why PP is an important material; it has a high softening point, good processability and economic advantages (Tomić & Marinković, 2020). PP is also tough, rigid, produced in a variety of molecular weights and has a low melting point (Greene, 2021; Menyhárd et al., 2020; Tomić & Marinković, 2020).

The polymerization of PP results in two main types for commercial applications, depending on temperature, pressure and reactant conditions (Greene, 2021):

- Isotactic polypropylene (i-PP): i-PP is the most widely produced type. The main applications are manufacture of injection molded containers, pipes, sheets and textile fibres. An advantage of i-PP is that it is rigid and crack resistant and it has good electrical insulation properties.
- Syndiotactic polypropylene (s-PP): s-PP has low density and mechanical strength. It is used in significantly lower amounts, and the main areas of application are use for coating material and in hot melt adhesives.

(Aguado, 1999)

4.4 Recycling plastics

As the use of plastic is steadily increasing, plastic waste management is becoming a growing concern. Yet, plastic recycling is still limited compared to most other bulk materials. Recycling rates for plastics are increasing in many countries, and an international market for recycled plastics is developing. (Shen & Worrell, 2014)

There are three main waste management strategies: landfill, incineration and recycling. Landfill is the conventional waste management approach and it is estimated that 60% of all plastics ever produced were collected in landfill. An issue with this is that plastics can persist up to several decades. Incineration reduced the need for landfill, however, PVC is particularly unsuited for it due to the chlorine content of the material. This can be remedied by using filters, but the technology is expensive. (Payne et al., 2019) Recycling is considered to be the most environmentally friendly alternative for disposal of plastics (La Mantia, 1996; Shen & Worrell, 2014). Recycling allows waste to be reintroduced into the consumption cycle, but it is crucial that the amount of energy consumed in recycling is lower than the energy required for production of new materials. The costs and impacts of producing virgin materials compared to recycling depends on unit size of materials, sorting and cleaning and so on (Aguado, 1999; Karsa & Hoyle, 1997). The environmental impact of recycling depends on many factors, for instance the energy used for collecting the waste and the type of material and application being replaced by the recycled plastics (Shen & Worrell, 2014).

Plastics can be recycled by two approaches: mechanical and chemical, where the most common is mechanical. Chemical recycling is a suitable approach if the materials are not suited for mechanical recycling, for instance if the material is of low purity. In case of chemical recycling, the materials are transformed to chemicals or fuels instead of polymers. (Aguado, 1999; Shen & Worrell, 2014)

Mechanical recycling consists of melting the material to produce granules or finished products, and typically includes four main steps: sorting, shredding, washing and drying, and melting and reprocessing (Payne et al., 2019; La Mantia, 1996; Shen & Worrell, 2014). The first step is to sort the material, as the collected and transported waste usually is a mix of various types and non-plastic impurities. Sorting and separation is required to improve material quality and subsequent steps of refining is necessary. This is a challenging process, where the achievable purity level is a trade-off between costs and market requirements. The next step, shredding, entails reducing the size of the scrap to allow more efficient transport and storage of the material. Then, the materials are washed and dried until they are ready for reprocessing. There are many techniques for reprocessing, and the choice of technique is based on the material and the aim of it. (Shen & Worrell, 2014)

Limitations of mechanical recycling such as limited compatibility between different polymers arises interest in and potential for chemical recycling. Chemical recycling is used when a single polymer stream is not available for recycling or when the sorting process is too costly or has a large environmental impact. (Payne et al., 2019; Karsa & Hoyle, 1997) This can be done through a number of chemical processes and the materials can be used as a source of chemicals and fuels (Payne et al., 2019; Aguado, 1999; Karsa & Hoyle, 1997). The main problem involved in chemical recycling techniques is high capital expenditure of the technologies and high energy consumption in the process (Payne et al., 2019; Aguado, 1999) . The polymer industry expresses interest in shifting to a circular economy approach, which in conjunction with policy and legislation will play a crucial role in accelerating the uptake of technologies (Payne et al., 2019) .

Plastic recycling is complicated by two main problems: degradation during processing and lifetime and incompatibility of different polymers. In addition, other factors such as melting points and size and shape of materials will affect recyclability (La Mantia, 1996). Recycled materials usually show lower properties and performance than virgin materials and can therefore in many cases only be used in applications where the material's properties are not critical (Aguado, 1999; Karsa & Hoyle, 1997; La Mantia, 1996).

Polymers suffer degradation during use due to impact from for instance temperature (Aguado, 1999). Repeated recycling and exposure to the environment damages the structure of the polymers and reduces durability, melt properties, solid properties and chemical and physical resistance (La Mantia, 1996) . Norner(2022) highlights processability, homogeniety, mechanical properties, odor and migration, color and traceability as some of the main challenges of using recycled plastics. The degree of degradation depends on the processing conditions and the nature of the polymer. This is a fundamental difference between plastics and for instance metal and glass. As an example, the metal content of a can may be refabricated to an identical can. (La Mantia, 1996)

Incompatibility of polymers is also a challenge. Polymers are difficult to separate and only a few polymer pairs are compatible. This is valid even for blends of virgin and recycled polymers of the same type and only small amounts of recycled materials can be used to avoid drastic decrease in mechanical properties. (La Mantia, 1996) This happens since it is challenging to establish a general recycling procedure that takes into account the large variety of chemical properties. Costly separation processes are required to obtain waste streams of homogeneous composition. (Aguado, 1999)

Recyclers also face a problem of finding reliable sources of used materials and organizing their collection and transportation. Collection requires sophisticated organization and transportation, which may jeopardize the profitability of the recycling process. (La Mantia, 1993) A stable and reliable supply of material is a prerequisite for recycling processes to be feasible. Consistency in quality is not yet achievable for all recycled plastics, due to the collection, sorting and processing of recyclables. Consistency is required to assure economical, uniform processing and known, acceptable end-product properties (Karsa & Hoyle, 1997).

4.5 Extended Producer Responsibility (EPR)

With a growing need for resources and amount of waste, proper management of waste is a growing concern for policy makers (Gupt & Sahay, 2015). As presented in subsection 4.4 on recycling plastics, the most environmentally friendly alternative for disposal of plastics is recycling. Despite of the benefits, a lack of incentives for stakeholders, information failure and technical constraints act as barriers to develop an operable recycling industry, which struggles to achieve the desired results (Gupt & Sahay, 2015; Stromberg, 2004). A policy that was developed to promote environmental improvements of products is Extended Producer Responsibility (EPR). EPR is increasingly recognized as an efficient waste management policy (Kosior & Crescenzi, 2020).

EPR is an environmental protection strategy where the producer is responsible for the entire life cycle of the product, especially for take back, recycling and final disposal of the product (Lindhqvist, 2000). This principle makes the producer responsible for the environmental impacts through the life cycle of products and extends responsibility and focus to the post-consumer stage of the product's life cycle (Lindhqvist, 2000; Gupt & Sahay, 2015; Nahman, 2010; Kosior & Crescenzi, 2020; Clift et al., 2022; Gaur et al., 2022; Sin & Tueen, 2023). Lindhqvist(2000) developed a model to distinguish the different forms of responsibility, which is shown in Figure 3 below.

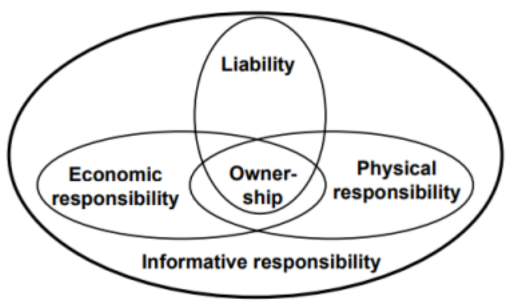

Figure 3: Different forms of responsibility in EPR

There is a need for defining the responsibilities, both in terms of who and what. Lindhqvist(2000) defines the responsibilities in the following way:

- Liability: responsibility for environmental damage caused by the product. The extent of liability is determined by legislation and can include different parts of the life cycle
- Economic responsibility: the producer covers all or part of the expenses for the collection, recycling or final disposal of the product, which can be paid directly by the producer or by adding fees
- Physical responsibility: describing the systems where the producer is involved in the physical management of the product

- Ownership: the producer must retain ownership throughout the life cycle
- Informative responsibility: possibilities to provide information on environmental properties

The aim of EPR is to reduce waste, by increasing the recycling rate and decreasing dependency on virgin raw materials (Kosior & Crescenzi, 2020). This is based on the polluter-pays principle, which encourages producers to develop designs that improve recyclability and minimize the impact of products (Kosior & Crescenzi, 2020; Gupt & Sahay, 2015; Lindhqvist, 2000). It moves the responsibility of managing products at the EOL stage partially or fully to the producing industry.

There are a number of benefits that can be achieved if EPR is implemented effectively: increased collection and recycling rates, reduction of public spending on waste management and design for environmental innovations (Kosior & Crescenzi, 2020).

EPR is still a relatively new policy that needs to be optimized to function as intended and its implementation is administratively and logistically complex (Gaur et al., 2022; Clift et al., 2022). There has been an increase in the number of policies implemented with EPR principles in the previous year and EPR policies are well established in for instance Europe and Canada (Gupt & Sahay, 2015; Kosior & Crescenzi, 2020). As an example, all EU member states have EPR schemes regulated by EU directives for packaging, batteries, EOL vehicles and electrical and electronic equipment (Kosior & Crescenzi, 2020).

EPR is rarely the most economically preferable alternative. There are only certain situations where the prices of raw materials are high enough to promote recovery and environmental taxes have in general not been high enough to promote recycling. (Clift et al., 2022) In addition, budgetary and physical restrictions hinders companies in making necessary supply chain modifications (Sin & Tueen, 2023). EPR is therefore in many instances a regulatory approach instead of a voluntary strategy where companies are mandated to take back products at EOL (Clift et al., 2022).

Another challenge with the principle is a lack of clarity in the roles and responsibilities of stakeholders, such as collectors and recyclers, municipalities and consumers (Gaur et al., 2022). There are several success factors for implementation, where some of the most important have been found to be: financial responsibility of the producers, separate collecting and recycling agencies and take back responsibility (Gupt & Sahay, 2015).

4.6 Circular business models

An important enabler of the circular economy is business models, as some see as the core of the circular economy or the driving force in the transition (Lieder & Rashid, 2016; Kirchherr et al., 2017; Lewandowski, 2016). Today, there is no comprehensive framework supporting companies in designing circular business models (CBM) (Lieder & Rashid, 2016; Lewandowski, 2016; Geissdoerfer et al., 2020; Antikainen & Valkokari, 2016). Most of the reviews that exist today focus on the concept of circular economy itself, as the concept of CBM has emerged more recently (Antikainen & Valkokari, 2016; Geissdoerfer et al., 2020). In this section, the concept of CBM is introduced.

4.6.1 Circular Business Models (CBM): an introduction

A business model can be defined as the conceptual logic of how an organization creates, delivers and captures value, where the value is a solution to a problem of a customer (Linder & Williander, 2017; Bocken et al., 2019; Antikainen & Valkokari, 2016). A business model is typically portrayed by a value proposition, value creation and delivery and value capture mechanisms, and illustrates how the business operates (Bocken et al., 2019).

Circular business models can be defined as the rationale of how an organization creates, delivers and captures value within closed material loops (Geissdoerfer et al., 2020; Mentink, 2014; Linder & Williander, 2017; Antikainen & Valkokari, 2016). The value creation is based on utilizing value maintained in products after use and implies a return flow to the manufacturer. The concept overlaps with closed-loop supply chains, and always involves recycling, remanufacturing or reuse activities. (Geissdoerfer et al., 2020; Linder & Williander, 2017). CBM focus on slowing, closing and narrowing loops to retain economic value, reduce environmental impacts and deliver superior customer value (Bocken et al., 2019).

The business models, products and supply chains that are dominating today were developed for linear systems and are not suited for closed-loop systems (Lieder & Rashid, 2016). Establishing well-functioning business models for distribution services and securing optimal utilization of resources is vital for the profitability (Lieder & Rashid, 2016; Deloitte, 2020; Geissdoerfer et al., 2020). There are many opinions on how they should be developed, where one popular approach is that manufacturers are responsible for the disposal or recycling of the products, as it would incentivize supply chains that facilitate recycling of materials (Manickam & Duraisamy, 2019).

Businesses should interpret the circular economy as a new way of making profit, instead of a tool to increase their resilience (Geissdoerfer et al., 2020), and creating innovating business models is therefore crucial. Closing the material loops will affect many, if not all, aspects of the current business models a business has (Mentink, 2014). Even though CBM can promote significant cost savings and radical reductions in environmental impact, there is still not widespread adoption in the industry (Linder & Williander, 2017). New business models will also be key to implement the circular economy on the organizational level and will allow a systemic shift (Geissdoerfer et al., 2020).

One of the challenges with CBM is the return flows. Efficient return flows is a critical aspect of the business model, but due to unstable predictability and reliability of the return flow it is challenging. Another challenge is the lack of supporting regulations in policy, laws and regulations. Due to inherent differences between circular and linear business models these can be hard to overcome. (Linder & Williander, 2017)

4.6.2 Circular Business Model Innovation (CBMI)

Business model innovation is necessary to reap the benefits from recycling activities (Linder & Williander, 2017). There is a need for establishing definitions and conceptual frameworks for how to develop circular business models, as most of the reviews that exist today focus on the concept of circular economy itself (Geissdoerfer et al., 2020).

Business model innovation can be defined as creating, delivering and capturing value that is achieved through changes to components in the business model (Antikainen & Valkokari, 2016). Innovating the business models can be done in one of two main approaches: design of an entirely new business model or reconfiguration of the elements of an existing business model (Bocken et al., 2019). It is important to consider that 100% circular business models do not exist due to practical limitations (Mentink, 2014; Antikainen & Valkokari, 2016). A system-wide innovation changing the whole process of value creation is needed to facilitate the transformation (Antikainen & Valkokari, 2016).

CBMI is a relatively young field and the tools and methods developed are generally in the form of guidelines with low level of detail and applicability in different settings (Bocken et al., 2019). Many tools developed for circularity purposes remain unused, likely due to them not being tested empirically and not including users and their needs in the CBMI process. Another likely reason is that they are too complex or time-consuming. Bocken et al.(2019) therefore suggests the following characteristics for CBMI tool development:

- The tool is purpose-made for CBMI
- The tool is developed from both literature and practice insights
- The tool is iteratively developed and tested with potential users
- Circular economy or broader sustainability objectives and impacts are firmly integrated into the tool
- The tool is simple and not too time-consuming
- The tool triggers business change

Researchers are developing tools for how to design CBM. For instance, Antikainen and Valkokari(2016) developed a framework for developing sustainable models based on the business model canvas and studies on the circular economy, which includes factors on several levels, for instance trends in the environment and business-specific factors. Considerations like this is important to create a broader understanding of value, which includes benefits and costs to stakeholders beyond the firm, such as environmental impact (Bocken et al., 2019). In addition, a CBM does not need to close material loops by itself within its system boundaries, it can be part of a system of business models that close material loops (Antikainen & Valkokari, 2016).

It is crucial to have joint support of all stakeholders to successfully implement circular economy at larger scale (Lieder & Rashid, 2016; van Buren et al., 2016), and consumer responsibility must also be promoted for this to work in practice (Gallaud & Laperche, 2016; Ghisellini, Cialani, & Ulgiati, 2016). The transformation sets challenges for the established companies, as their ideas are realized through their established business models (Antikainen & Valkokari, 2016).

4.7 Logistics networks in a circular economy

As described in subsection 4.2, there are fundamental differences between the linear and circular economy, which will also affect the logistics solutions and network design. The developed logistics networks has a fundamental impact on the profitability of reverse logistics systems and logistics solutions must be designed so that they facilitate optimal flow of materials (Fleischmann et al., 2004; Mishra et al., 2023).

Logistics involve the business activities that are required to supply products that meet the demand; from raw material extraction to product delivery (Beames et al., 2021). Reverse logistics is the process of moving products from their destination to disposal or added value to the products (Mishra et al., 2023). The conventional supply chains are open-loop and the product leaves the initial supply chain once it reaches the customer, while closed-loop supply chains also includes the collection of used products (Beames et al., 2021; Geissdoerfer et al., 2018). Reverse logistics does not necessarily entail closed loops, but one approach is to integrate reverse logistics in conventional supply chains to form closed-loop chains. This requires an integrated management of forward and reverse flows of products. (Golinska-Dawson, 2020; Mishra et al., 2023; Beames et al., 2021).

The design of the logistics network depends on the targeted products, for instance if they are perishable or complex, as well as the recovery type, for instance recycling remanufacturing or reuse. In this thesis, recycling is the relevant recovery type, where recycling is said to be completed in three broad steps: collection and re-processing, production and buying new products from recycled materials. The different practices may require specific supply chain network design and companies must understand their priorities. (Mishra et al., 2023)

There are three key strategic decision-making problems in supply chain design: centralization of the network, product-oriented versus service-oriented and coordination of the logistics services. There are also four main categories of supply chain network design: facility role, facility location, capacity allocation, and demand and supply allocation. (Beames et al., 2021).

There are many decisions to be made in circular logistics network design that are connected to the strategic problems. How these decisions are made, will have major impact on supply chain performance (Fleischmann et al., 2004). One decision to be made is the location of the various processes of the reverse supply chains, which includes facilities, location of production, storage, inspection of collected products and so on (Fleischmann et al., 2004; Mishra et al., 2023; Beames et al., 2021). Collection and distribution of the products must be determined, which includes transportation, how to collect products from end-users and how to distribute recovered products to future customers (Fleischmann et al., 2004; Beames et al., 2021). In some cases, specialized facilities to collect and reprocess products must be set up (Mishra et al., 2023). To reduce market variation, an optimum price of returned products must also be determined. Lastly, a proper legal structure and the sorting policies implemented must be decided. (Mishra et al., 2023). The decisions made will be a detailed planning of the flow of products through the supply chains (Beames et al., 2021). To make these decisions, it is essential to know about all the components involved in the supply chain process, from the raw material supplier to the end-user (Mishra et al., 2023).

There are several critical aspects that are necessary for successful reverse logistics, which will depend on the nature of the industry. For this specific case, critical aspects will be stakeholder participation, supply chain collaboration, recapturing value, logistics cost optimization, recycling efficiency, minimizing energy costs, transportation optimization, waste reduction and information transparency. (Mishra et al., 2023)

There are also challenges with managing the reverse logistics. Some of these are scalability of the system, establishing forecast for the volumes in the system, reverse logistics of EOL products being seen as costly and complex to be managed and collaboration between organizations (Mishra et al., 2023; Julianelli et al., 2020; Geissdoerfer et al., 2018).

5 A case study: The Norwegian plastic pipe industry

The case study performed throughout the work on this thesis lays the foundation for the results found. The aim of the case study was to gather information that can provide insights into the suggested solution. The case is based on the Norwegian plastic pipe industry and the case company is Pipelife Norge AS.

In this section, the case company is introduced. A summary of key characteristics of the industry was presented in section 3. Next, the customer segment is presented. This is done by first presenting an overview of the flow of materials between producers and end-users, as well as a section on the use of plastics in the construction industry. Lastly, an example of the waste handling at one construction site is used to illustrated solutions found today.

This section is based on meetings with and email discussions with the case company, the specialization project and information from Pipelife's website. In addition, information from Byggavfallskonferansen is used to present the customer segment ,and a site visit at a construction site is used to present an example of waste handling at a construction site.

5.1 An introduction to the case company: Pipelife Norge AS

Pipelife Norge AS is Norway's biggest manufacturer and supplier of pipe systems made of plastic. Pipelife Norge AS is part of the Pipelife group, which is one of Europe's leading manufacturers of plastic pipes. Pipelife has managed to develop a unique concept, where the whole western hemisphere is their market (Pipelife, 2023).

Pipelife has three facilities: Surnadal, Stathelle and Ringebu. In Surnadal, they produce pipes in PVC and PP for water and drainage, as well as pipes for gas, water distribution, sewage systems, cable protection and electrical installations. This is the headquarters and also the largest facility. In Stathelle, they produce pipes with large diameters in long lengths in PE. The pipes that are produced here are used in large installations both domestically and internationally for transporting water and other liquids. In Ringebu, they produce pipe systems with built-in frost protection in PE. Their production is classified as semi-process industry with continuous extrusion, and they have extreme demands for quality. (Strandhagen, 2021)

Supplying clean drinking water, transporting wastewater and protecting cables and electrical installations are fundamental. An increased use of Pipelife's products can have a positive impact on the environment, and the goal is therefore not to reduce the use of their products. Pipelife's goal is that their pipes have the least possible impact on the environment during production and transportation, does not harm the environment during use, are of good quality so that leaks are avoided, and has a long lifespan so that it contributes to reduced use of resources in a life cycle assesment (Pipelife, 2023).

Pipelife is part of the Norwegian plastic pipe industry. As the aim of this master's thesis is to suggest logistics solutions for the industry, the industry must be seen as a whole. The case company is one of the largest companies in the industry and can therefore initiate a transition in the industry. The raw material producer INOVYN Norge AS has also been an important contribution to this thesis. It is beneficial that they are included in the work to ensure different perspectives.

Pipelife is actively working on improving their practices. They for instance simultaneously have an ongoing project with Norner; a company working on sustainable solutions in industries where plastic materials are in center. The focus of this project is PE and PP.

5.2 Customer segment

Pipelife has customers within many different sectors and their products are used in both public and private construction projects. They therefore need to produce, distribute and market a wide range of pipe systems for different areas of use. This includes water and drainage, sewage, freshwater, cable protection and pipes for electrical installations. In this section, Pipelife Norge AS' customer segment is presented.

5.2.1 The flow of materials in the plastic pipe industry

Pipelife normally distributes its products through wholesalers, who place orders and receives invoices from Pipelife. The wholesalers distribute the products to entrepreneurs, who install the products. They are thus the end-users. In cases of large volumes, the materials can be transported directly to the construction sites and not physically go through the wholesalers. In most cases the materials go through the wholesalers.

The construction projects can be separated into two main categories: in-house and infrastructure. Most of the large entrepreneurs in Norway have projects within both categories, but the projects are separated into these categories. Infrastructure involves the road sector, energy sector and water and drainage, while in-house involves in-house soil, plumbing and electrical installations. For the case company, infrastructure represents around 80% of the volume sold and in-house represents around 20% of the volume sold. The distribution of these categories varies throughout the year and can not be said to be valid for all pipe producers. Both infrastructure and in-house projects will contribute with temporary installations, damaged products in the flow of goods, cut-offs and excess materials, while in-house will also contribute to pipes from demolition. A large percentage of the materials that are distributed to the projects are used in lasting solutions, while only a fraction of the total volume ends up as waste during the construction project. An overview of the flow of materials is show in the figures below.

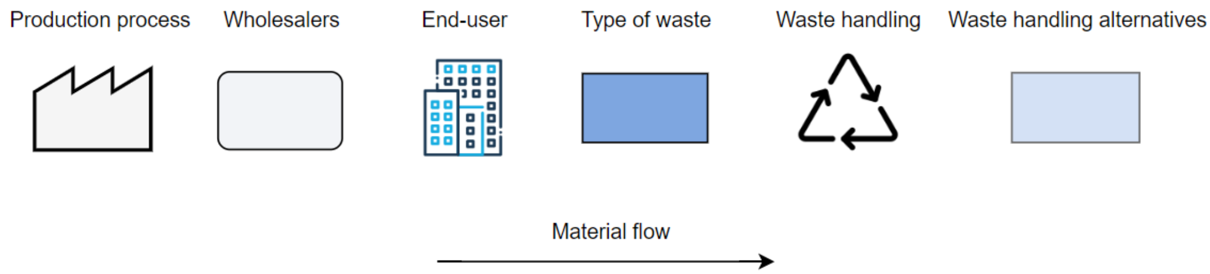

Figure 4: Legend for material flows in the plastic pipe industry

In Figure 4, an explanation of the necessary information to interpret the figures illustrating the material flows is shown.

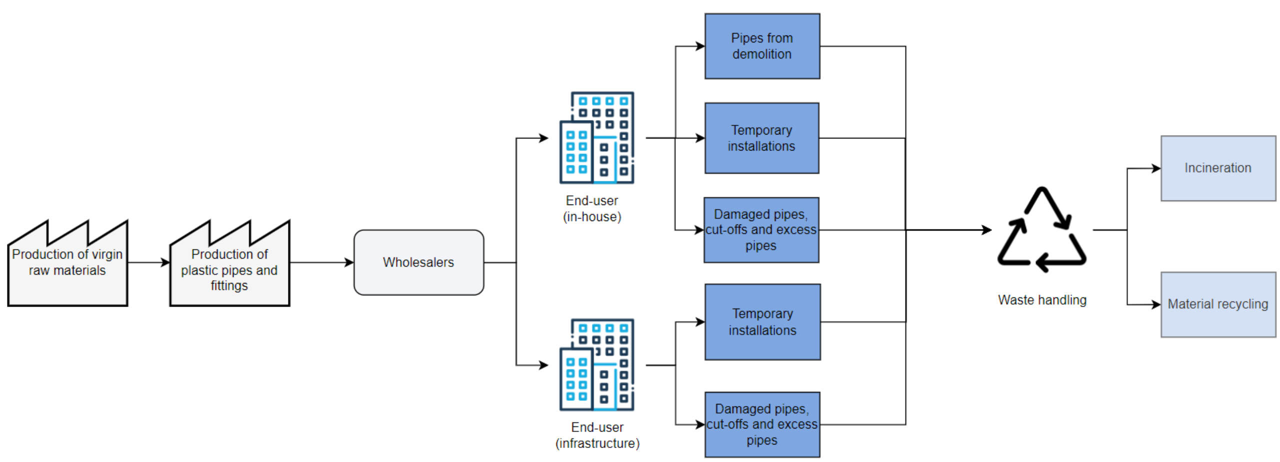

Figure 5: Illustration of the flow of materials in the plastic pipe industry: current situation

Today, the material flow starts from the production of virgin raw materials. The pipe producers purchase virgin raw materials directly from the raw material suppliers. After production of pipes and fittings, the products are sold to wholesalers. The wholesalers then distribute the products to the end-users. After use, the products end up in the categories of waste as shown in the figure and are sent to waste handling. The waste handling options are incineration or material recycling, where the materials can be used in production of plastic applications with lower demands for quality.

There is no organized scheme for the take back of materials today. However, there is to a certain extent a circular loop for plastic pipes today, particularly from recycled PE from the aquaculture industry. For Pipelife Norge AS, the fraction of recycled materials in their production is approximately 2%. The ambition is significant growth of this number in the next few years, which is why an organized take back is required. An illustration of the vision for this is shown in Figure 6.

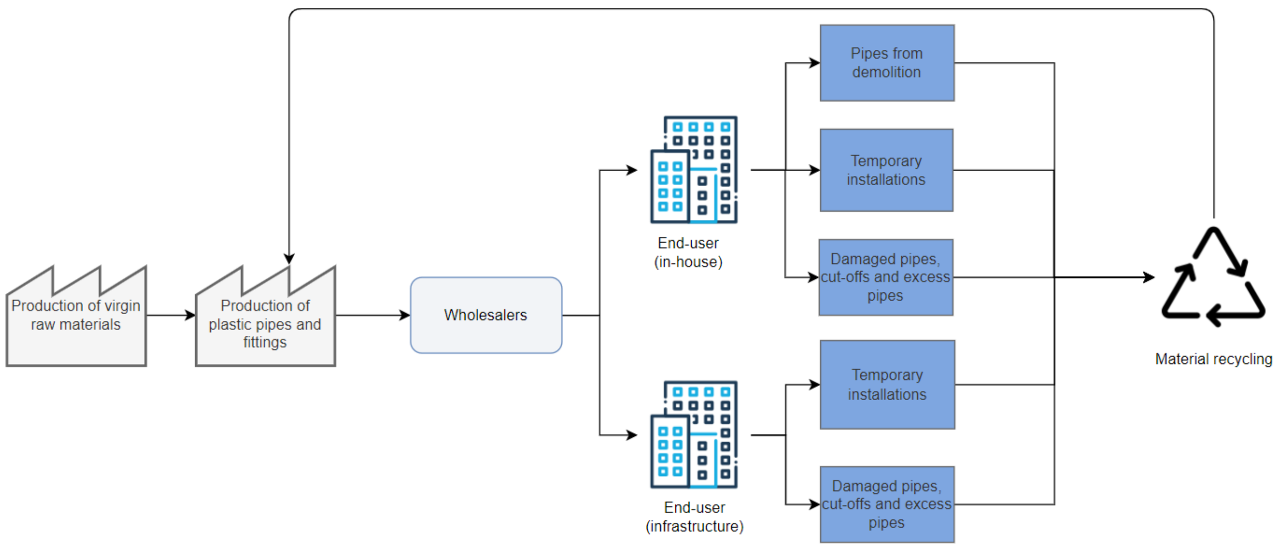

Figure 6: Illustration of the flow of materials in the plastic pipe industry:take back loop

In Figure 6, the illustration of the material flow is adjusted to show the material flows with a take back scheme. It is the same from the production of virgin raw materials until after use of the products. The materials will then go to material recycling, where they are processed and returned to the producers of plastic pipes and entered back into the flow. In this situation, the recyclers will also act as raw material suppliers. Growth of a circular solution would decrease the need of supply of virgin raw materials.

5.2.2 The use of plastics in the construction industry

The construction industry contributes to large amounts of waste and can therefore be an important part of the transition to a more circular handling of materials in the industry. In this section, the use of plastic in the construction industry is presented. Not all of the information in this section is based on pipes directly, but it is still relevant to illustrate the status in the industry.

A lot of plastic materials are used in construction projects. Some characteristics of the industry is that the amount of plastic is increasing, there is a low degree of sorting, use of long-lived products with additives and significant emissions (Mikkelborg, 2023).

In construction of buildings, plastics are used for many applications. Some of the main applications are:

- Pipes: water, sewage and flexible and rigid pipes
- Profiles: windows and window profiles

- Others: floor covering, waterproofing, electrical installations and so on

(Mikkelborg, 2023)

Materials account for 70% of the carbon footprint associated with building and construction activities (Sintef, 2023). PVC constitutes around 36% of the total plastic volume in the construction industry and is the most commonly used type of plastic. Different qualities of PE constitutes 18% of the total volume, and PP constitutes 8% of the total volume. (Mikkelborg, 2023; Plastics Europe, 2021)

There is a lot of uncertainty regarding the amount of plastic materials in the construction industry, how much is recycled and the percentage in different categories. The numbers you find depend on the databases used for retrieval of data, methods for calculations, differences between countries and different definitions of terms. However, numbers can be found to estimate the current situation. According to Mikkelborg (2023), 180 000 tons of plastic materials are introduced to the Norwegian market annually, where the distribution is pipes (38%), isolation (34%), windows and profiles (5%) and others (24%). These estimates are based on discussions with actors and available Norwegian and European literature.

Globally, the construction industry represents a large portion of waste production, environmental damage and climate emissions. Due to the uncertainty of numbers, there are different opinions on how much the industry represents. According to Isola AS (2023), the construction industry represents 40% of all CO_2 emissions, 40% of energy consumption and 40% of waste creation. According to (Ressurssentral, 2023), the construction industry contributes to 50% of raw material extraction, 40% of CO_2 emissions and 35% of waste creation. Sintef (2023)claims that the construction industry in Norway accounts for around 25% of waste.

According to Handelens Miljøfond (2023), the construction industry is the second largest end-consumer of plastic in Norway, only preceded by packaging. The use of plastics is also increasing and it is expected that by 2040 the Norwegian industry will generate 130 000 tons of plastic waste, which is almost seven times as high as in 2020.

The EU has set a goal of 70% of materials to be reused or recovered from the construction industry. According to Norwegian statistics, Norway is at around 45%. (NIRAS Norge AS, 2023; Sintef, 2023)Norwegian reporting to EU shows 63% "material recovery" (NIRAS Norge AS, 2023). There are many terms that can be used, such as "recycling", "recovery" and "backfilling operations". This makes it uncertain what the number reported actually represents. The statistics from EU can not be used to compare countries, but rather consider development within countries.

Most European countries have requirements for material recovery in their legislation and in Norway these regulations are called "Byggteknisk forskrift (TEK17)". TEK17 provides the minimum requirements a building must meet to legally be built in Norway (Direktoratet for byggkvalitet, 2023). TEK17 states that materials should be suitable for reuse and recycling and edifices should be suitable for disassembly later (Rockwool, 2023; Multiconsult Norge, 2023). There are also requirements for sorting of waste, but there are no requirements for where the waste should go. Therefore, it often goes where the costs are lowest (NIRAS Norge AS, 2023). The Norwegian regulations are affected by the legislation in the EU, which can affect the future of construction waste. For instance, the EU Comission is considering specific material recovery rates for different products and waste fractions (NIRAS Norge AS, 2023). There are increasing demands for sorting and reuse of materials both in new constructions and in renovation projects in Norway, which will lead to less waste and better utilization of materials (Rockwool, 2023). NIRAS Norge AS (2023) suggests requirements for separate collection of construction waste and stricter recovery rates in the industry. Mikkelborg (2023) suggests the concept of EPR, as described in subsection 4.5, as an incentive for actors.

There are other factors than legislation that will affect the recovery rate. For pipes specifically, the barriers described in section subsection 3.3 will complicate the process. Mikkelborg (2023) also highlights demand for recycled materials, additives in older products, purity of sorted plastics, costs of sorting waste, lack of knowledge and lack of incentives for recyling as challenges. At construction sites, lack of routines for cleanup and lack of responsibility and defined areas of responsibility are also challenges (Nomiko, 2023). Intermediate storage of waste and smaller amounts of plastic being rejected also creates problems, as it makes it seem like the total volume is smaller than it is (Nomiko, 2023).In addition, the plastic waste arises at different points in the construction process, for instance before, during and after, making the total volume seem smaller.

Attitude changes in the industry is important to facilitate change, for instance changing the perception that plastic waste is waste, it is an important raw material source (Isola AS, 2023). The industry's path to increased resource efficiency depends on communication and collaboration across the value chain (Sintef, 2023).

For the road section specifically, Statens Vegvesen has a goal to be "promoter of circular economy in planning, construction and operation of roads". They are planning on more than halving the emissions from construction, operation and maintenance of roads by 2030. The road section has "KFA-ordningen", which can be described as a control scheme for asphalt recycling that has requirements for asphalt materials to be sent to facilities across the country for processing and recycling. The facilities report annual material flows and they therefore have an overview of the status in the market. (Statens Vegvesen, 2023) The road section already focuses on circularity and reuse of materials and KFA-ordningen works well. This scheme only includes the asphalt materials, as it is the material with the most substantial volume and impact in the sector. Requirements that used to be "should be" have been reformulated as "must be" in regulations for the road section (Statens Vegvesen, 2023). The eagerness in the industry shows that there is potential for recycling plastic as well.

There are some take back schemes established both in Norway and other European countries. Some examples are the Norwegian company Vartdal Plast that work for EPS to be recycled and the German company Rewindo that recycles doors and windows of PVC into new PVC profiles (Mikkelborg, 2023). In Oslo, a collaboration among several actors resulted in "Sirkulær Ressurssentral", which is a center for recycling and reuse of used building materials (Ressurssentral, 2023). The objective is to contribute to increased reuse of building materials, making reuse the natural first choice. The center is a 4500 m^2 tent where materials from a predefined list are received and sold. There is increasing interest in initatives like this, but crucial infrastructure is missing to create a sustainable market (Ressurssentral, 2023). This is also a barrier for the plastic pipe industry. Another good example is ROCKCYCLE, which is an established circular system for insulation of buildings. This can be read more about in section subsection 6.2.

5.3 An example of waste handling at a construction site

To create a better understanding of the practical implications of waste handling at a construction site, a site visit to an ongoing construction site was performed. Stian Thorsen, my contact person in Pipelife Norge AS, put me in contact with an entrepreneur that is an end-user of Pipelife's products to schedule a visit. This visit is used in this section to describe a practical example of waste handling at a construction site, as well as some additional information about how this can be conducted in other projects.

The example project visited is a project that is run by the entrepreneur company Trym AS right outside city centre in Trondheim, Norway. There are many new residences being built in the area, consequently there is a need for new roads in the area. Trym AS' project is building these roads. The project has been ongoing for around one year and the deadline for completion is the 1^{st} of June, so they are in the finishing stage of the project.

They have four containers at the construction site: residual waste, wood, metal and mixed plastic. All four containers are located adjacently at an allocated section at the site. All plastic materials can be disposed in the container for mixed plastics and they do not differentiate products or type of plastic material. The plastic is sorted out so that additional elements are not included in the container. As can be seen in the pictures below, pipes are a large part of the waste in the container for plastic waste (on the right), but plastic materials also end up in the container for residual waste (on the left).

Figure 7: Collection of residual waste and plastic waste at a construction site

For this project, the waste management company Retura is used for all waste handling activities. When a container is full, Trym AS calls Retura. The containers are then picked up the next day. In most cases, they return the container after it is emptied. In some cases, they deliver an empty container when picking up the full container. Retura is paid for the rental and transportation of containers. The handling of residual waste costs more than plastic waste, since the materials must be sorted. As this is a relatively large project, containers are necessary to collect waste from the beginning of the project and this container of plastic waste is the second one thus far.

The project belongs in the infrastructure segment of the construction industry. They are building new roads in a developed area, which makes it so that they can not build in straight lines and must adjust to the surroundings. The pipes must be cut and adapted to the area, which increases the volume of cut-offs. In the picture below, the collection of cut-off pipes are shown. Cut-offs is the largest volume of waste in this project. The cut-offs are saved for the duration of the project, in case they can be used at a later stage of the project. If it is not used, they are disposed at the end of the project. Other plastic materials are disposed of during the project. All workers on the project is responsible for disposing waste correctly.

Figure 8: Cut-offs at construction site

Variance between different projects was also discussed during the site visit, as this project is only one example. The processes for waste handling are different based on the nature of the project, for instance due to different purposes and areas for construction. This must be considered when developing solutions for waste handling. The variations described further in this section is based on discussions during the site visit and can not be seen as the facts for all situations.

In bigger projects they have containers to collect waste, as the volume is big enough to fill them. For smaller projects where containers for each fraction with certainty can not be filled, everything is disposed as residual waste. This entails higher costs for sorting of the residual waste, but the additional costs of renting several containers are higher. In addition, if residual waste was not more expensive than plastic waste, it is likely that this would be the case for most projects to simplify waste disposal at the construction site.

It is typical to use a waste handling company that handles all aspects of waste handling, from container rental to pick up of full containers. Container rental is the most common for larger projects, as described previously. There are also available solutions for buying big bags for pick up. There are several actors that offer this and you order bags for a set cost and order pick up once it is full. An option is also to deliver the materials at the recycling station, which Trym AS rarely does unless they have big loads that can fill up a full truck.

The simplicity of sorting out several fractions of waste might be higher in large in-house projects, as they have larger volumes and are more dependent on disposing it right away. These projects often have several fractions of waste, meaning that it would be less of a difference to add plastic pipes as a separate fraction. On the other hand, you have infrastructure projects where you can build in a straight line and avoid a lot of cut-offs, meaning that there is less pipe waste.

In some projects, the waste handling reports from previous projects can contribute to winning an offer. In an offer for construction projects, price accounts for around 70% and quality around 30%. Waste handling can be put in the category of quality that can help win an offer, however, increased costs can occur from improved waste handling.

As there are already several fractions of waste, extending the number of fractions should be limited. Trym AS believes that it would not be feasible to have separate containers for PVC, PE and PP pipes, as limited knowledge on the materials would lead to wrong sorting of materials.

6 Solutions for circular waste handling: Examples from other countries and industries

In this section, selected examples on existing solutions are presented. These are used to illustrate different ways to conceptualize circular solutions. The purpose of this is to use it for the developed solution of this thesis. All schemes must be specified for the environment it is to operate in, but it is useful to learn from previous experiences. The solutions are separated by examples from the plastic pipe industry in other European countries and an example from outside the plastic pipe industry.

There are established and well-functioning solutions in other countries and industries for take back of materials. These countries and industries have different market characteristics and prerequisites than the Norwegian market, but can still be used as a source of inspiration and solutions.

6.1 Take back schemes within the plastic pipe industry

The information in this section is to a large extent based on the responses to S1, where key persons involved in the development and operation fo the solutions were respondents. In addition, information is retrieved through email, meetings and the take back scheme's websites. The descriptions have different levels of detail. This is due to the maturity of the schemes, as well as the responses to the survey.

The Netherlands

The Netherlands lead way in Europe in terms of separate waste collection, achieves good results in recycling and adapt to various initatives on circular chains (van Buren et al., 2016). In 1992, Buizen Inzamel Systeem (pipe collection system), hereafter called BIS, was established in the Netherlands as an industry initiative by some of the leading plastic pipe manufacturers. The Netherlands uses a lot of PVC and incineration of the waste caused issues due to the chlorine content of the polymer, as described in section subsection 4.4. The establishment of BIS led to PVC waste being collected, at the same time as waste incineration processes were improved by the waste management companies. BIS is the pipe waste collection scheme in the Netherlands and is now more than 30 years old.

There are five large plastic pipe manufacturing companies in the Netherlands: Dyka, Martens, Omniplast, Pipelife and Wavin, of which all produce pipes in PVC, and some also in PE and PP. These companies have an association, called BureauLeiding. In addition, the Netherlands have an industry platform for PVC producing and converting companies called Stuurgroep PVC & Ketenbeheer. BIS was originally only for the developers of the scheme, their customers and their own recycling company. The establishment of BIS led to the development of three layer pipes, especially for PVC, which allowed for the use of recycled materials in the middle layer. Due to technical and legal specifications this was only for sewage and wastewater pipes.

At this time, the collection of waste was performed by individual waste transport and management companies. The scheme developed and all BureauLeiding members joined BIS. All plastic pipe waste from PVC, PE and PP in the Netherlands was then accepted by BIS and one waste management company was responsible for the collection. Next, the current solutions in the scheme are presented.

The Dutch scheme collects pipe waste from the three main polymers: PVC, PE and PP. All pipes and accessories such as fittings of all makes, regardless if they support the collection, are collected. Non-pipe related plastics are explicitly excluded. The PVC waste is used as a resource for manufacturing of three layer sewage and wastewater pipes. PE and PP is traded on the market for recycled plastics, but is more and more, especially PE, used as a resource for manufacturing new pipes. Previously, PVC waste from window profiles was used to manufacture pipes, but due to legal considerations this will no longer be an option in the near future.

There are three collection options for the Dutch scheme:

- $>$ 1 ton waste: so called "BIS containers", $40m^3$ collection containers, can be rented to the site. This is typically used for larger infrastructural construction works. The container rental and transportation costs are paid for by the contractor, and no costs are involved for the pipe manufacturers
- $<$ 1 ton waste: there are 40 privately owned collection points all over the Netherlands. These are managed by BureauLeiding and placed at locations of the five member companies. The containers at these collection points and the collection are paid for by BureauLeiding and no costs are involved for bringing waste to these collection points for contractors and installers
- $2m^3$ big bags: smaller installer companies and contractors can buy $2m^3$ big bags to collect smaller amounts of waste. In the purchasing price for these bags, the collection and handling of the big bags are included

Around $\frac{1}{3}$ of the collection volume is collected at the collection points and around $\frac{2}{3}$ of the volume is collected in BIS containers. The $2m^3$ big bags is a very small part of the volume.

There are costs associated with the collection of materials. Below is an overview of the costs that occur, which depends on which collection alternative you choose:

- **Transportation costs** one way (delivering or collecting a container): €227.30
- **Container rental** per day: €2.15
- **Refunding** per kilogram of PVC, PE or PP: €0.02
- **Pollution disposal costs** per kilogram of material: €0.21

- **Other costs** occur for handling of other waste than plastic pipes. These differ depending on factors such as amount

These costs are based on the cost levels in the Netherlands and can thus not be directly compared to costs in other countries. They are still included to show the ratio between the different costs. If you follow the guidelines provided by BIS, the total costs for waste handling of plastic pipes will be lower than that of the regular waste handling streams due to the refund fee for materials returned.

The scheme was originally developed by some of the plastic pipe producers in the Netherlands. They tried to convince as many actors as possible to use the scheme to dispose of their plastic pipe waste, such as local authorities, water companies, natural gas companies, building companies and installers. The actors involved in the scheme today are:

- The companies that use the scheme (contractors, installers and so on)
- The five plastic pipe producing companies that set up the scheme
- BureauLeiding, the trade association that operates BIS, has the main responsibility and coordinates the scheme
- Renewi, the waste management company partnering with BIS that collects and places the containers
- Kunstof recycling Van Werven, the plastic recycler that make new resources from the waste and sells it

BureauLeiding has the main responsibility of the scheme. However, the market has taken over the scheme to a large extent. Around 90% of the market is autonomous, while the remaining 10% is controlled by BIS. The idea from the beginning was that the market would take over. Today, more than half of the plastic pipe waste is recycled for new pipes, meaning that the scheme is quite successful. BIS will continue to operate to support the market.

To simplify the use of the scheme for companies, BureauLeiding's website has all the necessary information collected in a straight forward and understandable manner. For containers, there is an online form to fill out for collection. For collection points, there is a map with an overview of the 40 collection points to see the locations and how to find it.

Denmark
WUPPI A/S, hereafter referred to as WUPPI, was established in 1997 by the five largest PVC producers in Denmark: Wavin, Uponor, Plastmo, Primo and Icopal. The objective was to organize the collection and recycling of EOL construction materials made of hard PVC. There is great potential for recycling and reusing PVC materials, but it requires a system that makes it easy for entrepreneurs, contractors and so on to collect and return products

for recycling to exploit this potential, which was the motivation behind the establishment of the scheme.

As mentioned, WUPPI was established by the five largest producers of PVC products in Denmark. Today, other companies that use PVC in their production is also part of the scheme. For instance, both Pipelife Denmark and INOVYN are part of this scheme. After establishing the scheme, WUPPI had their own collection points for materials, before they were sent to Sweden for recycling. This was quite expensive, due to costs of collection and transportation. Next, the current solutions of the scheme will be presented.

WUPPI collects hard PVC from the construction industry. They collect pipes, window profiles and so on. They do not collect PE, PP or soft PVC and other plastic products must not be mixed with the hard PVC products. WUPPI will only work if the products are sorted correctly and does not contain foreign matters such as iron, cement and metal. The focus of WUPPI is the material PVC and not pipes specifically as BIS.

WUPPI collaborates with the waste handling company Ragn-Sells, that is one of the leading waste handling companies in Scandinavia. Ragn-Sells offers two options for collection of materials:

- Collection points: there are four locations for collection where they process all types of PVC waste. Ragn-Sells must be contacted in advance of delivery. An overview of these collection points can be found on WUPPI and Ragn-Sells websites
- Other locations: Ragn-Sells offers collection and handling of materials through their sister company Miljølogistik A/S and their collaborators. For this option, the companies must contact Miljølogistik A/S

The customers can choose between renting a container at their location, order pick up through Ragn-Sells for a fee or deliver it at one of their locations themselves. The smaller contractors and industries often deliver material to municipalities, who then deliver it collected to Ragn-Sells.

There are costs that arise in the collection and recycling of materials. The customers, which are for instance municipalities, industries and contractors, pay Ragn-Sells for rental of containers and collection of the materials. Ragn-Sells then sorts the materials and pay freight costs to Van Werwen, the recycling company. According to the quality of the materials and the amount, Van Werven pays Ragn-Sells.

WUPPI is a nationwide scheme for municipalities, entrepreneurs, demolition companies, waste handling companies and others that handle hard PVC construction waste. It is for private companies, but also municipalities and waste handling companies. The actors that are involved in the scheme today are as listed below:

- The companies that use the scheme (contractors, installers and so on)
- Ragn-Sells, the main responsibility of collection
- Miljølogistik A/S, supporting Ragn-Sells on collection
- Kunstof recycling Van Werven, the Dutch recycling company that processes and sells the recyclates to pipe producers and other companies in the European market
- Recovinyl, a bigger European effort that is responsible for more than 800 000 tons PVC being collected and recycled annually
- WUPPI

The scheme is now run by the market itself, which is also directed by the legislation in Denmark. WUPPI does therefore not have control over the market and the scheme works autonomously.

Due to legislation in Denmark, the materials are exported for recycling and to be sold. The recyclates are used to produce new pipes, windows and so on in Europe. There are great environmental benefits to these processes. For instance, two kilograms of CO_2 is saved for each kilogram of PVC that is produced.

Finland
A Finnish scheme for collection of plastic pipe waste was established by the small company Muoviportti Oy, which after a few years was taken over by L&T Finland. L&T Finland is a large waste handling company that has specialized on circular economy and collection of pipes. The scheme ran for pipes and fittings from 1999 to 2011. Impurities of materials and too little valuable materials made it challenging to keep the scheme going. The scheme was established by three large pipe producers: Uponor, Pipelife and Wavin.

Pipes produced in PVC, PE and PP and fittings were collected in the scheme. The materials were sorted and regranulated for further use. Rejected products, for instance that they did not fit the scheme, were sent to waste plants to be used as energy instead. The collection of materials was done through around 20 containers that were placed at pipe retailers yards. The retailers offered a point for containers and recyclers received the material without a fee.

Containers filled with PVC, PE and PP were emptied and manually sorted three to four times per annum. PVC usually did not have export value and the materials were used for isolation foams, concrete pieces and PEX.

For cost handling, the voluntary EPR scheme Suomen Uusiomuovi Oy were responsible. They paid once per annum, for the handling of plastics. Retailers paid for container rental and provided space for them, which was hard for them to agree to. The total cost of the collection was not too high and cost them approximately 12 000 € per annum. The final materials were owned by the recyclers.

The scheme was discontinued in 2011, but pipes are still collected and recycled. Today, the collection and waste handling is done by three recyclers independently. They mainly get paid by the waste source themselves. There is no longer central coordination or support, the market handles it themselves.

Germany

In Germany, the collection of plastic pipes is established. The scheme was developed by the German plastic pipe association Kunststoffrohrverband (KRV) and their member companies, in collaboration with the waste management company and recycler PreZero.

In the German scheme, pipes produced in PVC, PE and PP are collected in a mixed collection. They collect EOL pipes and cut-offs from construction sites. The recycled materials are in most cases used for production of new pipes. However, they have different collection schemes for different products in Germany, for instance PVC window profiles. In some cases, recycled materials from pipes are used in the production of other applications, even though most of it is used for pipes. In addition, recyclates from other sources are also used in the production of plastic pipes. Changes in legislation from the EU will entail closed loops for PVC pipes and profiles, meaning that this no longer will be an option.

The materials are collected at established collection points, where either containers of lattice boxes are placed. These collection points are placed at the production sites of pipe manufacturers or at trading companies' locations. In addition, rental of containers for construction sites is an option for collection. The costs for these processes are determined by the involved companies, that is the waste management company and their customer.

The actors involved in the scheme are:

- The companies that use the scheme, such as contractors
- The plastic pipe association KRV and their member companies
- PreZero, the waste management company and recycler
- Other waste management companies

PreZero is a waste management and aluminium and plastic recycling company. They are dedicated to closing loops. They are focused on identifying where recyclates are generated and in which quantities to identify the ideal locations for waste containers, sophisticated waste separation and efficient transportation of the materials. This makes them an ideal partner in such a scheme. In many cases, they are the waste mangement company that is used. However, there are also other companies that handle waste management and recycling. KRV does not have a controlling function in the market, as it runs itself by the actors within it.

In Germany, more than 50 000 tons of recycled materials are collected and processed for use in production of new plastic pipes each year. However, more than double of this amount can be processed and used according to plastic pipe producers. They have little overview of the routes of materials and how to better utilize the materials that have potential for recycling. Therefore, KRV have involved consultants from the consulting company Conversio and initiated a project to analyze disposal routes and material flows and better the understanding of the market. The project has major targets. Firstly, it was initiated to get a complete understanding of the disposal chain in Germany, as EOL pipes and cut-offs from construction sites do not have known routes for disposal. The second target was to understand the volumes of plastic pipes in different parts of the disposal chain, which has been done by interviewing key actors in the industry. The overall objective of this project is to increase the volume of recyclates in the future.

6.2 A take back scheme outside the plastic pipe industry

In this section, an example of a successful scheme outside the plastic pipe industry is presented. Different characteristics of the materials used and the products that are produced does so that not all solutions will be transferable to the plastic pipe industry. However, an example is still included to illustrate an example of solutions to be implemented. The information is retrieved Rockwool's website and from their presentation at Byggavfallskonferansen.

ROCKCYCLE
Rockwool is the worlds leading supplier of stone wool insulation. They aim to offer a full range of high-performing and sustainable insulation products for the construction industry. By using stone, which is one of the world's most abundant resources, they reduce the impact of their production. Their vision is also to be a leading supplier of insulation, where contribution to a better environment and fire caution is leading.

In the ROCKCYCLE concept, the used materials are collected into the production and used identically as virgin raw materials. Rockwool also recycles stone wool and surplus materials from other industries and the Nordic facilities recycle over 30 000 tons of materials from other industries. In addition, they use renewable sources for energy and surplus heat is used as district heating in the area.

There are two alternatives for returning Rockwool materials for recycling:

1. For smaller volumes, the materials can be returned in containers placed at construction sites which are ordered through or at the local building material retailer
2. For larger volumes, Rockwool collaborates with a recycling company that collects and processes the materials before returning it to Rockwool for production

After collection, the materials can be produced into new insulation repeatedly due to the characteristics of the material. In contrast to plastics, it can be recycled repeatedly without the quality being degraded.

The advantage of materials being collected at construction sites is that the waste would normally end up in landfill and not be utilized, which ROCKCYCLE prevents. It has also reduced the CO_2 emissions in the Nordic factories with more than 70%. Rockwool also uses transportation run on bio gas to reduce emissions further.

7 Findings: survey responses and suggestion for take back scheme

This section is separated into two subsections: findings from surveys and the case study, and the suggested solution for a take back scheme in the Norwegian plastic pipe industry. The findings from the two surveys are presented in in subsection 7.1, to be used further in the thesis. The findings are not interpreted in this section, but rather used to support the development of the suggested take back scheme in subsection 7.2. The findings are interpreted and used to answer the research questions in section 8. In subsection 7.2, the suggested solution for a take back scheme in the Norwegian plastic pipe industry is presented. The suggestion is developed by interpreting the findings from subsection 7.1 and relating these to the case study and theoretical background from section 4. The answer to RQ3 is the solution found in subsection 7.2, and these answers are elaborated, interpreted and discussed in subsection 8.3.

7.1 Survey results

In this section, the results from the two surveys are presented in two separate sections. The answers to S1 are presented by summarizing the solutions implemented in other countries, ranking the most costly links and presenting the challenges and key lessons from establishing the scheme. The findings from S2 are then presented by highlighting the answers and trends of the answers.

7.1.1 Key learnings from established schemes (S1)

In table 4 below, the selected solutions in the established schemes are presented. This is the only part of this section where ROCKCYCLE is included, due to this scheme being used as an illustration outside the industry, they were not included in the surveys. These are based on the descriptions found in chapter 6.

Table 4: Summary of existing solutions in other countries and industries

	The Netherlands	**Denmark**	**Finland**	**Germany**	**ROCKCYCLE**
Materials collected	PVC, PE and PP	Hard PVC	PVC, PE and PP	PVC, PE and PP	-
Source of materials collected	Pipes and accessories	Pipes, window profiles and other applications from the construction industry	Pipes and accessories	Pipes	-
Application for recyclates	PVC: three layer pipes PE and PP: plastic applications, increasingly used in pipe production	Plastic applications	Isolation foam, concrete pieces and PEX	Production of pipes and production of other applications Materials from other applications used in pipe production	New Rockwool products
Collection options	1. Collection points 2. Containers 3. Big bags	1. Collection points 2. Containers 3. Pick-up	Collection points	1. Collection points 2. Containers	1. Collection points 2. Pick-up
Developing actors	Leading plastic pipe producers	Leading plastic pipe producers	Waste handling company	Plastic pipe association	Rockwool
Active scheme	Yes, the market runs 90% and BIS runs 10%	No, the market runs itself	No, the recyclers handle it independently	Yes, there is an ongoing project to increase volumes	Yes

There are big variations of the detail level for the costs distribution in the schemes, and they are therefore not included in this table.

In S1, the respondents were asked to rank which link of the take back processes that is most costly, from most to least costly. Of the eight alternatives, three were not once mentioned in top three. These three were sorting of materials at the construction site, quality controls before extrusion and others. These will still be necessary to consider, however, they are not prioritized. The five links were ranked as shown in table 5 below. As the table shows, both transportation and collection were ranked as most costly twice and transportation is top three for all countries. Administrative costs is only in the top three for Germany.

Table 5: Ranking of costs in the existing solutions

Link	The Netherlands	Denmark	Finland	Germany
Transportation	2	1	3	1
Collection	1	3	1	
Sorting of materials after collection		2		2
Hiring space and containers	3		2	
Administrative				3

Next, the respondents were asked to describe challenges they experience with the established scheme. In the Netherlands, a challenge is the low prices of virgin raw materials, which hinders investments in recycling. The Dutch have more than 30 years of experience with this scheme, so the system itself is working well. If legislation changes, new challenges might arise. In Denmark the most substantial challenge is the financing of the scheme; the system needs financing to work. In Finland, challenges in the establishment of the system were that too little valuable materials came in and that the returned materials were impure. The main challenge in Germany is that the amount of cut-offs and EOL pipes is unknown, which is why they have initiated their ongoing project.

When established the schemes, key lessons were also learned. These are described in table 6.

Table 6: Key lessons from established schemes

	Key lessons
The Netherlands	Keep the scheme simple and allow all pipe waste of PVC, PE and PP
	Keep the system open to all pipes, regardless if the producer is part of the scheme or not. This keeps the system easy and enforceable
	Make clear and long-lasting arrangements about the costs for all actors to ensure stability
Denmark	The scheme must be established in cooperation with all stakeholders, one company can not do it
Finland	The work needed compared to the overall benefit of the system was unclear
Germany	Analysis and creating a new strategy will be done when their ongoing project is done, which will facilitate changes

7.1.2 Demands and opinions for the take back scheme (S2)

In this section, the answers from S2 are presented. The questions can be found in Appendix B.

The respondents were asked to rank the importance of a predefined list of criteria: simplicity of participation, economical factors, location of collection points, transportation and materials collected. The number of times a criteria received each rank is shown in table 7 below.

Table 7: Ranking of criteria in take back scheme: frequency

Criteria	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5
Simplicity	5	2	3	4	0
Economical factors	4	1	1	5	3
Location	3	3	4	2	2
Transportation	1	5	3	3	2
Materials collected	1	3	3	0	7

To illustrate how well the criteria ranked in total, equation 7.1 was developed. x_1 is rank 1 and x_5 is rank 5, while 14 is the total number of respondents. Each fraction is multiplied by a predefined importance factor, where 5 equals rank 1 (x_1) and 1 equals rank 5 (x_5). Equation 7.2a through 7.2e are the calculations for each criteria, from simplicity to materials collected.

$$\frac{x_1}{14} \cdot 5 + \frac{x_2}{14} \cdot 4 + \frac{x_3}{14} \cdot 3 + \frac{x_4}{14} \cdot 2 + \frac{x_5}{14} \cdot 1 = importance \tag{7.1}$$

$$\frac{5}{14} \cdot 5 + \frac{2}{14} \cdot 4 + \frac{3}{14} \cdot 3 + \frac{4}{14} \cdot 2 + \frac{0}{14} \cdot 1 = \frac{25}{7} = 3.57 \tag{7.2a}$$

$$\frac{4}{14} \cdot 5 + \frac{1}{14} \cdot 4 + \frac{1}{14} \cdot 3 + \frac{5}{14} \cdot 2 + \frac{3}{14} \cdot 1 = \frac{20}{7} = 2.85 \tag{7.2b}$$

$$\frac{3}{14} \cdot 5 + \frac{3}{14} \cdot 4 + \frac{4}{14} \cdot 3 + \frac{2}{14} \cdot 2 + \frac{2}{14} \cdot 1 = \frac{22}{7} = 3.14 \tag{7.2c}$$

$$\frac{1}{14} \cdot 5 + \frac{5}{14} \cdot 4 + \frac{3}{14} \cdot 3 + \frac{3}{14} \cdot 2 + \frac{2}{14} \cdot 1 = 3 \tag{7.2d}$$

$$\frac{1}{14} \cdot 5 + \frac{3}{14} \cdot 4 + \frac{3}{14} \cdot 3 + \frac{0}{14} \cdot 2 + \frac{7}{14} \cdot 1 = \frac{33}{14} = 2.36 \tag{7.2e}$$

The results from the equations are summarized in Table 8 below.

Table 8: Ranking of criteria in take back scheme: frequency

Criteria	Equation	Importance ranking
Simplicity	7.2a	1
Economical factors	7.2b	4
Location	7.2c	2
Transportation	7.2d	3
Materials collected	7.2e	5

Simplicity is ranked highest most frequently, as well as being ranked as the criteria with the most importance in total. Even though economical factors is ranked highest second most often, it is ranked as number 4 in total. Location is ranked as number 2, transportation as number 3 and materials collected as number 5. Out of the eight entrepreneurs, five have simplicity ranked highest, two has it ranked second and one has it ranked fourth.

In addition to the predefined criteria, the respondents could add additional criteria that is important to them, which six of the respondents did. Purity of recycled materials was mentioned twice. Other criteria that were mentioned were simplicity of the system as a whole, tracking of the amounts collected for a reward system, reporting of volumes in an environmental management system and establishing a separate fraction of waste.

Next, the respondents were asked who should have the main responsibility for the system. Of the 14 respondents, nine answered that the pipe producer should have all or parts of the responsibility for such a system. These nine belonged to different categories of respondents, so there seems to be consensus among the actors to some extent. Of these nine, some also mentioned that the pipe producers should have the responsibility in collaboration with the end-users. Including the ones that answered end-users in collaboration with pipe producers, three respondents think the end-users should have responsibility. One of these respondents think the end-users then should have the exclusive rights for the materials. One of the entrepreneurs answered that they would want to be responsible for such a system in their region, in regards to reception and intermediate storage of materials. Three respondents think the waste handling companies should have all or parts of the responsibility, at least collection, sorting and further distribution of the materials. Two of the wholesalers think they could use their role as a logistics partner to outline a return system that has collection points in their system, given that their costs for return logistics, collection and storage of pipes are considered.

The next question asked how the system should be organized, which provided many different responses. The variety of responses is to some extent related to their answers on responsibility. The responses were mainly related to collection, transportation and costs:

Collection: Many of the respondents think there should be established collection points where the materials can be delivered, for instance at the wholesalers locations. One of the respondents also highlights that there should be several of these. Another respondent also wrote that there should be collection points at recycling stations where there is a separate fraction for plastic pipes. One respondent thinks that there should be collection points at the producers' locations. A few of the respondents answered that the producers should organize collection from the collection points and that the recyclers handle the further process.

Transportation: For the respondents that answered about the transportation to collection points, there is a divide between it being the end-users responsibility and it being the recyclers responsibility. Several respondents believe that the end-users must be responsible for transporting materials to the collection points. One respondent also believes that the recyclers should be responsible for transportation to the collection points. Some of the respondents also answered that when new pipes are delivered to the end-users, the plastic pipe waste should be picked up, which can not depend on who produced the return materials.

Costs: In regard to costs, there are different opinions on how it should be distributed. Two of the respondents think that transportation from the construction sites/ end-users should be free. One of them highlighted that the recycler then gets the economic gain by selling the recycled raw materials. One respondent thinks that the costs of transportation/ delivery should be reduced based on the purity of the sorting and materials of exceptional quality should give a payback per kilogram. Another respondent thinks that there should be a cost per kilogram when delivering materials at collection points. On the other hand, one respondent believes that the end-users should pay for the collection points. There is consensus among the actors that it must be cost-efficient for this system to be likely to work.

In total, the answers show that the actors in general believe that more liability should be placed at other actors in the chain. For instance, the entrepreneurs believe more liability should be placed at the recyclers.

Next, the respondents were asked what they would expect to get out of participation in the system. Five of the 14 respondents said that they do not expect any compensation for their participation. Eight of the 14 respondents expect economical compensation in some form, whether it is free transportation of containers, a price per kilogram material delivered, expenses for delivery and handling being covered or reduced price of recycled raw materials compared to virgin raw materials. One of the actors also said that it either must be an economical upside, or a governmental requirement to participate. Another actor also answered that there should be an overview of the economical advantages and disadvantages for the actors in the value chain, to ensure transparency and fairness. Two of the entrepreneurs also highlight their work with environmental declarations and waste accounting, where they would need papers to confirm that it is delivered as sorted waste.

The respondents were also asked what they see as the benefits of taking part in such a system. Out of the 14 respondents, 13 of them mention the environment, sustainability or a circular industry as a benefit of the system. The transition to a circular economy is thus a clear incentive for participating in the system. Waste reduction and improved collection processes are also mentioned frequently. Six of the respondents also answered that they see it as an option for economic gain for actors in the value chain, for instance through increased utilization of materials, cheaper raw materials and saved costs for collection of waste. Some actors also answer that this can make the waste handling processes simpler. One of the respondents mentions profiling as a contributor to the circular economy, which can be a competitive advantage.

Even though there are many benefits, they also see challenges in establishing such a system. Out of the 14 respondents, five answer that they see it as fully solvable if the system is well-developed. Another respondent answers that they do not see any practical challenges, however, the economical aspect will be challenging. The system will not be profitable from the beginning, and it requires collaboration in the value chain. Another respondent agrees with this point of view and highlights logistical costs and transaction costs as possible challenges; everyone wants to be portrayed as sustainable, but few are willing to pay for it. On the other hand, three of the respondents believe that there will be practical challenges, such as transportation distances, intermediate storage and other logistical challenges. Out of the six respondents that do not see challenges with the system, five of them already sort out plastic waste to varying extent. Out of the three respondents that believe there will be practical challenges, two of them already have established solutions where either hard plastic or PE pipes are sorted. The last respondent that sees logistical challenges is one of the recyclers. Four of the respondents also believe that there will be challenges with the purity of materials, both due to many types of plastics that are mixed together and pipes that are dirty from use and storage. Only one respondent has answered that they see volume as a challenge.

The respondents were then asked how they handle waste today, for those that are involved in projects today. 12 of the respondents answered this questions and three of them answered that they dispose waste without any sorting of materials. Five of the respondents sort plastic in separate containers, where one says that they have hard plastic as its own fraction. Two of the respondents sort plastic pipes separately and two respondents sort PE in separate fractions, one of them pipes.

Lastly, the respondents were asked if they had additional information to add. Here, it was highlighted that it is challenging with many different types of plastic, which requires knowledge with the end-users.

The trends of the answers to this survey is that the respondents are positive to the system and believe that it is feasible. However, the economical aspect is mentioned frequently throughout the survey. There is also some uncertainty around how it should be solved practically.

7.2 Suggestion for take back scheme in the Norwegian plastic pipe industry

In this section, the suggestion for a take back scheme in the Norwegian plastic pipe industry is presented. The foundation for this is the survey responses, descriptions of existing solutions, site visit to a construction site and theoretical background. It is important to consider that the scope of this thesis has been limited to account for materials, collection, costs and actors, meaning that these are the links of the value chain that are presented here.

7.2.1 Materials and products collected

The first category for decisions is materials. The materials to be collected in the scheme are plastic pipes produced in PVC, PE and PP. This includes accessories such as fittings. Non-pipe related plastics are explicitly excluded from the scheme. Plastic pipes can be delivered regardless who the producer is and if they support the scheme, as long as the materials are within the scope. Materials can be delivered without being cleaned of first. There is a technical plastic waste fraction for industrial waste, that includes pipes, window profiles and similar fractions. This fraction must be defined and informed in the industry. This includes separate fractions at recycling stations, separate containers marked correctly and so on. In addition, separate legislation, marking and reporting must be created.

7.2.2 Collection options

The collection options suggested are:

- Container rental for construction sites
- Collection points at set locations
- Big bags that can be bought for small volumes
- Self-delivery at recycling stations in a separate waste fraction

The containers are rented from waste handling companies companies and placed at the construction site, and picked up and transported to the recycling stations when full. The collection points will be established locations where containers are placed and end-users can deliver materials. These will be placed at the locations of collaborators' sites and the containers are picked up by the waste handling companies. Big bags can be purchased through waste handling companies, where smaller volumes can be filled. Collecting and handling of the big bags are included in the purchasing price, so they are collected after they are filled or when the project is finished. The end-users can also choose to deliver the materials directly to a recycling station.

7.2.3 Costs and cost distribution

The cost distribution in the suggested scheme is presented in Table 9 below.

Table 9: Cost distribution in the Norwegian take back scheme

Collection option	Cost distribution
Container rental	1. Container rental: end-user 2. Container transportation: end-user 3. Refund: recyclers pay end-user
Collection points	1. Container rental: the responsible actors 2. Transportation of materials: end-users 3. Refund: recyclers pay end-user
Big bags	1. Purchasing big bags: end-users 2. Transportation of materials: included in purchasing price
Self-delivery	1. Transportation of the materials: end-users 2. Refund: recyclers pay end-users

For container rental, the end-users pay a fee to the waste handling company per day of container rental and a fee per way for the transportation of the container. They receive a refund fee per from the recyclers for each kilogram of materials that is delivered.

For collection points, the end-users are responsible for organizing transportation of the materials and cover the costs of this. The responsible actors, who are introduced in the next section, pay for the containers and receives a refund fee from the recyclers for each kilogram of materials that is delivered.

For big bags, the end-users pay a purchasing price for the bags to the waste handling company, which includes collection and handling of the materials. The collection and handling of the materials are included in the purchasing price. There is no refund fee when big bags are used.

For self-delivery, the end-user is responsible for transportation to the recycling station and covers these costs. The end-user receives a refund fee from the recyclers for each kilogram of materials that is delivered.

When materials are sorted wrong there is a fee per kilogram of materials that the end-user pays to the recyclers, for instance if window profiles are delivered in the fraction for pipes. In the beginning, there should be a trial period where all materials sorted wrong under a set limit of kilograms do not entail a fee.

When the recyclers receive the materials, they sort and process the materials before selling them to the pipe producers. The producers pay the recyclers for the materials, as they act as raw materials as shown in Figure 6. The end-users purchase pipes from the producers like they would today.

7.2.4 Actors and responsibilities

The different actors have different areas of responsibility. The first area of responsibility is developing and establishing the scheme, as well as having the administrative responsibility once it is established. The suggestion is that the Norwegian pipe producers have this responsibility, which should be facilitated by the industry organization NPG Norge.

NPG Norge and the pipe producers need the support of other actors in the value chain. The suggestion is thus to establish an association for the take back scheme where the other actors, that is entrepreneurs, wholesalers, waste handling companies, recyclers and end-users, are members to participate in the scheme. The members are responsible for collecting materials correctly and workin towards full participation in the scheme.

The largest waste handling companies in Norway should have the responsibility for collection and waste handling. The smaller waste handling companies can be included through the responsible companies. The recycling activities after collection depends on the capabilities of the waste handling companies. If they are not capable of processing the returned materials into raw materials, the materials must be delivered to a specialized recycler that handles the recycling activities.

7.2.5 Summarized suggestion: a take back scheme for the Norwegian plastic pipe industry

To summarize the suggestion for a take back scheme in the Norwegian plastic pipe industry, Table 10 is shown below.

Table 10: Suggestion for take back scheme in the Norwegian industry

	Suggestion
Materials collected	PVC, PE and PP
Source of materials collected	Pipes and accessories
Collection options	1. Container rental for construction sites 2. Collection points at set locations 3. Big bags that can be bought for small volumes 4. Self-delivery
Costs	1. Container rental 2. Transportation costs 3. Collection points 4. Fee for wrongly sorted plastics 5. Refund per kilogram of materials
Developing actors	Pipe producers driven by NPG Norge
Actors running the scheme	Association for the take back scheme

The suggestion for the take back scheme includes the links that the scope is limited to in subsection 1.3. Other factors, such as legislation and ownership of the materials, also need to be developed.

8 Discussion

The main part of this section is dedicated to answering the three research questions presented in subsection 1.4. RQ1 and RQ2 are answered in subsection 8.1 and subsection 8.2, to uncover the obstacles and potential of implementing a take back scheme in the Norwegian plastic pipe industry. This is done by bringing together the theoretical background and findings from the case study and surveys. RQ3 was answered in subsection 7.2. In subsection 8.3, the suggested scheme is elaborated on and the theoretical background and findings that were used to develop it is discussed. In addition, the answers to RQ2 and RQ3 are used to discuss the obstacles and potential that follows the suggestion. The chapter is rounded of with a discussion of the limitations of the study and the further work that remains to be done.

8.1 Research question 1: Obstacles for increased circularity in the industry

The research question to be answered in this section is as follows:

RQ1: *What are the obstacles that hinder the implementation of a take back scheme that would increase the circularity of the Norwegian plastic pipe industry?*

As presented in subsection 3.3, there are barriers present in the Norwegian industry that hinder the transition to a circular industry. In this section, the obstacles that are hindering the exploitation of potential for increased circularity are discussed. These are related to the industry and the actors within it and does not consider the suggested solution for take back scheme. The challenges with the scheme are discussed further in subsection 8.3.

As presented in section 5, plastic pipes are used in very varying projects. The projects vary between the two main categories in-house and infrastructure, as well as size and location and so on. The variations are an obstacle of establishing a general recycling procedure that functions well for all projects. One could argue that the procedures should be adapted to infrastructure projects as this represents the largest volume sold, at least for the case company. However, as presented in subsection 5.3, there are also variations in infrastructure projects such as the amount of pipe waste that is generated, meaning that a general recycling procedure can not be developed for this segment either. In addition, large volumes may also arise in the in-house segment, which implies that a solution that enables participation from both segments is essential to utilize the full volume.

There is uncertainty regarding the amount of plastic materials in the construction industry, as well as the percentage of materials that is recycled and what the recyclates are used for. As described in subsection 5.2, the data found on this depends on the source used and it can be challenging to find data for high-quality plastics specifically. Recycling is the most environmental alternative for disposal but it is unclear how often pipes are incinerated instead. Establishing a successful scheme will be challenging without an overview of the volumes in the material flow. As described in subsection 6.1, the lack of overview of the amount of cut-offs and EOL pipes and flows in the German and Finnish scheme has been an obstacle in the operation of the scheme. There was only one respondent to S2 that mentioned volume as a challenge in establishing a scheme, however, it was an open-ended question where the respondents could fill in what they saw as challenges. Several respondent may still see volume as a challenge and a reason for it not being brought forward could be the lack of clarity today. Nevertheless, when asked about additional criteria for the scheme, two respondents brought forward reporting of volumes. If the amount of plastic pipe waste is too low, it will be an obstacle in establishing a profitable and operable scheme. Utilizing the full potential of the volume in the industry must therefore be prioritized to successfully implement a scheme.

Plastic waste arises before, during and after in a construction project, which can make the volume appear lower than it actually is. For large projects, such as the one from the site visit conducted, this is not necessarily a challenge. They have containers for plastic throughout the project. However, for smaller projects or in cases where it is not cost-efficient to have containers for separate waste fractions through the duration of the project, plastic may be disposed as residual waste to reduce costs.

The utilization of the recycled materials is complicated by the quality requirements. As described in subsection 4.4, recycled materials show lower properties than virgin materials and can therefore in many cases only be used in applications where the materials' properties are not as critical. In addition, even small amounts of recycled materials can decrease the mechanical properties of the materials. It will thus not be feasible to use recycled materials of lesser quality in the scheme. The upcoming legislation change from EU will also hinder use of other recycled materials in plastic pipes. In the ROCKCYCLE scheme, the recycled materials have characteristics that allow the recycled materials to be used identically as virgin raw materials. The characteristics of the plastic materials is therefore an obstacle that must be considered in the use of plastic recyclates.

It is also described previously how there is a cut-off point where the recycling processes are too complicated or resource-demanding, , as well as how important it is that the amount of energy consumed in recycling is lower than the energy required for production of new materials. The technologies that are developed can therefore only be used if they are not too resource demanding. This obstacle makes the barrier of quality even more pressing, as the use of the recycled materials is dependent on finding a technology that has high enough quality, low enough costs and low environmental impact.

In the Danish scheme, the materials are exported to be used in applications in other countries due to the discrepancy between quality and legislation. A challenge in the Finnish scheme was that the materials that were collected were too impure. In S2, four respondents see challenges with the purity of materials. In the Netherlands they started by using PVC in three layer pipes to utilize the recyclates. PE and PP were traded on the market for recycled plastics, however, these materials are increasingly used in the manufacturing of new pipes. Today, more than half of the plastic waste in the Netherlands is used to produce new pipes.

They have overcome some of the obstacles of impurity. This means that solutions can be found in Norway as well, however, the Dutch scheme has long experience and has had time to develop their solution.

In the implementation phase of the scheme, the materials can be used for other applications with less strict quality demands if they can not be used in pipe production. That way, the logistics solutions can be developed in practice alongside the development of recycling processes. According to the key lessons in Table 6 a long-term perspective is crucial, which this will contribute to. Environmental impacts will still be made, even if the scheme is not directly circular in this phase.

The costs of the scheme will create obstacles for its implementation. Costs and economical factors are mentioned throughout all of S2, which makes it essential for the success of the scheme. As presented in Table 7, economical factors is ranked as the fourth most important criteria of five in total. However, it is frequently mentioned in several of the other questions. The validity of the ranking is discussed in subsection 8.4. It was also noted in subsection 6.1 that they experiences challenges with the low prices of virgin raw materials and financing the existing schemes.

The economical factors covers all costs of the logistics activities and recycling, which is discussed further in subsection 8.3. When establishing CBMs new costs will arise and the existing business models must be adapted to include these. Instead of exclusively focusing on the new costs that arise, the business must also consider the possibility of new ways to make profit. Economic prosperity is mentioned before environmental quality in the definitions of the circular economy, which makes this an essential obstacle to overcome.

The linear thinking and linear models is highly inherent today. As described in subsection 4.2, the linear and circular economy are based on fundamentally different perspectives and the linear model is dominated by short-term profit. In addition to this, there is conceptual confusion of the circular economy and no comprehensive framework supporting businesses in CBMI. This acts as obstacles of designing optimal and effective CBMs, where the transition requires a systemic change. CBMI for the Norwegian plastic pipe industry is discussed further in subsection 8.3. The case study and development of a take back scheme in the Norwegian plastic pipe industry is based on considering the existing solutions, to gain a better knowledge foundation in conjunction with the theoretical perspectives. However, as described in subsection 4.7, different practices require specific supply chain network designs and the solutions are thus not directly transferable. The conventional waste management strategies for plastics are suited for linear models, so the obstacle is finding out how to adapt to the circular model. As mentioned in section 1, the research on sustainable logistics systems is not sufficiently focused on the reverse flows. The reverse flows are crucial for the circular systems and a lack of research creates an obstacle for their development.

As it is unclear how CBMs should be developed, it is also challenging to define roles and responsibilities in the new models. From the answers to S1 there seems to be disagreements regarding responsibilities in the new scheme. In general, most actors state that other actors in the value chain should have more liability than themselves. The challenge is to find a compromise where the responsibilities are distributed fairly among the actors. How these compromises should be made is discussed further in subsection 8.3. Roles and responsibilities at the construction sites is also a challenge. From the site visit it was noted that the responsibility for waste handling is not appointed to anyone. With no clear responsibilities there is greater potential that it will not be done properly and a lack of routines for cleanup and lack of responsibility and defined areas are challenges.

Legislation can act as an obstacle and a facilitator for a transition to the circular economy. If legislation makes recycling the preferable option, it facilitates the transition and acts as an incentive for it. On the other, hand there are rules in TEK17 for how buildings must be built to facilitate recycling, but not for where the waste should go. The waste will therefore end up where the costs are lowest, which is not necessarily recycling. The EU is considering specific recovery rates for waste fractions, which can facilitate change.

8.2 Research question 2: Potential for increased circularity in the industry

The research question to be answered in this section is as follows:

RQ2: *What are the potentials for increasing the circularity in the Norwegian plastic pipe industry?*

There is strong correlation between the obstacles and the potential for the increased circularity in the Norwegian plastic pipe industry. The obstacles must be tackled to reach the full potential of the system, but it is important to consider if the potential that can be reached is worth the work of tackling the obstacles. Thus, the potential for the industry is discussed in this section.

It has been established schemes in other countries and industries, which makes it likely to believe that it can be possible in the Norwegian industry as well. There are differences between legislation, practices and characteristics between the countries, but many factors will also be similar. The Dutch scheme is a good example, as it has been established for over 30 years and according to S1 they do not experience practical challenges as of today. There are challenges within the other schemes, such as unclarity of volumes in Germany. The advantage in the Netherlands is that there is a lot of focus on circularity, for instance them being leading in Europe in terms of separate waste collection. The potential in Norway could therefore be increased by increased focus in the country. Both the Dutch and Danish scheme are run autonomously today, so there is potential for this to be the standardized option for waste collection.

The key lessons learned in developing the established schemes, as presented in Table 6, can increase the potential for success in Norway. It is crucial to learn from the mistakes made and challenges overcome, to avoid making the same mistakes. The key lessons can in general be said to be that the scheme should be simple, have a long-term view and facilitate cooperation among actors, which is considered in developing the scheme presented in subsection 7.2.

In S2, 13 of the 14 respondents answered something related to the environment, sustainability or a circular industry as benefits of partaking in the scheme. It was an open-ended question where the respondents could answer freely, which makes it promising that nearly all respondents focus on environmental benefits of the system. As it is presented in subsection 4.1, the economic benefits are what attract the participation of the stakeholders and economic prosperity is mentioned before environmental quality in the definitions of the circular economy. It is therefore unlikely that the environmental benefits will be sufficient. Economic prosperity must therefore be in place to utilize this potential. Six of the 14 respondents answered that they see it as an opportunity for economic gain and eight respondents also expect some sort of compensation from participating in the scheme, where a refund per kilogram of materials and free transportation are mentioned as examples. The potential for success will increase greatly if solutions are found for the economical obstacles. A respondent suggested an overview of economical advantages and disadvantages of participation to ensure transparency and fairness in the scheme, which could increase the potential of participation. Five of the 14 respondents do not expect compensation anywise, as long as it is not an economic disadvantage to participate. The suggestion for how the costs should be distributed and compensated are discussed further in subsection 8.3.

If environmental benefits and no economic disadvantages does not drive participation, other measures can be used to increase participation and potential. One of these is EPR, which as described in subsection 4.5 is increasingly recognized as an efficient waste management policy where the producers take more responsibility. An example of how this can work is the Norwegian scheme for recycling of plastic bottles and can. The end-users pay a fee when they purchase a bottle, which they get back when returning the packaging for recycling. Over 92% of the packaging for beverages in Norway is recycled. Every point of sale in Norway is legally obligated to collect beverage packaging at their locations. (Infinitum, 2023) The end-users have an economic incentive for participation due to the refund of money, while the points of sale have legal incentives for participation. The high recycling rate shows that this is an efficient approach.

As presented in subsection 5.2, the construction industry contributes to large amounts of waste, materials account for 70% of the carbon footprint in construction activities and is the second largest end-user of plastic in Norway, only preceded by packaging. As discussed previously, the potential for success is higher if the volume is high enough. The volume for each project will vary a lot, so the potential for individual projects will vary. Given that pipes are a large part of the volume, the potential will be high. How to capture the full volume to utilize the potential is discussed further in subsection 8.3. As presented in the same section, the EU has set a goal of 70% of materials to be reused or recovered from the construction industry. As of today, Norway does not reach this goal, which can incentivize changes in attitudes and legislation. As legislation can be an effective measure to drive, and potentially force, change, it increases the potential for the industry reaching the set target.

A focus on long-term effects is necessary to reap the benefits of implementation of the scheme.

In the established linear system today there tends to be focus on short-term profit, which impacts the potential. Attitude changes are essential to facilitate change, for instance through changing the perception that waste is waste and not resources, which is challenging due to the established linear attitudes. However, there is increasing awareness that the linear system is sustainable and should be replaced with a circular system as described in subsection 4.2. As attitude change is an important factor for the potential, increased awareness will be an important step in the right direction. As discussed previously the actors of the industry see benefits of participating in the system, which can affect their attitudes toward change. In conjunction with legislation, this can accelerate the development of technologies and logistics solutions.

In subsection 3.3, it is presented that the will to change generally is higher in consumer-related industries, as for instance packaging consumers are under higher pressure from the public than pipe producers. It requires more of the industry and its actors to make changes if there is no pressure from the outside. However, an actor highlighted profiling as a contributor to the circular economy as a benefit of participation in S2. This illustrates that actors of the industry applies pressure to make changes. In conjunction with increased awareness, this sets potential for a transition.

Several enablers must be present to facilitate a transition, such as joint support of stakeholders, promoting consumer responsibility and cooperation with the logistics industry. If these are present, it is more likely that there is potential for success. Another important enabler is CBMs, which as discussed previously can be challenging to develop. As presented in subsection 4.7, the logistics network that is developed will also have a fundamental impact on the success of the scheme. If well-functioning business models and optimal logistics networks are developed, there will be great potential.

In conclusion, there are obstacles that must be overcome in transitioning to a circular plastic pipe industry in Norway. However, the general trends of the answers to S2 are positive and the actors believe it can be feasible to change the industry. To realize the potential, solutions must be found to the obstacles, which is discussed in the next section.

8.3 Research question 3: Suggestion for a take back scheme in the industry

The answer to the third research question can be found in subsection 7.2. The question is:

RQ3: *How might the process for the recycling of plastic waste in the Norwegian plastic pipe industry look to overcome the obstacles and exploit the potential for increased circularity?*

In this section, the decisions made for the four developed scheme are elaborated on and discussed, before the scheme as a whole is discussed, with focus on the validity of the resulting scheme, obstacles and potential for success.

8.3.1 Materials and products collected

As presented in subsection 4.7, a key decision in the design of a logistics network is the sorting policies implemented. Pipes that are produced in PVC, PE and PP are collected in the suggested scheme and other plastic materials are not accepted. The collected materials can be pipes and fittings, but not other non-pipe related plastics. This is similar to how they collect pipes in the Netherlands, Finland and Germany. Denmark has a different approach where they only collect PVC materials, but the products can be pipes, window profiles and so on. The advantage of collecting all PVC applications from the construction industry is that it makes it simple for the customer to dispose all PVC waste in one fraction, without considering what application it is. However, they must be certain that the applications are produced in PVC. The approach in the suggested scheme is chosen as the quality requirements in the Norwegian industry hinders use of recyclates from other applications and the applications must therefore be sorted. In addition, the EU has announced changes in legislation for closed-loops for pipes.

As discussed in subsection 8.1, purity of the materials is an important criteria for actors in the industry. Collecting PVC, PE and PP will increase the need for sorting compared to separate collection of the materials, as the materials are incompatible and can not be recycled in the same fraction to reach the required level of purity. However, simplicity is ranked as the most important criteria in S2. Collecting the pipe materials in three separate fractions would require extensive effort from the end-user, increasing the need for competency and motivation. This leads to a trade-off between simplicity and sorting costs, where simplicity is prioritized. Limiting the scheme to the three materials and pipes will yet to some extent make the sorting processes simpler, compared to all plastic applications being collected in one fraction. In addition, if the end-users were to separate the pipes by type of material, it would likely be lower volumes collected and wrongly sorted materials. This would in turn lead to more extensive separation processes, as the materials must be inspected thoroughly after collection.

As presented in subsection 4.3 and subsection 5.2 , PVC is widely used in the construction industry and it is estimated that 36% of the total plastic volume in the construction industry is PVC, while 18% is PE and 8% is PP. The percentage of PVC collected compared to the other materials is expected to be the highest. However, collecting the three materials together can lead to a higher percentage of PE and PP materials also being collected, as they do not need separate collection options for the small amounts.

For the scheme to function optimally, it is important that the materials are sorted correctly and do not contain foreign matters. One solution to encourage end-users to sort correctly is a fee for wrongly sorted materials, which is discussed further in subsubsection 8.3.2.

The vision is that the collected materials are used for production of pipes where the recyclates are used identically as virgin raw materials, as in the ROCKCYCLE scheme. The scheme needs a long-term focus and the recyclates can be used for other applications and three layer pipes.

8.3.2 Collection options

As described in subsection 4.7, collection and distribution in the logistics network must be designed. This is an important decision, as the options for collection of the materials will affect the scheme and how well it utilizes its potential greatly. The first collection option is container rental for construction sites, where the containers are rented from the waste handling company. Based on the responses to S2, several of the respondents already have containers where they collect different waste. At the site visit, it was said that they use containers for projects with high enough volume. Container rental will thus contribute to the largest volumes of pipe waste being collected. As discussed in subsection 8.2, collecting high enough volumes will be important for the potential of the scheme. As containers are already used at construction sites, this will not affect the way of working.

For smaller projects it would be too expensive to rent separate containers for plastic pipe waste, it is necessary to have other collection options. As presented previously, plastic waste is sometimes disposed as residual waste if a full container can not be filled. Having multiple options for collection will thus contribute to capturing a larger percentage of the total volume, even if it requires more coordination and administration.

The second option is collection points at set locations, where the end-users can deliver materials. The distribution of responsibility for the collection points is discussed in the next two sections. Collection points is an option in all five of the established schemes and it is mentioned several times in S2 that it should be an option in the Norwegian scheme. Having established locations where the end-users can dispose their pipe waste can contribute to larger volumes being collected. As presented in subsection 4.7, a decision to be made in the design of a logistics network is the location of the various processes and one of the key strategic decisions is whether to centralize the network or not. There are various opinions in S2 on where they should be located and it is challenging to decide this. If one for instance compares Norway and the Netherlands, the geographical differences make it more challenging to locate the collection points. Norway is an elongated country, and covering all areas with collection points can be quite costly. They should therefore be located strategically so they in collaboration with the recycling stations cover a large part of the country and facilitate for a high amount of volume being collected. This can be done either by focusing on areas where a lot of volume arises, such as the largest cities, or locations where transportation to a recycling station is too long.

The third option is big bags that can be bought for small volumes. There are waste handling companies that offer this today, which makes it plausible that this could work. From subsection 6.1, it is presented that in the Netherlands $\frac{1}{3}$ of the volume is collected at collection points, $\frac{2}{3}$ in containers, while the big bags is only a small part of the volume. This could make an efficient argument for not offering big bags, however, there is not a lot of costs or work needed before a big bag is ordered. When a big bag is purchased, the costs of handling and transporting the bags are included in the purchasing price. The advantage of this option is that even if the volume is too low to rent a full container, the end-users can collect materials through a collection option where then handling and transportation is included. They do not need to transport the materials or make an extra effort to dispose the materials.

The last collection option is self-delivery at recycling stations. This will be beneficial in cases where the volume is too low to rent a container, as well as cases where the volume is large and the end-user would rather transport the materials themselves than use a intermediate link to transport the materials.

Out of the established schemes, four of the five have at least two of the presented options for collection. One argument for having differentiated collection options is that it allows collection of nearly every flow and any volume. This leads to the smaller volumes also being collected, which in total will lead to a higher volume and greater potential for success. As the plastic pipes will be a smaller fraction than plastic waste, it is likely that the total volume in a construction project is lower than the total volume today, as they will have an additional fraction to collect. Having various options to choose from means that they can choose the option that is best suited for their projects, which potentially leads to more participation. As discussed in subsection 8.1, it is challenging to establish one general procedure to the nature of each project and too few collection options would therefore exclude many projects from the scheme. As already discussed, simplicity is highest ranked in S2. The possibility to choose collection options therefore makes it simpler to participate in the scheme. In addition to materials collected the collection options will be of great importance for simplicity of participation, as it will affect the actors in the day-to-day actions. Location and transportation is ranked as number two and three respectively. This is also closely related to the collection options, so several factors are considered in the development of this solution.

A challenge with having several options to choose from is that it makes the scheme more complicated. The end-users must have a clear overview of the options they can choose, as well as clear guidelines for what each option entails. It is therefore, to the extent it is possible, essential to establish standardized practices with clear guidelines. Once it is implemented fully, it will likely be simple to separate the options.

8.3.3 Costs and cost distribution

The cost distribution in the scheme is discussed in this section. This only includes the distribution of the costs between the actors, not set prices for each cost. This must be based on a more thorough cost analysis, compared to today's level and set at a level where it will be feasible.

The suggestion for the container rental is that end-users pay a fee for container rental and transportation of the containers, which was also said in the site-visit that they do today and how they are distributed in the Netherlands, Denmark and Germany. Today, the costs of container rental for plastic waste is lower than for residual waste. The cost level should also be like this for the plastic pipe scheme. Economical factors are mentioned throughout allo of S2, so it will be important to incentivize participation of the end-users. Containers will contribute with high volumes, meaning that it is important that it is attractive for projects with high volumes to use this option for collection. The suggestion is that the collection points are funded by the responsible actors. These actors are discussed further in the next section, but will include the pipe producers.

The economic responsibility of EPR was presented in subsection 4.5, which says that the producer covers all or parts of the expenses for the collection, recycling or final disposal of the product. The collection points will be an addition to the current waste handling options and someone must therefore take the responsibility of funding these. It would not be feasible that the producers take responsibility for funding all collection options, but it can be feasible to cover this. As presented in subsection 7.1, the retailers paid for container rental and provided space for them in Finland. It was challenging to get them to agree to this, this might be due to lack of clarification of benefits of it. The responsible actors can also get something in return in a long-term perspective, for instance lower prices for raw materials. The responsible actors will also get a refund for each kilogram of materials they deliver, which to some extent will limit the economical liability of funding the collection points.

Based on the survey answers, the costs should be evenly distributed across the chain. The end-users are responsible for organizing and funding the transportation to the collection points and will not get a refund for the materials. This way, the financing is distributed between several actors. In addition, if collection points are the preferable options they will contribute to it being an option. There should also be transparency, as the actors are more likely to accept this if they know that other actors also have financial liability. If the end-users received a refund, the cost savings for the responsible actors would be covered elsewhere, for instance through increased prices for pipes produced with recyclates. The producers will also have some physical responsibility from EPR by managing the collection points; describing the systems where the producer is involved in the physical management of the product.

For big bags, the collection and handling is included in the purchasing price. The end-users will not get a refund fee for this collection option, as it would lead to increased purchasing price of the bags. It is therefore beneficial to maintain the purchasing price at a lower level, to collect the smaller volumes with this option.

For self-delivery, the end-user organized and funds the transportation to the recycling station and get a refund fee per kilogram of materials. As the end-users organize and finance the transportation of materials, the refund fee can encourage them to use this option rather than disposing small volumes as residual waste. As mentioned, both big bags and self-delivery will contribute to collecting the smaller volumes that can not be disposed in their own containers. In the site visit, it was said that self-delivery is not used as much as other collection options. This might be because it entails more work than waste being collected at the construction site. For this reason, it is likely that big bags will be a more appealing option for end-users as everything besides ordering the bags is handled for them.

Next is the fee for wrongly sorted materials, that is meant to cover the recyclers increased costs for sorting materials. In the beginning there is a trial period where worngly sorted materials under a set limit of kilograms does not lead to a fee, which is used to encourage participation in the scheme. The weight limit must be set at a reasonable level. There will be more mistakes in the implementation period of the scheme, as it will be a new fraction they must learn to operate. In the site-visit, it was said that it is unlikely that the end-users will try to participate if it is an economical disadvantage. However, a fee will occur in the trial period if the weight of materials wrongly sorted is above the set limit. This is to ensure that the end-users make an effort to sort correctly, and do not use it as an easy or cost-efficient way to get rid of other materials.

Another option for the trial period is a discounted fee, regardless of the amount of wrongly sorted materials. This means that the end-users would pay a fee for each kilogram of materials that is sorted wrong, but it would be lower in the beginning than the actual fee. However, this could lead to end-users not participating, as they know they would end up paying a fee for the wrongly sorted materials. A discounted fee could thus lead to end-users not participating in the scheme to avoid the fee. On the other hand, there are also disadvantages of the chosen option of no fee under the set limit. Someone must pay for the increased sorting costs, even if the end-users do not have to. Yet again, the concept of EPR makes an efficient argument for the producers being responsible for this, as the recyclers will not take the responsibility for this. However, the producers can not cover all costs alone. The more collaborators they have, the lower would the costs be for all actors. The actors and their responsibilities are discussed further in the next section.

As discussed in subsection 8.2, many actors are interested in participating in the scheme. However, eight of the 14 respondents to S2 expect some sort of compensation for their participation. Due to this, it can be challenging to convince the actors to take part in the financial liability of the implementation period of the scheme. One of the key lessons learned in Finland, as presented in Table 6, is that the work needed compared to the overall benefit of the system was unclear. If the short-term investments are seen in conjunction with the long-term benefits the system can contribute to, this might persuade other actors to take part in the financing when changes must be made with focus on long-term system change.

There are uncertainties connected to the economical factors to a circular economy. As presented in subsection 4.2, the transition to a circular economy can reduce costs and impact through reducing sourcing of raw materials and waste processing. The scheme may reduce costs for sourcing of raw materials, however, it will lead to increased waste processing to achieve the desired quality levels, which in turn might lead to increased prices from recyclers to justify the level of processing of materials.

As presented in subsection 6.1, the Dutch scheme is cheaper than the regular waste handling streams if you operate it correctly. In the site visit, it was also said that collection of plastic waste is cheaper than the handling of residual waste, which can be effective to encourage end-users to participate. An important factor when the costs are set is therefore to ensure that they are lower than for the conventional waste streams. As presented in Table 3, a barrier to the transition to a circular economy is the lack of investment power for the considerable amount of upfront investments, which can hinder setting the cost levels low enough. However, regulations and investments from the government can facilitate the transition. This would also be in their interest, as for instance the changed requirements from the EU will necessitate changes in the Norwegian markets.

In the existing solutions, they experience challenges with the low prices of virgin raw materials. The recyclates will require the use of new technologies and extensive processing, which is likely more expensive than virgin raw materials. As presented in subsection 7.1, 13 of the 14 respondents mention the environment in some form as a benefit of partaking in such a system. This can be a motivation to buy the recycled materials even if they are more expensive than virgin raw materials, however, since economic gain is so important for the actors this might not be enough.

8.3.4 Actors and responsibilities

As presented in subsection 4.7, one of the key stategic decision-making problems in designing a supply chain is how to coordinate the logistics services and to make decisions it is essential to know about all components of the supply chain, from the raw material supplier to end-user. In this section, the actors and their responsibilities in the Norwegian take back scheme is elaborated and discussed.

Having clear roles and responsibilities is important for the scheme to function properly. The suggestion is that the industry organization NPG Norge has responsibility for the scheme, driven by the pipe producers, which is done accordingly to the existing solutions. The five largest producers of pipes of pipes and PVC respectively established the schemes in the Netherlands and Denmark, while the plastic pipe association established the scheme in Germany. The pipe producers are repeatedly involved in the development, which can be connected to the concept of EPR. A challenge with EPR is the lack of clarity of roles and responsibilities of stakeholders, where the roles are clarified by having the pipe producers and NPG Norge driving the development. NPG Norge is included to have the role as a junction point between the pipe producers, to ease the coordination among them. As presented in subsection 7.1, nine of the 14 respondents to S2 believe that the pipe producers should have all or parts of the responsibility. Pipelife Norge AS has already initiated the development and can include the other producers and NPG Norge, to combine resources and efficiently develop and implement the scheme.

One of the key lessons from Table 6 is that the scheme must be established in cooperation with all stakeholders. To include the other actors in the development and operation of the scheme, an association for the take back scheme is established. Even though nine of the 14 respondents to S2 answered that the pipe producers should have all or parts of the responsibility, several of them also answered that they are willing to take on some responsibility or believe several actors should. For instance, three respondents believe that waste handling companies should be responsible for at least collection sorting and further distribution of the materials, while two wholesalers believe they could have collection points in their system. In the association, the pipe producers are responsible for establishing and developing the scheme, as well as the collection points, while the waste handling companies are responsible for collection and handling of the materials. The waste handling companies may also have partners in different regions that share their responsibility. The advantage of establishing an association is that more actors feel ownership and responsibility of the scheme, as they are more involved. Solutions must be found as to how members can be enrolled to join the scheme, which will require extensive marketing and discussions with the actors. A solution to the issue of financing the scheme could be an entry fee to join the association. However, for this to work there needs to be a clear difference between actors partaking in the scheme and not, and they need to get advantages of partaking in the association.

The largest Norwegian waste handling companies have the responsibility for collection and waste handling. The largest companies should be included as many of the end-users are probably using them today, meaning that they have established solutions that the end-users are accustomed to. The waste handling companies can also collaborate with smaller actors to increase their capacity, however, this should go through the main actors like in the Danish scheme for simplicity. The solutions will then be standardized which actors they can choose from, where one company handles the project from start to finish. The waste handling companies must have standardized practices that follow the solutions presented previously. In addition, optimum prices must be set to avoid market variation. Once the scheme is established and potentially run by the market itself, the end-users can go directly to their preferred waste handling company.

The recycling activities of the scheme must be further developed. The responsibilities of the recycling activities depend on the capabilities of the recycling companies. If the waste handling companies have the capabilities of performing the recycling activities themselves, this would be a valid option. However, as presented in subsection 4.7 specialized facilities to reprocess products must be set up in some cases. In the Dutch and Danish scheme they use the company Van Werven for recycling activities. The advantage of this is that they are specialized and can focus on developing their capabilities and advance the technologies used. On the other hand, it leads to an additional link in the value chain, which will lead to more transportation, an increased need for coordination among actors and increased costs.

The actors taking part in the suggested scheme are quite similar to how the supply chain is organized today. The pipe producers' responsibilities will change quite a lot. As presented in subsection 4.7, the conventional supply chains are open-loop and the product leaves the initial supply chain once it reaches the customers, and do not include the collection of products. Figure Figure 5 and Figure 6 illustrate how the flow of materials will change at a superior level.

8.3.5 Summarized suggestion: a take back scheme for the Norwegian plastic pipe industry

As presented in subsection 4.7 the developed logistics network will have fundamental impact on logistics systems and facilitate optimal flow of materials. As the example solutions from section 6 shows, there are variations in how a take back scheme can be developed and the different practices require specific supply chain network design. As described in subsection 1.1, there is not a "one-method-treats-all" strategy for the plastics industry and solutions need to be diversified. The suggested solution in this thesis is based on the results of the case study and surveys conducted, which have been seen in conjunction with key theoretical perspectives.

The established schemes presented in section 6 have been important in the development of the Norwegian scheme. They have varying maturity levels, but there is something to be learnt from all of them. The Dutch scheme has been working well for many years and they claim to not experience any practical challenges as of today. The other schemes have good solutions to learn from, but they experience challenges that can also be learned from. For instance the challenge of a lack of overview of the volume and material flows in the German scheme. This is discussed further in subsection 8.5.

As the vision is to increase the circularity of the industry, it must be discussed whether the solution is circular or not. As presented in subsection 4.1, the waste hierarchy is a key concept focusing on utilization of resources. The two most preferred options, "recude and avoid creation of waste" and "reuse", are not the focus of this study. The third option of "recycling" is prioritized in this scheme, as it will have a big impact on th circularity of the plastic pipe industry. The fourth option of "energy recovery" is an option through incineration if the materials are too degraded to be used in production. However, with the development of advanced technologies the vision is that this is not an option. Lastly, the fifth option of "disposal" shall not be used in this scheme. From the concept of the 9Rs, which are also presented in the same section, "reduce", "recycle" and "recover energy" will be the relevant Rs, where "recycle" is prioritized.

Figure 2 illustrates the differences between the linear economy, economy with feedback loops and circular economy. The suggested take back scheme will allow the use of virgin raw materials, to a greater extent in the implementation period where the volume is too low to support the production of pipes. The scheme will not result in enough recycled materials to avoid the use of virgin raw materials fully, as long-lasting pipes are used in the construction projects. However, as decribed in subsection 5.2, the case company uses approximately 2% of recycled materials in their production today, and the scheme will contribute to increasing this number greatly. The scheme does not result in residual waste, as the vision is that all plastic pipe waste ir recycled and used in the production of new products. If some materials are too degraded or contaminated to be used in the production of pipes, it can be used for other plastic applications with lower quality demands. This means that the suggested scheme is in between the economy with feedback loops and a fully circular economy.

The suggested scheme will affect how the business operates, and they need to create, deliver and capture value within closed materials loops through a return flow to the manufacturer. As presented in subsection 4.6, new business models are key to implement the circular economy and promote systemic change. Parts of the business model are developed through the suggestion of the scheme. One of the challenges in CBMs is the return flows, which are considered in this scheme. CBMI can be performed by designing new business models or reconfiguration of an existing one. The suggested scheme is an extensive adaption of the existing model. As presented in subsection 4.7 the producers are not part of the processes once the product reaches the customers in conventional supply chains. As presented in Figure 5 and Figure 6, a loop back to the manufacturers is added to the material flow. This changes the functions of the supply chain and will lead to practical changes for how the businesses think and operate today. In subsection 4.6 it was presented how this will set challenges for businesses as their ideas are realized through their established models. The obstacles discussed in subsection 8.1 occurs in relation to this.

As CBMs are an important enabler of the transition to a circular economy, it was an important aspect of developing the scheme. Theoretical definitions of the circular economy state that one can not only twist the status quo, but must make systemic changes. Yet, it is argued through subsection 8.3 that it is tried to avoid considerable changes in practices for waste handling at construction sites. The way the businesses capture value has been changed, even though considerable changes for the end-users have been avoided.

As discussed previously, the nature of the project and practices for collection of waste will affect how big the changes are for the actors when adapting to the take back scheme. Out of the 12 respondents from S2 that handle waste today, three dispose waste without any sorting. For these actors, the changes will be more considerable, as they are not used to sorting waste already. This might lead to more wrongly sorted materials, as well as a smaller volume of pipes being collected for these projects. Five of the 12 respondents sort plastic in separate containers, where one has a separate fraction for hard plastic. These actors will need to change their routines for collection, which can be a challenge. However, they are accustomed to sorting waste, meaning that the changes will be less of a transition than for those who do not sort waste. Simplicity is ranked as the most important criteria and the actors will experience the fulfilment of this criteria to different extents, as they need to make different adaptions. On the other hand, it was noted at the site visit that even if they have separate collection of plastic waste, some of it ends up as residual waste. However, the scheme has been developed so that it should be simple and straight-forward how to participate in it, to simplify the transition for all actors. It must be described and illustrated thoroughly what the actors must do.

There is disagreement between the respondents in S2 whether there will be practical challenges, economical challenges or both in the implementation and operation of the scheme. Out of the six respondents that answer that they do not see challenges with such a system, five already sort plastic to varying extent. On the other hand, there are also two respondents that separate plastic fractions, who see challenges with the implementation of the scheme. Based on these results, it can not be concluded that actors that have solutions for sorting plastics will transition without obstacles. Economical challenges and financing of the scheme are mentioned frequently in S2 and as discussed previously there are challenges related to cost levels and the amount of upfront investments. The suggestion of the scheme has been developed to handle these challenges fairly and transparently. The potential for success for the scheme still depends on actors being willing to share the financial liability.

As presented in subsection 4.5, both budgetary and physical restrictions hinder companies in making the necessary modifications to their supply chains. Modifications must be made in the plastic pipe industry to enable a transition to using the take back scheme. A tool that can be effective to drive the necessary modification is EPR, where producers take responsibility for the entire life cycle of the product. This concept is used several times in the discussion of the suggested decisions for the take back scheme, as it seems essential that actors take more responsibility for the transition to be feasible. However, EPR is in many cases a regulatory approach instead of a voluntary strategy, as it is rarely the economically preferable alternative. It seems evident that EPR must be used as a tool to drive participation from responsible actors. Without regulatory actions it is challenging to get actors on board with added liability and it can be both administratively and logistically complex. Joint support of the stakeholders is one of the enablers of the circular economy, and other actors than the liability, both financial and administratively, should therefore be included to limit the liability of the producers. The take back scheme can lead to benefits for several actors in the long run, such as reduced materials costs compared to virgin materials, which can be used to encourage actors to take responsibility.

As EPR is often used as a regulatory approach, changes in legislation could force participation from several actors. As presented in subsection 4.5, the EU has EPR schemes that work well and are regulated by directives. The recycling of bottles and cans in Norway that is described in subsection 8.2 is also a good example of a successful legislation change. A challenge with EPR is the lack of incentives for stakeholders. In the Norwegian scheme for recycling bottles and cans, end-users get refunded for each bottle or can they return for recycling, which is beneficial for participation. By for instance making waste handling of plastic pipes more cost-efficient than regular waste handling, the end-users have incentives for participation. As presented in subsection 3.3, there are regulations for return companies in Norway. This illustrates how regulations can be developed, which should be utilized in the implementation of the scheme.

One of the key lessons presented in Table 6 is that the scheme must be establised in cooperation with all stakeholders, which argues for encouraging several actors to take responsibility for the full life cycle of the product. As the case company, Pipelife Norge AS, is the leading manufacturer and supplier in Norway, they have potential to drive the transition and drive other actors into participation. Internationally, the Pipelife group has taken part in developing schemes in the Netherlands, Denmark and Finland, and can therefore contribute with experiences and success stories.

If the suggested solutions are implemented in the Norwegian plastic pipe industry, it can contribute to great benefits for the actors. As described in asubsection 4.4, recyclers face a problem of finding reliable sources of materials, as well as organizing their collection and transportation. The collection requires sophisticated organization, which can hinder the profitability of the recycling process. Having an organized and explicit system for collection will make the resource flow more reliable and can contribute to more profitable recycling processes.

It is apparent that the changes can contribute to environmental benefits through recycling and less extraction of virgin raw materials. Nevertheless, the total impact of the system must still be considered. As presented in subsection 4.4, the impact of the recycling activities can not exceed the impact of production of virgin raw materials. As presented in subsection 4.6, the impact beyond the firm must also be considered. To ensure this, environmental accounting must be conducted for the scheme as a whole. This is discussed further in subsection 8.5. The economical benefits are less apparent in the scheme, as it also requires investments and fees. However, as discussed previously it can for instance lead to reduced sourcing of raw materials.

8.4 Limitations to the study

In this section, the limitations of this study and their impact are discussed.

This thesis has almost exclusively been performed as a qualitative study. Certain quantitative implications are provided through for instance ranking of criteria, but these are limited. To reach the objectives of the study within the limitations of resources and competency it has been beneficial to perform the study as a quality study, however incorporating quantitative considerations could strengthen the findings of it. An example of a quantitative study that could be performed to consider if the suggestions are realizable is a cost analysis, which is discussed further in subsection 8.5.

In subsection 4.3 and subsection 4.4 that concerns plastic materials, several sources used are older. These were used as I believed that chemical aspects of the materials are still valid and have not changes, for instance characteristics of the materials, differences between the materials and basic characteristics of recycling plastics. However, a lot has happened in the plastic industry in the past years, for instance in regards to recycling technologies. Using several more recent sources and updated numbers could therefore have given a more nuanced view of the status of the industry and the challenges related to it.

To strengthen the study, including numbers or estimates of the volume of high-quality plastics that are recycled to lower quality materials or used for incineration today could have been included. In addition, an estimate of the volumes of plastic pipes in the Norwegian industry could have strengthened the study further. As described previously, a challenge is to find reliable sources for the amount of plastic materials in the construction industry, as well as numbers specifically for high-quality plastics. However, including rough estimates could say something about the potential for increasing the circularity in the industry.

Surveys and a site visit were used as methods of data collection in this study, which was very beneficial in answering the research questions and reaching the objectives of the thesis. However, there are limitations of how it was conducted that affect the results of the study. The site visit provided valuable insights into the development of the solution. Nevertheless, I only visited one infrastructure construction project. A visit to an in-house construction project should have been conducted to collect perspectives from both main categories of the customer segment.

S2 was used to collect information from the actors in the plastic pipe industry, which was very useful to get a broad overview of the industry and its actors. However, the answers to a survey are often more superficial than they would be in an interview or in-person. It could therefore have been a benefit to discuss the answers with respondents, for instance one from each category of respondents. In the open-ended questions it is challenging to consider if several actors agree, as they answer freely and might bring forward different aspects. In-depth conversations could therefore have confirmed if they agree with each other or not. However, the open-ended questions allow respondents to answer freely which uncover aspects that would not have been covered with closed questions. Another limitation of S2 is that no pipe producers were involved as respondents. The case company is establishing a knowledge foundation for driving a change, but other pipe producers should have been included to collect information and opinions from them as well.

Lastly, the importance ranking from Equation 7.2a through Equation 7.2e has been used to reason for decisions made in the development of the Norwegian take back scheme, which has been an important foundation for making decisions that coincide with the actor's opinions. Each rank from one through five were given an importance factor, where each increase in rank increased the importance factor. The importance factors and their validity might therefore have impacted the outcome of the ranking. In addition, individuals ranked the criteria, so it can not be said to be 100% representative, even if it points in what direction the actors prioritize criteria.

8.5 Further work

There is still much within this topic that can be researched and further developed. Not all links of the value chain and business model are considered in this thesis and there are limitations of the study that creates a need for further work.

This is as described in asubsection 8.4 mainly a qualitative study, further work should therefore include quantitative studies to verify the suggestion and its potential. First, the cost distribution must be developed. As of now, the suggestion is purely qualitative and a cost analysis must be conducted to understand if the suggestion is realizable. Next, it was also discussed in subsection 8.4 that an overview of the volumes in the material flow would strengthen the study, and tracking of volumes in the scheme should be available for all actors. A project to identify this is currently conducted in Germany, which can be used as inspiration for the Norwegian industry. The amount of cut-offs that are disposed of annually, the percentage of recycling of high-quality plastics and the disposal chain should be uncovered to gain better understanding of the potential for success. To identify if the suggested solution does not have more environmental impact than the production of virgin raw materials, environmental accounting should be conducted of the recycling processes, transportation and so on and compared to the impact of today. Conducting the studies described here would give a better indication if the potential discussed in subsection 8.2 is realizable in the industry.

In subsection 4.7, the decisions for logistics network design and key strategic decision-making problems were introduced. As this thesis is limited to account for only a few of these decisions, the rest of the network must also be developed. This for instance includes decisions on location of the collection points. It must be decided how many and where to locate them, which must be seen in relation to the cost analysis and environmental accounting to decide on an optimal flow. A proper legal structure must also be decided on, which is outside the scope of this thesis. This includes defining legal ownership of the materials at each stage, traceability of the origin of the materials and documentation of materials. As presented in subsection 4.7, information transparency is a critical aspect for reverse logistics, which is already touched upon in this thesis. Solutions must be found that ensure transparency for all actors.

For implementation of the scheme and full utilization of its potential, the suggested solutions must be verified in the industry. Even though suggestions are based on the case study and surveys, it should be presented to actors of all categories in the industry to get their opinions on suggested solutions and potential drawbacks of the scheme. In addition, in-depth discussions with the actors of other European schemes should be conducted to further develop the suggestion. As companies of the Pipelife group have participated in the development of schemes in other countries, this should be utilized to gain insights from pipe producers of the other schemes. Once the scheme is fully developed and verified with actors of the industry, an implementation period where it is tested and adjusted to the practical limitations of the industry must be conducted before implementing full scale.

9 Conclusion

This section summarizes the findings of the thesis and presents the concluding reflections to answer the research questions. This also includes an assessment of the achievement of the objectives of the thesis, before the contribution to knowledge is presented and the results are generalized beyond the particular context. Lastly, the limitations of the study and suggestions for further work are summarized.

The aim of this study was to identify if there is potential for utilizing recycled plastic pipes in the production of new pipes and to suggest logistics solutions for a take back scheme in the Norwegian industry. To do so, three research questions were formulated and answered through the study.

The first research question aimed to identify obstacles that hinder the implementation of a take back scheme that would increase the circularity of the Norwegian plastic pipe industry, where several obstacles were identified. These obstacles are in general related to the nature of projects and volumes that arise, strict quality requirements, economical factors and financing the scheme, and the inherent linear thinking. The variety between the construction projects makes it challenging to establish a general recycling procedure. This also makes it challenging to estimate the volumes for each project, making the potential of each project unclear. The strict quality requirements for raw materials in the plastic pipe industry necessitates resource-demanding recycling processes, which are costly and time-consuming. The economical factors will be crucial to ensure potential of the scheme, where financing the scheme is dependent on actors accepting increased responsibilities. Lastly, the linear model is very inherent in people's attitudes, the business models and supply chains. A systemic change of the linear model is required for a take back scheme to have potential.

As there are established schemes in other countries, there is reason to believe that there is potential for a scheme in the Norwegian industry as well. The general trend of responses from the actors in the industry is that they are positive to such as change. They focus on the environmental benefits of a transition to a circular economy, however, they are dependent on economic gain for these benefits to be sufficient incentives for participation. The construction industry contributes to a lot of waste in the Norwegian industry, so collecting this creates potential for success. In conclusion, there is potential in the industry if the economic challenges are overcome and attitude changes of the linear thinking are successful. To enable this utilization of the potential there needs to be a long-term focus on the effects of a scheme, and joint support of stakeholders, circular business models and legislation are important to enable this.

To answer the third and final research question, a suggestion for a take back system in the Norwegian plastic pipe industry was developed. This was developed based on the insights from the previous two research questions, to overcome the obstacles and utilize the potential fully. The suggestions are within four categories: materials and products collected, collection options, costs and cost distribution, and actors and responsibilities. Pipes produced in all three materials used in the plastic pipe industry are included in the scheme, to ensure simplicity of sorting for the end-users. There are four collection options suggested for the collection of pipe waste: container rental, collection points, big bags and self-delivery. Four different options are suggested to differentiate based on the varying nature of projects, to ensure all projects have a suited option available. The high number of options do not entail significant cost increases, as big bags and self-delivery do not entail high increase in fixed costs. The costs of the scheme are distributed between the actors, to ensure fairness. However, the pipe producers are expected to take on more of the financial liability for establishing the scheme. The pipe producers, in collaboration with the industry organization, are responsible actors for establishment and administration of the industry, while an association for the actors of the scheme is required to establish ownership for the actors.

In conclusion, there is potential for success of a take back scheme in the Norwegian industry. For this to be realized, the suggestions must be verified with the market and the remaining links of the business model must be developed. The objectives of the thesis can be said to be reached, as potential for utilizing recycled plastics in the production of new pipes is identified.

This master's thesis is a contribution to the Norwegian plastic pipe industry and the transition to a circular economy. Even though work still remains for the scheme to be possible to implement in the industry, it is an important knowledge foundation that can be developed further and utilized in the industry. Logistics networks, supply chains and business models must be developed based on insights from specific industries and characteristics of products, materials and supply chains must be considered. However, this thesis contributes to other industries as an example of how a circular economic scheme can be developed. The findings of the study are based on theories on circular economy and logistics network being seen in conjunction with a case study of the industry. This methodology can also be applicable in other industries, and thus contributes beyond the particular context of the plastic pipe industry. Research in the area of sustainable logistics systems is predominantly focused on the forward supply chains, without sufficient focus on the reverse flows. It has gained focus in the recent years, but there are still knowledge gaps that needs to be covered. This thesis thus contributes to cover parts of the knowledge gap, as the focus is to develop sustainable supply chains with successful reverse flows.

The objectives of the thesis have been reached and the findings and contributions of the study are satisfactory as to the expectations and limitations in regard to resources. However, limitations related to the research methodology might have impacted the findings. The main limitations of this study is related to the qualitative nature of the study and data collection. More quantitative considerations to support the qualitative findings would strengthen the conclusions of the findings. For data collection, the limitations are related to the relevancy of sources used for the theoretical background on plastic materials. The data foundation would also have been strengthened by broadening the scope of the survey sent to actors in the Norwegian industry.

There are still many aspects within this area of research and within the industry that must be further researched. First, the findings should be quantified to strengthen the suggestion and the potential for the industry. Next, the remaining links of the logistics network must be developed, as only parts of it is within the scope of this thesis. Lastly, the suggested solutions must be verified with actors in the industry, if the solutions are to be applicable in the industry.

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A List of questions (S1): Take back schemes for the plastic pipe industry

1. What is your name?

2. Which company do you work for?

3. What is your position?

4. Please provide a description of the take back scheme:

5. What is the scope of the take back scheme? For example materials (PVC, HDPE, PP, mixed plastics or others) and applications (pipes, profiles or others)

6. What is the collected materials used for? Are the recycled materials used for production of pipes, profiles or other rigid applications?

7. Which option(s) do you have for collecting pipes? For instance, allocated collection points or pick-up from construction sites? Are the materials collected in big bags, containers or in other ways?

8. Which actors were involved in the development of the system?
For example: waste management companies, entrepreneurs, carriers, local authorities, local wastewater and water companies, consultants, competing companies, the builder, consultants, your company

9. Which types of actors are involved in your take back scheme and what is their responsibilities or role in the take back scheme? Does one actor have the main responsibility, and if so, who?

10. Which link is the most costly? Please rank from most to least below:

1. Transportation
2. Collection
3. Sorting of materials after collection
4. Hiring space and containers
5. Administrative
6. Quality controls before extrusion
7. Sorting of materials at the construction site
8. Others

11. If "Others" is used in the previous question, please provide a description of which link(s):

12. Do you experience challenges with the take back scheme that is established? For instance lack of material, lack of willingness from the industry, costs, lack of space for containers for collection, competing solutions for plastic recycling/ collection etc.

13. Are there any key lessons learned from planning and operation of the take back scheme? What has been the bottlenecks and challenges?

14. Do you have any additional information you would like to add?

15. Can I contact you if clarifications or more information is necessary?

B List of questions (S2): Løsninger for innsamling av rør produsert i plast ved endt bruk

1. Hva er ditt navn og hvilken bedrift kommer du fra?

2. Hvilken stilling har du i din bedrift?

3. Hvilken type aktør i verdikjeden er din bedrift?

   1. Gjenvinner
   2. Renovatør
   3. Entreprenør
   4. Distributør
   5. Annet:

4. Vennligst ranger viktigheten av disse kriteriene i en fremtidig returvareflyt av rørplastavfall (fra mest til minst viktig for din bedrift):

   1. Enkelheten av å delta (feks. om det krever innsats å bidra)
   2. Plassering av innsamlingspunkter
   3. Transportløsning
   4. Økonomiske faktorer (kompensasjon, kostnader for deltagelse og lignende)
   5. Type materiale (kan man levere all plast fra byggeplassen eller bare rør?)
   6. Andre

5. Dersom "Andre" ble brukt i forrige spørsmål, vennligst beskriv hvilket kriterium som menes:

6. Hvilken aktør bør ha hovedansvaret for et slikt system (rørprodusent, transportør, kunde eller andre)?

7. Hvordan mener du at et slikt system bør organiseres? Hvilke aktører har hvilke ansvarsområder? Hvor skal innsamlingspunktene lokaliseres, og bør sluttbrukerne være ansvarlige for å transportere avfallet dit eller bør det hentes hos dem? Hvordan bør det økonomiske aspektet løses? Oppsummer dine tanker rundt dette her:

8. Hva forventer dere (bedriften) å få igjen for å ta del i et slikt system? Forventer dere en form for økonomisk kompensasjon, eller er dere villige til å delta for å bidra til en overgang til en sirkulær bransje uten egen vinning?

9. Hva ser du som fordelen(e) ved å ta del i et slikt system når det er velfungerende?

10. Ser du noen utfordringer med å etablere et slikt system?

11. Dette spørsmålet gjelder aktører som arbeider på byggeplass: hva gjøres med plastavfall (kapp og spill, midlertidige installasjoner, skadede materialer) i dag?

1. All plast samles i container for materialgjenvinning
2. All hardplast samles i container for materialgjenvinning
3. Alt avfall kastes uten sortering
4. Plastrør sorteres separat
5. Annet:

12. Har du noe mer du ønsker å legge til?

13. Kan jeg kontakte deg i ettertid dersom jeg har behov for oppklaringer eller mer informasjon?

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