CHALMERS
UNIVERSITY OF TECHNOLOGY

Overcoming logistic barriers to enable circular supply chains

A case study of physical distribution of cascaded biomass

Master's thesis in Supply Chain Management

Miri Thrane Ødum

DEPARTMENT OF TECHNOLOGY MANAGEMENT & ECONOMICS
DIVISION OF SERVICE MANAGEMENT & LOGISTICS

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
www.chalmers.se
Report No. E2023:147

REPORT NO. E2023:147

Overcoming logistic barriers to enable circular supply chains

A case study of physical distribution of cascaded biomass

Miri Thrane Ødum

Department of Technology Management & Economics
Division of Service Management & Logistics
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023

Overcoming logistic barriers to enable circular supply chains
A case study of physical distribution of cascaded biomass
Miri Thrane Ødum

Report no. E2023:147
Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Cover:
Front page illustration generated by Bing AI image generator

Gothenburg, Sweden 2023

Overcoming logistic barriers to enable circular supply chains
A case study of physical distribution of cascaded biomass

Miri Thrane Ødum

Department of Technology Management and Economics
Chalmers University of Technology

Abstract

The green transition is increasing the demand for renewable energy based on various sources of biomasses. Energy recovery via cascading of by-product biomasses has great potential for supporting the green transition and is enabled by circular supply chains. However, there is limited empirical research and a current lack of practical knowledge on how to structure such circular supply chains handling i.e. cascaded biomass. In turn, potentially viable circular business models fall short, despite a competitive market. This is problematic since the demand for biomass is high, and regional markets are under pressure to deliver to the demand. The consuming sectors are therefore highly dependent on facilitation of global biomass supply to produce renewable energy sources such as biogas.

The study aims to explore how to overcome practical and economical barriers in a supply chain of cascading biomasses with high melting points for biogas production via logistics improvements. Through an exploratory and problem-solving approach, a scenario analysis of a case company's potential standard transport scenario and an alternative transport scenario, was conducted and analyzed according to costs and practical functionality. As the business cases had no prior examples, data was limited and had to be based on estimations and assumptions. This motivated a sensitivity analysis of the alternative solution to provide better understanding of how the business case was impacted by change in parameters. The overall aim was to enable better decision making on uncertain ground regarding the company's potential business cases.

The study suggests that cost efficiency should be priority in the supply chain strategy due to current expensive standard solutions and the characteristics of circular offerings. Moreover, suggestions are made on how to overcome practical barriers and reduce costs via incremental changes in a standard logistics solution, based on changes in equipment, modes, and placing key activities where it is considered optimal both in the supply chain and cost wise. However, the focus on reducing costs to enable viability can compromise finding solutions that actually fits the changed requirements and overcome the barriers that circular offerings induce. Instead, sub optimal solutions are developed, with the same problems in a slightly cheaper package.

Bundling, strategic partnerships, and sectorial innovation are proposed as three dimensions to focus attention towards. Bundling will enable volumes that can enable more tailor-made solutions for transportation, and together enable establishing solutions outside the standard scope. Strategic partnerships can enable innovation. Many potential solutions are already possible outside the actor’s standard domain, through industrial symbioses and exploitation of resources and facilities of other industrial actors. Radical innovation is dependent on strategic partnerships as well, to optimally design circular supply chains. Large volumes and many actors can leverage together and push innovation. It is crucial to critically challenge the squared, standardized, and conventional logistics sector, and its ability to adapt to new kinds of products. Radical innovation of the fundamental structures of a conventional sector does not happen overnight. But if global transportation of i.e. biomass gradually increases volumes and causes a phase-out of transportation of fossil energy sources, design of circular transport solutions might become more the norm than the exception. Enabling that tipping point might create the opportunity to rethink fundamentals of current logistics structures.

Keywords: Sustainability, Circular Supply chains, Circular Logistics, cascading of biomass, closing the loop, Waste Management, Biogas production

Acknowledgements

This Master thesis is the product of 20 weeks of work from September 2023 to January 2024. The thesis is written as partial fulfilment of the Master of Science degree within the program of Supply Chain Management and is corresponding to 30 ECTS. The thesis is written in cooperation with a Danish waste management company, the Service Management & Logistics Division within the Technology, Management, & Economics Department of Chalmers University of Technology.

A special thanks to Assistant Prof. Ivan Dario Cardenas Barbosa for his positive approach, dedicated engagement, and guidance in my work. It has been very educational to be in the process of discussions, idea sharing and brainstorming. Despite the projects at time unclear frames, and as well with data that at times made it unclear where to go, the process of seeing possibilities and scoping was very giving and made me realize that there will always be many options, but the important matter in a process like this is to take a decision and go through while continuously reflecting on adjustments. I have learned a lot from Ivan of attitude of how to approach complex projects which will help me later in my professional work.

A great thanks to the case company for letting me gain insights to their company and business. They are moving with 100 km pr hour, so I appreciated that they saw value as well in investing time in this project. I had the pleasure to talk with in total four different employees. The project managers always took their time for either talking, or mailing to discuss, explain, and help me with my questions. An always critical approach and stress-testing my ideas was an important catalyst for reflecting on my ideas and being critical to them as well, while seeing possibilities.

Thanks to the external experts that were always positive, helpful, and interested to hear about my project and assist with their point of view, to add depth and understanding of the complexities. The positive approach and engagement I were met with, made me hopeful that there a driven people out there that are motivated and invested in finding better solutions for the future.

The project was carried out completely on distance from the company, which at sometimes had its obstacles and challenges and reduced the hand-on experience. At the same time, the interviewees always took their time to contribute how they could on distance. The process of managing the project and being completely responsible for my own project has been a very valuable experience I am taking with me.

It is assumed that the reader has knowledge in the areas of supply chain management and circular waste management.

Contents

List of Figures

List of Tables

Nomenclature

$3PL$ Third Party Logistics

$B2B$ Business to Business

$B2E$ Business to Energy

CE Circular Economy

$CEBMs$ Circular Economy Business Models

CSC Circular Supply Chain

$D\&D$ Design & Development

IBC Intermediate Bulk Container

LC Life Cycle

LCA Life Cycle Assessment

LCC Life Cycle Costs

MFA Material Flow Analysis

$MFCA$ Material Flow Cost Accounting

SC Supply Chain

SCM Supply Chain Management

TEU Twenty-foot Equivalent Unit

Chapter 1

Introduction

Enormous amounts of by-products and waste are created every day in various productions. These by-products are resources that has enormous potential to enter in circular business models through connecting businesses across supply chains. To create efficient business-to-business (B2B) and business-to-energy (B2E) networks of waste and by-products, efficient and well-fitted logistic solutions needs to be developed. These solutions will potentially deviate from the standard solutions, as the products are not standard and therefore needs a different scope to i.e. enable cascading of waste and by-products to energy recovery. As these by-products are often cheaper than 'new' resources, it increases the cost discrepancy in transportation which calls for both innovative and cheaper logistics solutions that deviates from the standard solution. As well the lack of support in secondary raw material markets can limit the ability to exploit and capture remaining value in resources of i.e. waste and by-products. Application of by-products and waste, sets complete new requirements to capabilities of transportation, managing activities, handling, equipment, facilities, and internal resources.

1.1 Motivation & Background

The world is facing a wide range of environmental threats. Global heating and bio-degradation are consequences of growing populations, excessive consumption, over-exploitation of resources, and extensive waste generation. As sustainability measures and circularity is becoming embedded in business models for progressive improvement of the global environmental situation, logistics to support the business models needs to be designed accordingly to enable full the potential of circular economy business models (CEBMs). Unfortunately, logistics to support and strengthen viability of circular business models have been overlooked for too long. Cost of logistics are becoming a major barrier for enabling circularity. Logistics are being stuck in traditional and standardized patterns, and are not adapted towards circular offerings of products with other requirements to i.e. transportation. This means that the full potential and value of CEBMs are either not fully captured, or never realized due to both logistics related practical barriers and cost barriers.

Transitioning to CEBMs is a part of the solution to reduce use of resources and eliminate waste. CEBMs builds on circular principles of either *narrowing* use of virgin materials and resources, *slowing* resource life cycles by extending lifetime of products, or *closing* the loop, and ensuring maximum value capture of the resources throughout life cycles. Circularity of biomasses, via cascading principles of by-products of biomasses-to-energy productions are an important factor for enabling green transition. The demand for biomasses, i.e. in the Nordic countries is high due to the potential of biomasses in many different industrial sectors. The markets nationally and regionally are under pressure to be able to respond to the increasing demand. By-product and excess biomasses are generated everyday globally, having huge potential to be cascaded to other industries, if logistics to distribute it is organized efficiently. Enabling product flows of these masses globally is an important factor to continuously supply producers of green energy and phase out the fossil fuel based productions, and take the next step in the green transition.

The case company studied in this research is an environmentally progressive Danish waste management company, that are specializing in B2B circularity of bio-products and waste. The indicators of high future demand for biomasses in several industries and the risk of biomasses on national markets to become a limited resource are causing them to see the potential outside borders. But logistics of by-products and waste are very dependent on the selling price of the biomass and low logistics costs for it to make economically sense to transport by-products biomasses on long distances.

1.2 Problem Description

Structure and design of standard logistic solutions needs transformation to fit the purpose of supporting and enabling circularity of biomasses. A majority of current business models and logistics solutions are designed according to linear principles of *take-make-waste* principles. Conventional logistics and supply chain strategies are forced to fit to the new CEBMs, creating either sub-optimal or unfeasible and costly solutions. Logistics needs to be structured in ways that ensure economically viability and support of the CEBMs, to actually realize them, while minimizing logistics impact on the TBL (Koosila 2022).

The requirements to the green transition are impacting especially heavy industries. This has lead to electrification of many industries. A concurrent increased demand for biomass are happening within different sectors, which will challenge the CHP[1] plants using biomass and waste to generate surplus heat. These plants supply heat and electricity to other industries, such as biofuel and bioenergy plants, that are build on access to the same biomasses, which in turn can cause these industries to create constraints for each other if the sufficient supply of biomass is not available. This potentially could slow down and restrict the green transition. All together these dynamics are pushing requirements and prices. This is especially happening in the Scandinavian countries when several industrial sectors are competing for the same biomasses. The biomass waste can come in various form. In Denmark it is mainly biomass as agricultural waste, while in Sweden it is mainly roundwood bulk that is applied in various industries (Kjärstad et al. 2023). As the development of plants using biomasses in productions in the Nordics is under a rapid growth, the market is under pressure to be able to meet the demand. Looking outside borders to import biomasses is becoming increasingly relevant to maintain and develop the green transition with application of biomasses. The future high demand can cause biomasses to become a limited resource due to high consumption and competition between industries (Kjärstad et al. 2023). t2

[1] Combined Heat and Power

1.2.1 Logistics

Logistics are considered to be the activities concerning *order processes, handling, warehousing, inventory and inventory control, transportation, & packaging* (Chopra and Meindl 2013). Since circular business models often require a return flow or take-back mechanism, reverse logistic services and activities are crucial to circular business models functionality. The limitation of this often comes down to the actor integration across supply chains and lack of vertical network approach across supply chains. New approaches to how to maximise usage of facilities etc. is required, as sometimes logistic activities is simply not structured to handle take-backs or other circularity logistic activities, in a economically sustainable way nor even being able to handle the products itself (Yadav and Majumdar 2023). Supply chains handling these kinds of resources need to be efficient rather than responsive, and activities should be focused on keeping prices down to ensure cost efficiency (Chopra and Meindl 2013).

1.2.2 Waste Management

Generation of waste is expected to grow by 70% by 2050 (UNECE 2022). When waste products from consumption or production can no longer be prevented or reused, the material is lower in the waste hierarchy and new approaches to waste management needs to be applied; recycling, energy recovery or disposal. Enormous amounts of waste is generated everyday, and if managed correctly there is still a lot of value to be captured from these waste resources. It is in these stages where circular supply chain management (CSCM) becomes crucial to be able to capture value of by-products and waste. Circular supply chains (CSC) differentiates from traditional SCs by emphasizing value creation and waste elimination across supply chains, via both open and closed loop approaches (Montag 2022). Energy recovery via cascading principles is essential to enable production of green and renewable fuels in a sustainable way (Kjärstad et al. 2023).

1.2.3 Cost barriers and challenges for circularity of waste

Current barriers in CE are related to logistics are *lack of supporting secondary raw material markets, lack of infrastructure, current linear design of products, convenience and pricing* (United Nations 2020). There are several economic barriers. I.e. some virgin materials are too cheap for it to be viable to apply recycled materials, where as well incineration is the cheaper option for the waste. Other cost-related barriers such as the discrepancies between transportation and recycled products are great barriers for fully supporting i.e. circularity of products. Long distances and efficiency in collection can as well become a barrier for the viability of circularity (Salmenperä et al. 2021). Fortunately the potential for high prices of biomass are looking bright in Scandinavia and Germany, as the demand for potent biomasses is predicted to increase. At the same time there is an increasing presence of inter-industrial issues due to the use of the same resources while inter-dependencies between productions and industries (Kjärstad et al. 2023).

1.3 Case Company Background

This section provides the empirical background for the case company as a foundation for the thesis. The section will lead to a problem discussion based both on the literature and the case background, that lastly leads to a presentation of the research question. The empirical background for the case is obtained via company interviews as displayed in the methods in chapter 3.

1.3.1 Company Introduction

The case company is a Danish waste management and consulting company with global operations. The company was acquired by another large operator with core competencies within waste collection. The acquisition of the case company was due to their strength within know-how of chemical and materials engineering that enables their strength in connecting industrial actors in a circular perspective, B2B and often B2E. They have a strong brand in the industry and managed to keep gaining customers and developing into new markets and develop greentech solutions.

The company connects industrial clients B2B across industries via their waste and production by-products. This means, that waste created in one industrial context, will provide a resource that is possible to create value from in another place and production. The company manage the functional and logistic connection between the companies. The logistic is managed through 3PL providers and not directly by the company. The company makes contracts with other companies and industrial productions that produces waste in some sort, that could be used in another production context, where the company ensures the chemical and material functionality and quality. In order to keep developing the network globally and making it viable and efficient, well-functioning logistics services that supports the product specific requirements and enables circular flow of resources cradle-to-cradle. This is illustrated below.

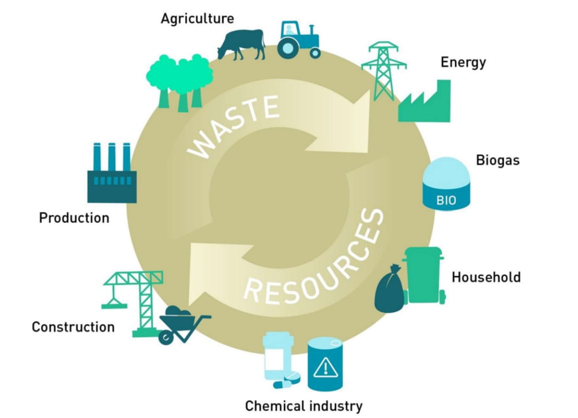

Figure 1.1: The cradle-to-cradle business model of the case company. Source: The case company.

The company operates within six sectors, where it is the end-product, end-use, or market, that defines the categorization of the sector. The six sectors are *Bio-gas, bio-fuel, alternative fuel, minerals and materials, agriculture* and *Hazardous waste*. The fourth sector of *minerals and materials* includes textiles, plastics, and other sorts that cannot fit in the 5 remaining categories. Many of their business sectors are operating according to cascading principles and energy recovery. The circular business model of the company is primarily built on the circular principle of *closing the loop* or cradle-2-cradle.

The biogas sector is one of their six operational sectors where they coordinate solutions for biomass and leftover residue from production to distribution for biogas plants. Biomass is a product with great variety in product characteristics, and biogas production can accept a very large variety of organic biomasses. This means as well that there is no *one-solution-fits-all* approach to the logistics of it. The biomass can come in different forms and hence have unique logistics requirements. The company is facing a wide range of logistics challenges related to circularity of a highly potential biomass for biogas production. Many of these logistics barriers need to be lowered to fully exploit the global biomass potential for biogas production.

1.3.2 Global circularity of byproducts and waste for biogas production

In Denmark the company already have established different sized scale businesses with redistribution of bio-masses for biogas, bio-fuel and other alternative fuel productions. The biomass can be manure, straw, grain, rotten stock of bio-masses, or other organic compositions often from agriculture or by-product from other productions.

Globally there is a huge potential for circularity of bio waste used as input in various different sectors (Comission n.d.). The company sees great potential in the biogas production especially in Denmark, Sweden, and Germany, where the bio-gas plants are well developed and the price of biomass is high in comparison, which means potential for providing a viable business for the by-products. As the biogas production grows in northern Europe, it also means that the biomasses generated locally, nationally, or regionally are exploited almost to a maximum, hence it is necessary to look further outside borders to import biomass. Enormous masses of biomass is produced globally, in all kinds of compositions and forms, where a lot of it is suitable as input in biogas production or other types of biofuels and alternative fuel. The biomass that stays consistent either liquid or solid is rather straightforward, as transportation of masses with these characteristics are rather normal. The company has prospects of biomass producers globally, specifically in Argentina, Oman, and Ukraine, where there is good potential of high volumes and high quality biomass. The problem with this energy dense biomass is that it is also very high in fat content, which is the reason the gas potential is very good. But the characteristics of the biomass is causing various challenges to the logistics and to find a cost efficient solution for the global transportation of the product.

1.3.3 Complicated but potent biomass

Biomass applied for biogas production can vary a lot and come in many different forms with different characteristics (Comission n.d.). In general the types can be separated into either liquid or solid bio-masses. These are the common types the plants are handling. The specific type of biomass that the company are investigating has a very high fat content and is very energy dense. This means the by-product has a great gas potential due to the content of carbon and is attractive to use in biogas production. But due to the product characteristics there are many practical issues causing logistics challenges. Biomass with the high energy density in form of fat, have high melting points, often above 40 or 50 degrees, meaning solidification of biomass at lower temperatures are causing severe logistic challenges.

These issue are so far a deal breaker for the business potential in large scale and across longer distances, as the company have not established any solutions that are economically viable nor practical do-able in large industrial scale yet. The transport scenario of the standard solution is too expensive. Due to the product characteristics, more product handling activities emerge and adds costs. The need for specific equipment and facilities to handle these new product handling activities, leads to more man hours spend on processing and loading. All together contributes to increased costs. The increased costs are becoming a great barrier to develop the logistics network globally for these types of products. The business potential falls short, as the standard transport solution does not fit this type of products and as the same time is too expensive. Enabling the potential of the products could support the circular principle of closing the loop, waste elimination, as well as contribute to production of a green and renewable energy source.

1.3.4 Logistic Challenges

The characteristics of the biomasses characteristics will set requirements and limitations to the way of transporting the masses. The logistic challenges for handling the temperature sensitive biomass are related to containers and storage during transportation, transportation modes, handling and other product related activities; load, unload, heating, pumping, and cleaning. The company has not yet succeeded to find a practically good and viable solution that can handle large volumes. Skills among the 3PL partnerships are crucial for functionality as new solutions can challenge the standardized solutions and cause increased costs. General issues regarding where and how heating activities should be made, leads to challenges regarding inventory and storage, as the plants once accepting a new substrate, needs a stable flow to maintain the production. The plants need some consistency in product flow as the digestion process needs time to adapt to changes in substrates. This means that there either needs to be inventory at the plant or accuracy and timing in the deliveries.

1.4 Problem Discussion and Problem Identification

This section provides a summary of the problem description above with the purpose of framing the problem more specifically.

Analyzing how to improve viability of the CEBM via improved logistics and reduced costs is important to exploit the full potential of the business case. Circularity of the biomass supports the circular principle of *closing the loop*. As well the biomass is a link to producing green and renewable energy, via the principle of *energy recovery*. Supporting both these principles are seen as a strong incentives to investigate the underlying challenges to promote this kind of sustainable circularity.

1.4.1 Costs and Economic Incentive

As the underlying problem currently is the cost barrier induced by requirements from products, it is important to understand if a different design of logistic solutions for a specific biomass will reduce the derived costs of logistics. Reducing costs is critical to strengthen incentive and performance of circular business models, to optimally achieve both objectives of sustainability, performance, and reduced costs. Cost discrepancies between products and transportation is essential to overcome, but is challenging due to the lower product price of by-products. Increased handling and new processes as well contributes to increased costs that impacts the contribution margin negatively.

Many cost related barriers are related to unsuitable logistics solutions driving costs to increase. Both structure of transporting networks, practical do-ability of handling the biomass, inappropriate use of facilities, inventories, and resources, or unexplored logistics solutions needs to be investigated. This in order to achieve 1) solving the practical issues of the temperature sensitive mass making a viable and do-able business case, 2) reducing cost directly via improved and better fit in logistics. It as well is important to understand how general barriers in the logistics sectors can assists to overcome the case specific barriers.

1.4.2 Environmental Challenges

Focus mainly on cost improvements is more tangible, but it is important to highlight the importance of as well investigating the influence on environmental and social aspects of the solutions and business case. It is considered that both incentive and requirements for reducing environmental impacts in a supply chain will only intensify. Therefore, the environmental impact of the solutions needs to be evaluated.

1.4.3 Creating a viable business case

The biomass business potential in large volumes is great in Europe and even in Asia and South America. But a barrier for exploiting the full potential is the product difficulties and the economic barriers of transporting the mass. The company looks for solutions to optimize the logistics for the temperature sensitive biomass with high gas potential. The incentive to overcoming the barriers is large, as the business case has great potential.

1.5 Aim of the thesis

The high gas potential of this of biomass is unexploited and so far not successful, which creates a great incentive to investigate this business case, emphasizing costs, practical issues, and environmental impact of logistics.

The thesis aims specifically to discover the logistics barriers and potential for cost reductions in international physical distribution of biomass with high melting points for being cascaded to biogas production. The aim is to propose a recommendation for logistics aspects of further improvement to reduce costs and create a viable business case. The aim in a broader context is to cast light to the general innovation challenges that impacts the logistics sector and inhibits radical improvements. The aim in this context is to apply the specific business case to cast light to how to overcome these general sectorial barriers for circular supply chains. Below in figure 1.2 overall aim of the thesis are summarized.

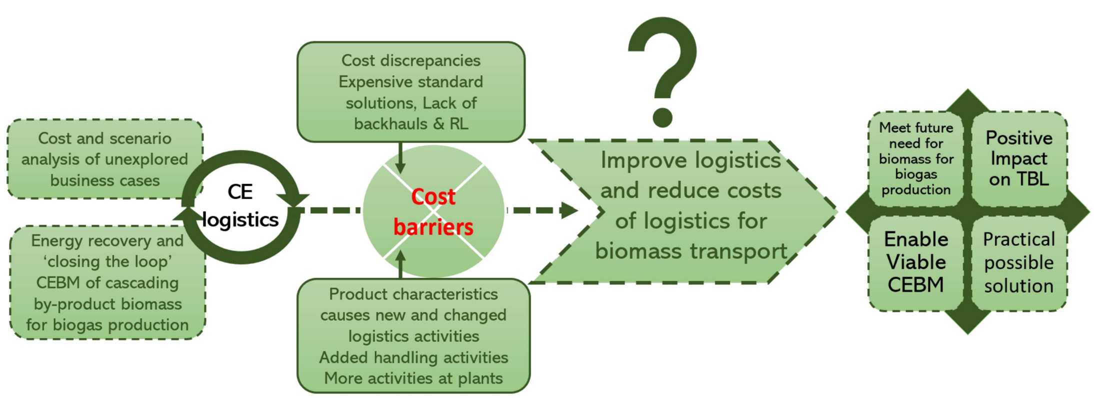

Figure 1.2: The overall aim of the thesis. Own figure.

1.5.1 Research Problem

The problem framework leads to the research problem proposed below, and three supporting research questions;

How can logistic and cost barriers for circular supply chains be overcome to enable viability and full potential of CEBMs?

1. What are the current possible logistics solutions for transporting and handling the specific biomass and what are the costs?
2. Which aspects in the logistics are currently the greatest barriers and main cost drivers?
3. What are the requirements to logistics to overcome the identified barriers and costs drivers?

The issue is complex and impacted by many external and internal factors. As it is not possible to embrace it all, restrictions, scoping and demarcation needs to be made. The system demarcation for the thesis is discussed in the next section.

1.6 System Demarcation, Assumptions, and Limitations

Below in fig. 1.3 is an illustration of the project demarcation in four different levels is illustrated. The demarcation is further elaborated below.

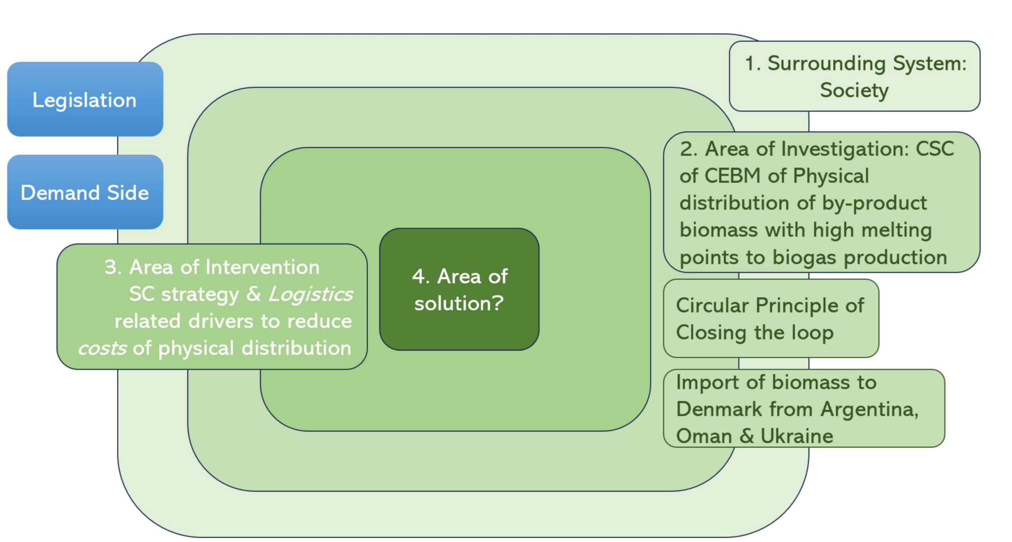

Figure 1.3: Project demarcation.

The projects surrounding system is the society with an increasing focus on sustainability and green transitioning of industries. Increased demand is together with increasing legislation and requirements to sustainability, driving the sustainability agenda and green transition forward, impacting not only how and what is produced but also with which resources.

This thesis will investigate the provided business case of the company, and discover the possibilities of enabling circular waste management of the specific product in a global scale.

The circular principle in the study is 'closing the loop', via energy recovery with focus on three business cases within the biogas sector of the company, that concerns logistics of by-product biomasses with a melting point at 40-60 degrees Celsius. The biomasses are imported from three origins globally to Denmark for biogas production. The productwise challenges is more or less the same, but due to the different origins and respective case requirements, there is small variations in the cases.

The area of intervention has two aspects; First, is the aspect of logistics drivers of transportation, inventory, and facilities, in an overall supply chain strategic focus. Second, is the dimension regarding monetary costs of logistics, from when the biomass is being bought until it is ready to be pumped to the plants. Hence, costs associated to extraction and handling of biomass before it is loaded, is not considered. Same goes for the other end of the supply chain. The company itself is not in charge of production of the biomass by-products, which brings a wide range of uncertainty that they are not in control of. The uncertainty related to production sites variate from being internal production schedules the suppliers supplier, markets in the origins of the main production, etc. These uncertainties affecting production of the main production is considered out of the scope of the thesis, but the uncertainty it brings needs to be considered. The demand side is in general not considered but discussed. Same goes for external markets factors that could impact the case. These are discussed, but not analysed in the logistics scenarios.

Product prices of the bio-masses are considered in a static matter, well-knowing that the prices are fluctuating and will be dependent on many different market and political factors. It is assumed that the prices will be attractive now and in the future and the demand for these products with high gas potential will be high. This is not only because of the product potential, but perhaps as well due to future legislation for circularity of resources, as well as requirements to renewable fuels used in production as well.

Regarding legislation, regulations, and compliance, it is considered out of the scope for this thesis. In general this type of by-product is considered a *product* and as non-ADR (not dangerous waste), which means it does not need to comply to waste- specific compliance and directives. Requirements directly from actors, like suppliers, shippers, logistics providers and receivers are considered within the scope of the thesis. These factors mentioned above will not be within the scope of the analysis. Legislation both on the supplier and demand side is considered out of the scope, although it is assumed that the product demand will increase and that legislation potentially could impact both sides of the supply chain.

Chapter 2

Theory

This section will review relevant literature for the thesis in a broad and specific scope. The literature will create foundation and framework for the further analysis.

2.1 Circular Economy

The concept of Circular economy (CE) has grown rapidly the last decade as a counter economic structure to the so far dominating linear economy (Sassanelli et al. 2019). CE is an economic system structured to reduce waste and pollution, with great emphasis on resource efficiency (Vanhuyse 2023) and aims to reduce waste, extend product life cycles, and regenerate natural resources by designing products and processes that are restorative and regenerative (Zhang et al. 2023). CE concepts strive to liberate from the common linear perspective and decouple economic growth from resource depletion (Walzberg et al. 2021). The Ellen MacArthur foundation (Ellen McArhtur Foundation n.d.) develops state-of-the-art knowledge and research within CE with the entry point that resources are finite. According to the foundation the overhead principles of CE is as follows;

1. Eliminate waste and pollution: This principle aims to reduce waste and pollution by designing products that are durable, easy to repair, and can be recycled or composted at the end of their life cycle.
2. Circulate products and materials (at their highest value): This principle aims to keep products and materials in circulation through processes like maintenance, reuse, refurbishment, re-manufacture, recycling, and composting.
3. Regenerate nature: This principle aims to regenerate natural systems by using renewable energy sources and materials 12.

The principles are illustrated below;

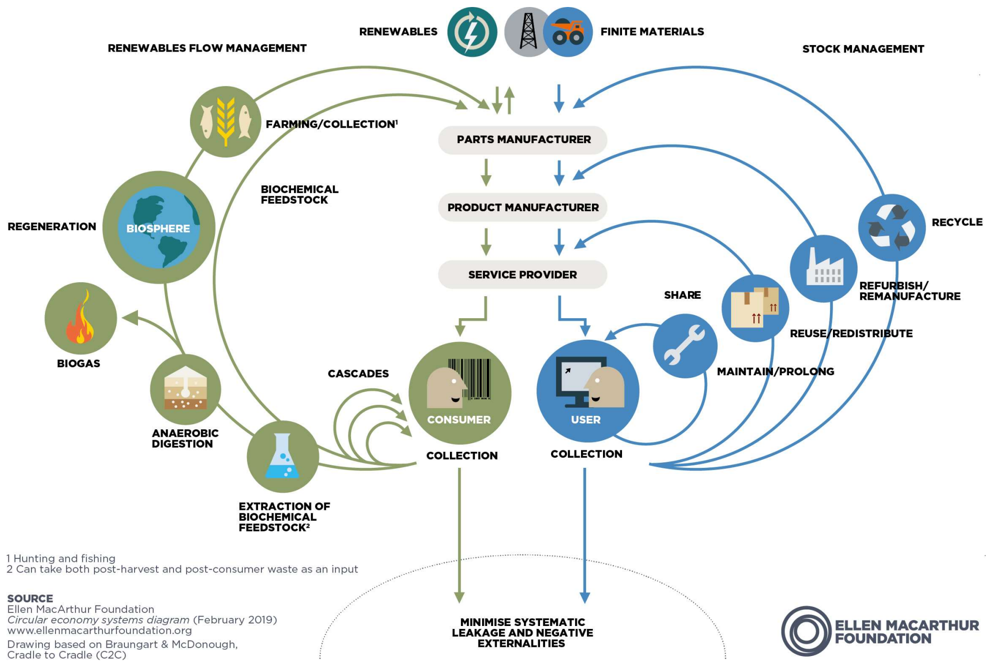

Figure 2.1: Ellen MacArthur butterfly diagram mapping CE principles, (Ellen McArhtur Foundation n.d.).

Kumar et al. 2023 conducted a comprehensive review of CE including the topic of green finance (GF). CE and GF was found to support society, sustainability, and prevent climate shifts by investing in the circular economy. The review found that there is a wide range of barriers in order to overcome, where inadequate knowledge about CE and GF, lack of coherence between legal frameworks on CE and green financing, legislation and lack of financially viable incentive to promote sustainability.

2.1.1 Circular Economy Principles

Circular principles liberates it self from anything associated to traditional linear economy, *take, make, dispose* (Ellen McArhtur Foundation n.d.). A wide variety of circular principles are presented in literature, while they are all similar. The 4R Framework, the 6R Framework, and the 9R framework, are all different versions of the same. Together with definitions for waste hierarchy and systems levels definitions (micro, meso, macro), they provide extensive definitions for work and categorization of CE (A.1), (Kirchherr, Reike, and Hekkert 2017). Below is the 9R framework presented in Figure 2.2.

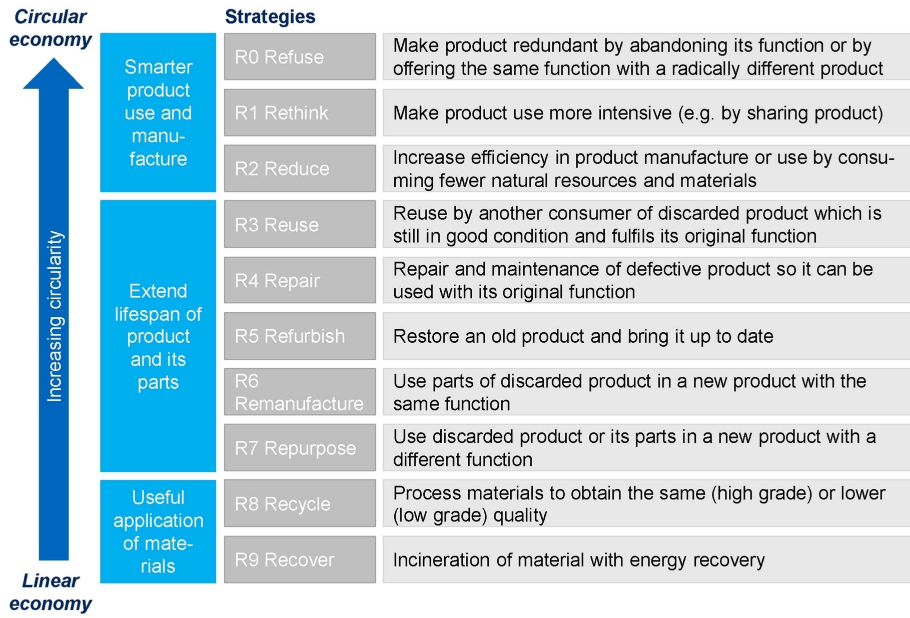

Figure 2.2: 9R Circular Economy Principles, (Kirchherr, Reike, and Hekkert 2017).

Literature has great focus on the concepts of reduce, reuse, and recycle, while the concept of recover takes little focus (Kirchherr, Reike, and Hekkert 2017) .

A more recent adaptation of CE principles is the three CE strategies of respectively, narrowing, slowing, or closing the loop (Lüdeke-Freund, Gold, and Bocken 2018). The first strategy of narrowing is the starting point for resource efficiency strategies. Slowing loops focuses on extending product life, often through design or via the principles displayed in Figure 2.2. Lastly, the strategy of closing the loop, which is considered the most sustainable, focuses on eliminating resource waste or 'leakage' from the system or between systems, to as great extend as possible (Jensen 2018). Efficiency in consumption and ideally retaining product and material value is priority (Kalmykova, Sadagopan, and Rosado 2018). Efficiency principles in consumption is seen to reduce energy consumption in EU between 8-15% (Commission et al. 2016a), (Commission et al. 2016b). The Circularity Gap Report 2022 has collected five years of analysis to show the potential of CE to equitably fulfill our global needs and wants, with radically fewer materials and emissions (Walzberg et al. 2021). With growing populations, increased requirements for food and basal consumption, it is critical too to understand how resource efficiency can be improved (Commission et al. 2016b).

2.2 Circular Economy Supply Chains and Business Models

The Ellen MacArthur foundation is the most forward driven developer within CE including CEBM, and as well focus on the CE in respect to Supply Chains (SC) via Closed Loop SC (CLSC) (Ellen McArhtur Foundation n.d.). CLSC are seen to be an important foundation for efficient and optimal functioning CEBMs, as not only functioning but just as much value creation is possible via a well fitted SC solution(Lüdeke-Freund, Gold, and Bocken 2018). The concepts of respectively slowing and closing has led to the area in logistics of CLSCs. CLSCs is defined as *the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from* *different types and volumes of return over time* (Lüdeke-Freund, Gold, and Bocken 2018), (Guide Jr and Van Wassenhove 2006). The 6 major cycles of CLSC are seen in Figure 2.3 (Ellen McArhtur Foundation n.d.), (Lüdeke-Freund, Gold, and Bocken 2018).

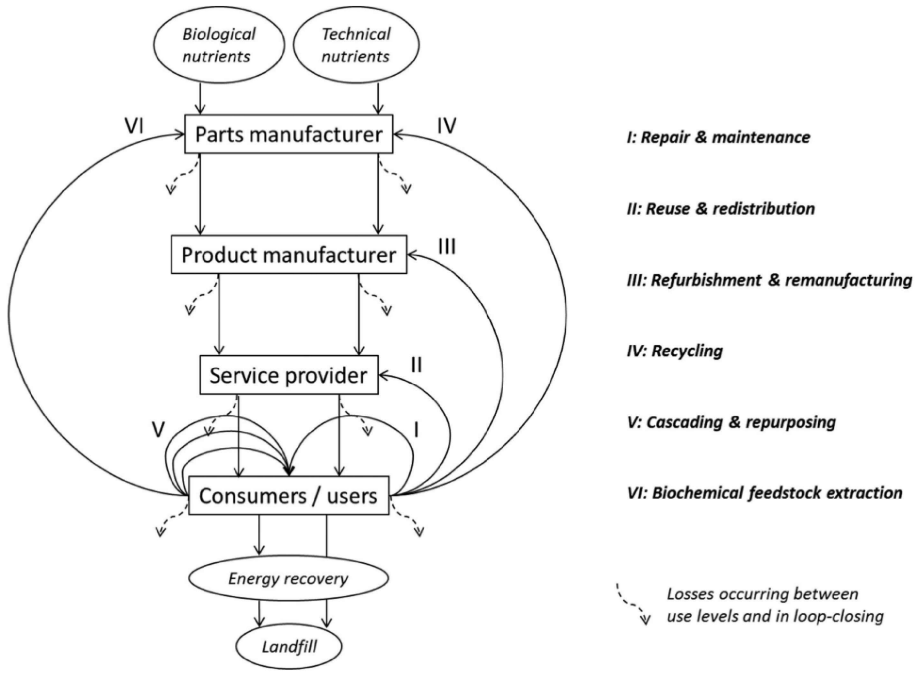

Figure 2.3: Major reverse cycles in CEBMs, (Ellen McArhtur Foundation n.d.).

Proper design of a CLSC can support and strengthen CEBMs. But if they as well can be adapted and transformed into supporting a viable business, creating environmental, social and economical value will be dependent on the design of the business model. CEBMs are increasingly discovered to provide value that exceeds customer value creation and economic value creation and a well-fitted SC is considered to amplify this further (Lüdeke-Freund, Gold, and Bocken 2018).

CEBMs are most often restricted to micro level, meaning the scope is an individual company, while CLSC as well is addressed on meso-level across multiple companies (Lüdeke-Freund, Gold, and Bocken 2018). The goal of CEBMs is to create value through reuse of resources in several cycles, while reducing consumption and waste. As well input to production can be waste from other cycles. Via this, CEBMs can cause new markets or extending already existing markets via connecting industries in *industrial symbiosis*. This is considered the most advanced form of CEBMs where new resource flows and partnerships are created (Lüdeke-Freund, Gold, and Bocken 2018). Lüdeke-Freund, Gold, and Bocken 2018 suggest 4 dimensions, with 8 subcategories to identify 26 CEBMs (appendix A.2, appendix A.4). In Figure 2.4 these are formulated in 6 major CEBMs.

Table 3 Major CEBM patterns

Major CEBM patterns	*Reviewed CEBMs supporting the patterns (cf., appendices I and II in the supporting information on the Web)*[a]
Repair & maintenance	"Repair"; "product life extension"; "classic long-life model"
Reuse & redistribution	"Reuse / refurbish / maintain / redistribute / next-life sales"; "reuse"; "product life extension"
Refurbishment & remanufacturing	"Remanufacturing / next-life sales"; "upgrading"; "product life extension"; "extending product value"
Recycling	"Closed-loop production"; "rematerialization"; "recycling and waste management"
Cascading and repurposing	"Multiple cash flows / multiple revenues"; "co-product generation from waste"
Organic feedstock	"Co-product generation from waste"; "circular supplies"; "resource recovery"; "industrial symbiosis"

[a]Available in the Supporting Information on the Web.
CEBMs = circular economy business models.

Figure 2.4: Major CEBM patterns, (Lüdeke-Freund, Gold, and Bocken 2018).

Enablers and barriers for CEBMs can be divided into respectively micro-, meso- and macro perspective (Urbinati, Franzò, and Chiaroni 2021). The specific enablers and barriers related to each of the three levels are illustrated in appendix A.8. The reference framework is seen below in Figure 2.5.

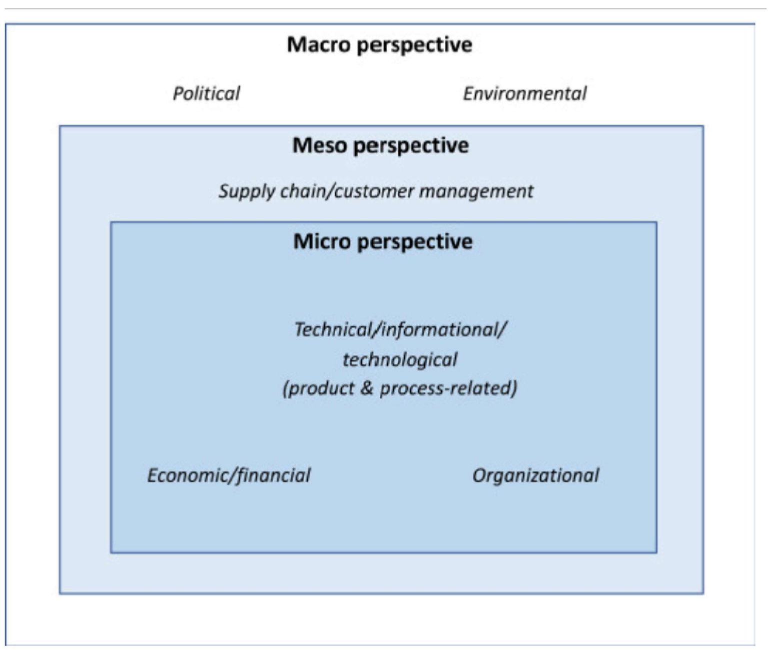

Figure 2.5: Enablers and barriers for CEBMs on respectively Macro-, meso-, and micro-level, (Urbinati, Franzò, and Chiaroni 2021).

2.2.1 Circular Supply Chain Management

Circular supply chain management (CSCM) is the concept of applying principles of CE to supply chain management (SCM). SCM is the process of planning, implementing, and controlling the flow of materials, information, and services from the source to the customer (Montag 2022). Global markets, increased customization, shorter life cycles and high responsiveness has the last decades created a large pressure on supply chains and forced management of SC to go beyond normal boundaries such as nations, companies and industries (Simchi-Levi and Edith Simchi-Levi 2011). The requirements have created responsive and efficient supply chains, but is taking a toll on the environmental aspect of sustainability. Circular SCs therefor has several purposes; being build on sustainable principles as well the design of the supply chain to adapt to the requirements that circularity puts to the CSCM.

Montag 2022 described the present paradigm shift in production and SC philosophy and maps the transition states form linear to CSC via change and variations in SC concepts (Luciano Batista and Maull 2018), (Hussain and Malik 2020), (Genovese et al. 2017), (Korhonen et al. 2018). Successful CSC requires clear understanding of entities responsibility areas (Montag 2022). A frequent perception of SCM is a one-to-one relationship, but the reality is that supply chains are becoming more as networks due to increasing factor of shared resources and cooperation's across supply chains (Lamber, Cooper, and Pagh 1998). Management of SC involves efficient and strategic integration's of upstream and downstream processes, operations, information slows, and relationships that all together adds value for customers and the SC network (Lamber, Cooper, and Pagh 1998).

Closing product and material cycles will enhance the goal of decoupling economic development and resource consumption (Fennemann, Hohaus, and Kopka 2018). A major challenge but requirements for achieving this is cooperation of stakeholders across SC networks, where planning is directed towards closing cycles instead of primarily production. Logistics is decisive for this as it will cross link levels of value creation (Fennemann, Hohaus, and Kopka 2018). The logistics solutions should consider both supply and disposal, as well as stock managements. The greatest challenge is consider to be the aspect of stakeholder integration across the network that allows the paradigm shift of material flows. All though there is a large opportunity of value capture in CE implementation, organizations as well sees risk organizationally and cost risks with transitioning into a new kind of business model. That is why guidelines, frameworks, directives, and especially legislation plays an important role in full implementation of it, as it is shown that regulations triggers innovation and technology, that could also be applicable on CE. Although logistics are seen as a great enabler, logistics should as well seek not to become a part of the problem via i.e. increased transportation and integration of technology solutions, but even the logistics should apply to efficiency principles regarding resources (Fennemann, Hohaus, and Kopka 2018).

Montag 2022 identifies 6 CSC archetypes of CSCM according to the SC features they possess. These are seen in appendix A.3. Furthermore the study identifies CSC propositions that distinguishes CSC sustainability concepts from other sustainability concepts. These propositions are listed below:

- CSCs are proposed to be both restorative and focus on regeneration.
- CSCs applied both open-loop and closed loop flows, with the same goal of reducing waste and use of virgin materials within and across SCs.
- Value creation and waste eliminations are core focus of CSCs.

.

A CSC contains both a forward and reversed flow to enable circularity of waste and products. In Figure 2.6 a closed loop SC describes a CLSC in the following Figure (Amin, Guoqing, and Eldali 2020).

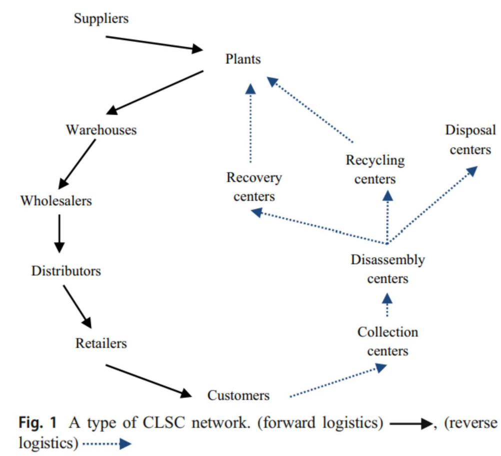

Figure 2.6: Graph of forward and reverse logistics connection in a CLSC, (Amin, Guoqing, and Eldali 2020).

Companies that are dependent on external resources to improve financial situation through vertical coordination, i.e. via a circular logistics network. Due to resource constraints, vertical coordination in CSCs is becoming more important. It is as well proposed that companies that can improve social and environmental sustainability will naturally enhance the economic aspect of the TBL, and as well be hard to imitate (Carter and Rogers 2008).

Shifting focus from short term economic profitability towards long term sustainability and economic benefits in the SCs is crucial. The strategic issues of structuring sustainable supply chain (SSC) goes beyond product design and reverse logistics and supply chain structure and system design requires attention. SSC concerns all three aspects of the TBL and therefor it is important to understand trade-offs and supporting effects between the dimensions of the TBL (Wu and Pagell 2011). Wu and Pagell 2011 presents a trade-off decision diagram in the SSC.

2.3 Logistics as enabler for Circular Economy

Logistics in CE needs to apply a different approach than current waste management and recycling approaches that primarily fulfill tasks as take-back and disposal (Fennemann, Hohaus, and Kopka 2018). To enable this, the SC networks and cross actor integration as mentioned earlier needs to be enabled and designed. The following highlights two different approaches to logistics and their functionality for circularity.

2.3.1 The Classic Approach

The classic approach to logistics function is separated in two dimensions. One part is concerning procurement and production and distribution logistics of new products. The other part centers around products disposal and EoL. In the intermediate phase between these two dimensions, a change in ownership happens that can disrupt information flows, which means that product as well can be less efficiently recycled compared to what it could be. Supply chains under classic circumstances rarely has a focus of closing the loop, but merely production and distribution of non-durable products (Fennemann, Hohaus, and Kopka 2018). Integrating recyclers on one side, that supply secondary products of high quality, and on the other side manufacturers offering repair services, logistics is one of the most important enablers for CE success (Fennemann, Hohaus, and Kopka 2018). It is argued that full potential of CE can only be realized when adapted and adequate logistics solutions are in place. This requires capture and enhancement of current trends within logistics and development and adaptation in all logistics fields.

2.3.2 The Future Approach

There are several trends and developments within logistics that are not innovated specifically for CE, but where it has potential to be exploited for CE. 5 trends that are currently present is illustrated in Figure 2.7. As well the benefit or impact that the specific trend or technology could have on reverse and circular logistics is explained.

Technology/Trend	Use cases (examples)
Atomization of shipments	• Reverse logistics of valuable material such as in end-of-life electric and electronical equipment Reverse logistics of hazardous waste
Information logistics and data sovereignty	• Use of decentralized systems for the provision of information (even on highly individualized products) relevant for the processes in the circular value chain »material passport«) • Protection of transport documentation and respective data security
New manufacturing technologies	• Use of secondary raw material as a substitute to primary raw material • Integration of secondary raw material producers as raw material supplier in the supply chains
Autonomous systems in Industry 4.0	• Autonomous supply chains make use of raw materials and components from primary and secondary sources on equal terms • Transport planning within supply chain networks is done across actors and functions for an optimal use of transport capacities
Social Networked Industry	• Better human-machine-interaction to improve the work efficiency such as to avoid redundant paths in waste collection • Augmented reality-assisted disassembly of complex products helps raising recovery rates and reducing the risk of injury

Figure 2.7: Technology trends in CSC, (Fennemann, Hohaus, and Kopka 2018).

The trends above will impact different levels of logistics and involve different actors depending on which level the trend is relevant (Fennemann, Hohaus, and Kopka 2018). Feng et al. 2023 proposes two different scenarios of the future of CE and logistics. The first one is based on follow-up and tracking of current efforts and much less ambitious, while the other is politically driven on high level. Legislative framework are suggested to be the most ambitious approach to drive the transformation of CE. The regulatory framework should be based on efforts within; *Producer responsibility, recycling rates, indicators & monitoring, standards, products* appendix A.7. A SC networks contribution should optimally be to provide decentralized information infrastructure that in an extensive way can enable companies interaction across to align from strategy to operation. It is stressed that CE logistics solutions at all times should be developed with full consideration to potential rebound effects that might be (Fennemann, Hohaus, and Kopka 2018).

2.4 Supply Chains and Strategic fit

Having a strategic fit in supply chain requires both competitive and supply chain strategy have aligned objectives. Competitive and functional strategies need coordination, to enable synergy effects between functional strategies. There must be support structures in the business where processes and resources are coordinated and fitted to support the strategy of the business. The supply chain must be designed in a way where each stage fit its specific purpose and support the overall supply chain strategy. Having a strategic fit across the companies strategy with a supply chain that supports and enable this is key for a functioning business (Chopra and Meindl 2013). Understanding uncertainty in the SC is the first step of achieving strategic fit, as this ensures that the design of the SC is considering the uncertainty of the markets and is fairly robust to these. Overcoming uncertainty in a SC is about creating SC capabilities that can meet customer demands even under uncertainty. There are different characteristics of a SC that defines either its responsiveness and efficiency. A SC is designed according to these depending on which abilities the SC needs to provide. A high degree of *responsiveness* is required if there is wide range of required quantities, short lead times, large product variation, innovative products, high service level, and SC uncertainty. If the degree of these characteristics is lower, the more *efficiency* is important to meet demand. The more responsive a SC needs to be, the more costly it will be as well. In Figure 2.8 the cost-responsiveness efficiency frontier is illustrated.

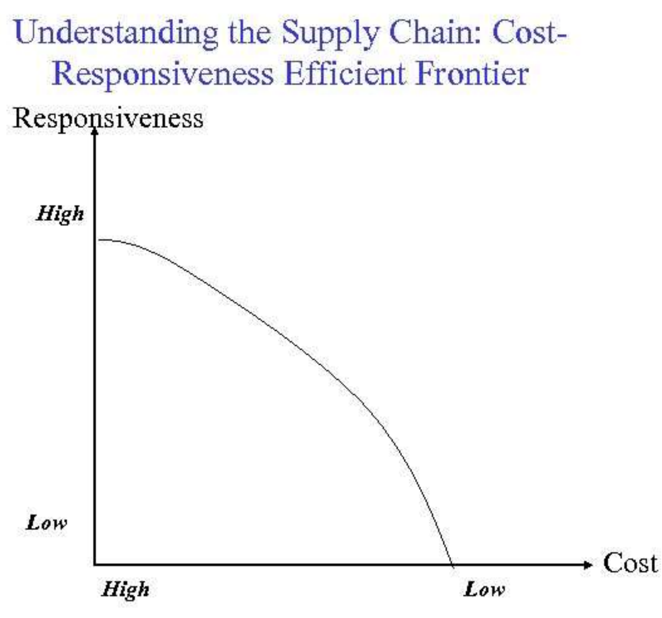

Figure 2.8: Cost efficiency vs. responsiveness in a supply chain, (Chopra and Meindl 2013).

Trade-offs between responsiveness and efficiency is always made, and will be dependent on the type of product and demand there is for the products and how the supply chain is designed. The less responsive a supply chain needs to be the more focus is on cost efficiency, while increased costs and less cost efficiency is a result from a supply chain strategy with emphasis on high responsiveness. Understanding the dimensions of uncertainty and the degree of responsiveness that is required, the SC can be designed according to creating a strategic fit. In the table below the characteristics and comparison of an efficient or a responsive supply chain is shown.

	Efficient Supply Chains	**Responsive Supply Chains**
Primary Goal	Supply demand at the lowest cost	Respond quickly to demand
Product design strategy	Maximize performance at a minimum product cost	Create modularity to allow postponement of product differentiation
Pricing Strategy	Lower margins because price is a prime customer driver	Higher margins because price is not a prime customer driver
Manufacturing Strategy	Lower costs through high utilization	Maintain capacity flexibility to buffer against demand/supply uncertainty
Inventory strategy	Minimize inventory to lower cost	Maintain buffer inventory to deal with demand/supply uncertainty
Lead-time strategy	Reduce, but not at the expense of costs	Reduce aggressively, even if the costs are significant
Supplier strategy	Select based on cost and quality	Select based on speed, flexibility, reliability, and quality

Table 2.1: Characteristics of respectively efficient and responsive supply chains, (Chopra and Meindl 2013)

Creating a strategic fit is finding the right balance in the supply chain between responsiveness and efficiency. Finding the balance is centered around structure in the combination of three logistical drivers and three cross-functional drivers. Figure 2.9 illustrates this. The structure within these in total six drivers and the combination between each of them will depend on the degree to which the strategy is towards a responsive or efficient strategy in the supply chain (Chopra and Meindl 2013).

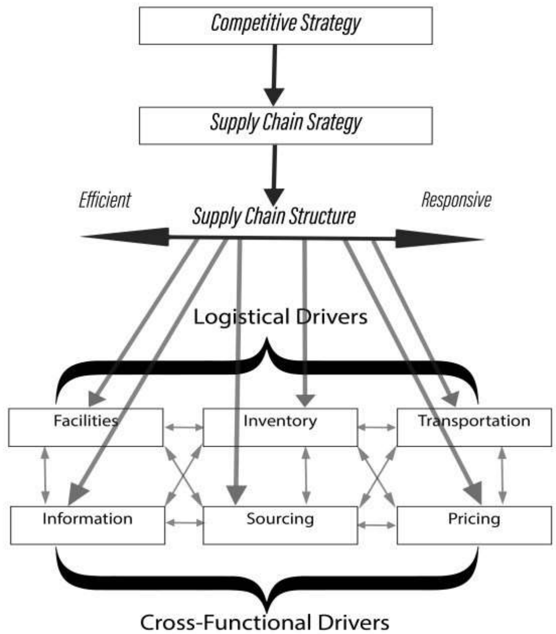

Figure 2.9: Supply chain competitive strategy framework, (Chopra and Meindl 2013).

The logistics related drivers of *facilities, inventory* and *transportation* have an important role in the Supply chain and can have direct impact on the financial performance. Facilities defines the parts of the supply chain where inventory is moved between. At the facilities, products are either stored or in a transforming process, i.e. manufacturing. Inventory is existing in a supply chain when there is a mismatch between supply and demand, and is often intentional, as it can improve responsiveness and ensure i.e. material flow. Transportation is the dimension enabling and adjusting balance between inventory and facilities. All the three dimensions are key drivers for responsiveness and efficiency, depending on how each element is designed and implemented in the supply chain (Chopra and Meindl 2013). In each aspect there will be trade-offs towards either responsiveness or efficiency.

2.5 Waste Management

According to Koosila 2022, remnants from production can either be classified as by products or waste. The type of category the remnants goes is decide on how it should be treated. To be treated as by-product the remnants must have a planned use after the production and should be treated this way. There is some defined handling activities associated to it, and it should meet legal compliance that might be to the specific by-product type. If the remnants falls into the by-product type, the company is allowed to store, handle and use it according what regulations tell. If on the other hand it is classified as waste, there is another set of compliance and legislation that applies. The classification as well decides if the remnants are allowed to be stored and transported as a 'normal product' or if it should be handled by authorized third party waste handlers. Waste regulations applies until recycling of products has been conducted and it is possible to make a re-classification of the products or raw materials.

The driving force of CE is to improve resource efficiency and productivity across all LC stages (OECD 2022). Waste management as an aspect of CE will reduce of environmental and social impact, but as well realization of potential major material savings throughout the value chain and further generation of value generation with economic opportunities and business cases that can be reached with improved CE and waste management (UNECE 2022). UNECE highlights a number of important enablers and focus areas for the future to ensure quality and results of CE. Waste monitoring, data management, information systems, etc. of waste data is important enablers of efficient CE. Legislation and waste reporting systems are as well requirements and enablers. The UNECE highlights the positive impact of CE would have on the entire TBL. Extended Producer Responsibility (EPR) is becoming a major topic that will influence companies extensively the coming years, as more responsibility is moved towards the producer instead on merely on end-of-life, but to ensure the linkage end-to-end(OECD 2023).

There are many ways to approach waste management. The hierarchy in 2.10 illustrates where in the waste process different approaches can be used (OECD 2022)

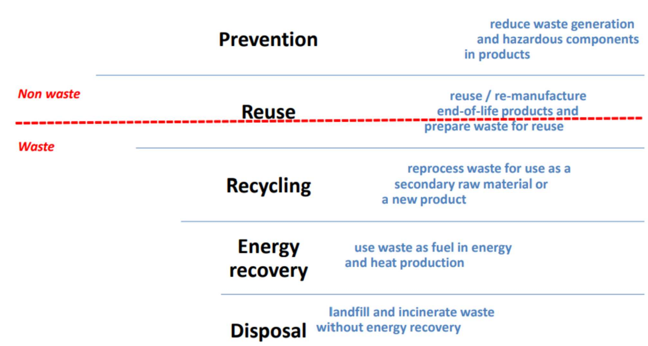

Figure 2.10: The waste hierarchy defined by the OECD, (OECD 2022).

The OECD introduces different indicator groups for measuring progress and performance. These i.e. includes estimation of total waste generation and intensities on municipal and country level, together with recovery, recycling and disposal shares. As well material consumption mix, productivity of materials and footprint. (OECD 2022). This is linked to the requirements for data and reporting systems as mentioned by the UNECE above.

Traditional waste management with incineration as primary EoL activity, is expected to shift towards circular waste management in the coming years (Salmenperä et al. 2021). The transition is illustrated in fig. 2.11. Increasing amounts of waste are diverted from landfill and incineration being fed back into economy via circular principles. Solid landfills have decreased 13% from 2000 to 2020, and the methods has been stopped in several European countries (OECD 2022).

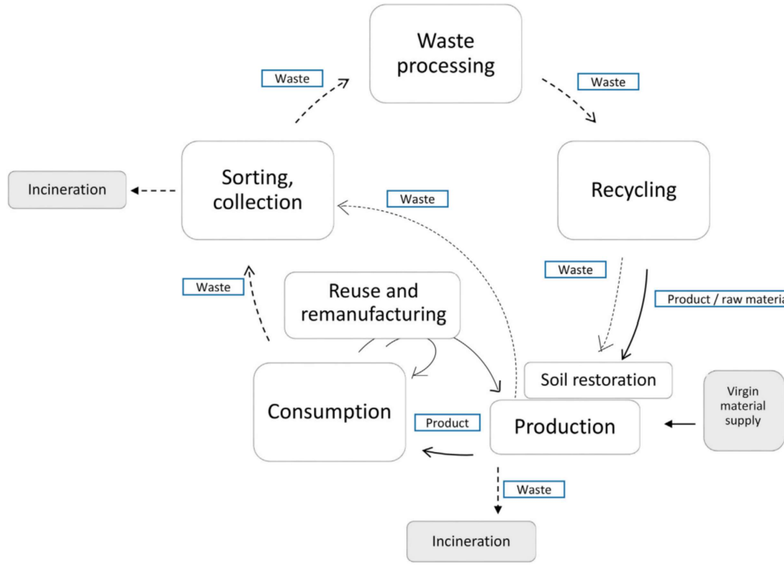

Fig. 1. The expected shift from traditional waste management to a more CE in material use and waste management. The figure reflects the closed materials loop vision the pilots studied aim at. The arrows represent both biological and technological material flows from supply to production, manufacturing, farming, and consumption, and further onwards from waste management to recycling and processing, and the development of waste-based materials into new materials. Technological materials can also provide additional value through reuse and remanufacturing, whereas soil restoration is the key phase of biological cycles.

Figure 2.11: Waste management flow and activities, (Salmenperä et al. 2021).

Energy consumption is a big environmental sinner, which stresses the need for renewable energy sources. Renewable energy such as solar, wind, liquid biofuels, biogas and other alternative fuels, has the smallest share of total energy supply but highest growth rate during the last decade, and now has a share of 30% of electricity production. Biofuels and waste are currently the largest share in renewable sources (OECD 2023). CE model concerning biofuels and waste as input to generation of alternative energy, can be seen as a part of business models that aims to closing the loop. BMs addressing this aspect of circularity is often defined by strategies concerning extending resource value and and building an industrial symbiosis across SC networks (Jensen 2018).

The main difference is that the collection does not merely lead to incineration, but that waste will enter in a CLSC. There exists a number of barriers related to this transformation and adaption of waste management. Some are linked to developers, while others are linked to intermediaries (Salmenperä et al. 2021). The main categories of barriers are listed below.

- Economic and market barriers
- Technology and Information barriers
- Institutional and regulatory barriers
- Sociocultural barriers

Waste management is perceived to enhance economic opportunities as through retaining product value in loops. the authors stresses the need for dialogue between developers and intermediaries to improve further potential for waste elimination and circularity. Bringing CE into SC is seen as highly important and beneficial for improving sustainability. A clear barrier is the lack of cooperation between developers and intermediaries, as they often merely see issues within their own domain (Salmenperä et al. 2021). Vertical cooperation is identified as an important requirement for efficient CLSC. Furthermore Industrial symbiosis (IS) is seen as an important enabler of efficient waste management, as a part of the vertical cooperation. A lack of trust and information is characterised as barriers for IS (Yadav and Majumdar 2023), Here implementation of BCT can play an important role (Giovanni 2022).

2.5.1 Biomass for biogas production

Circular Bio Economy (CBE), and B2E models is considered an efficient way to improve sustainability, as a wide range of by-product biomasses can be used, and beside biogas, organic fertilizer is also produced as a by-product in production (Feng et al. 2023). Interest in bio energy are growing as due to the attractiveness for renewable energy sources and as well the sustainable aspect of energy recovery, via sources that can create energy independence (Lin et al. 2016). In Sweden about 60% of renewable energy is from biomass and the large majority of biomass source is from solid biomass (Bionenergy 2021).

Biogas is a bio-based and completely renewable energy source, in the aspect of reducing emissions of carbon-dioxide while maximizing circularity (Gasum 2023). Beside this, it has a small carbon footprint when looking at the isolated transformation process from biomass to biogas. Biogas is produced from a digestion process by microorganisms where biomass of various kinds are processed into methane CH_4 and carbon dioxide CO_2 (Koosila 2022). Biomass-based biofuels have gained recognition and attention due to the large volume renewable energy source it could provide (Lin et al. 2016).

The biomass can originate from manure, straw, grain, rotten material, leftovers from food industry, and other sources of industrial organic waste. Biogas production in Denmark takes place both in very large and very small scale. There is the large industrial productions that provides biogas for pipelines to national gas distribution networks. In the other end of the scale there is the small self sustaining biogas production on farms, where generated agricultural waste are input to a local biogas production in low volumes (Bigaden n.d.). Bigaden in Denmark is a centralized consulting organization for construction and operation of biogas plants. In Figure 2.12 below, a map of biogas plants in Denmark that is operated by a large common owner is illustrated.

The figure shows the large variety in size of biogas plants and as well application for the produced biogas. And this is as mentioned only those operated by the same owner, meaning the actual number of plants is larger.

Some substrates requires pre-treatment to enhance gas potential and quality (Zhurka et al. 2020). Other substrates are applied with other kinds of substrates to enhance gas potential (Bhukya et al. 2023). In the plant, biomass is mixed and pumped to a reactor for production where the time it takes depends of the process applied for production which can variate depending on the type of substrate. As well there is low temperature and high temperature processes. Some processes requires as little as 38 ° to 52 ° and other more than 3500 ° (Esfandyari, Hafizi, and Piroozmand 2021). The degassed substrate and mass can be sorted out and then used for fertilizer in agriculture. The residual products fertilizer is claimed to be more potent than artificial fertilizer. The fertilizer is applied for all kinds of crops, that are potentially as well later will be a by-product for the biogas, which means the process here will start all over again (Biogas Express 2023). When the digestion process is finalized, the biogas can be pumped directly in to the gas networks, why it is important for optimal function to have well functioning gas infrastructure (Gasum 2023).

The process of having biomass as input in a circular setting, transformed to biogas and

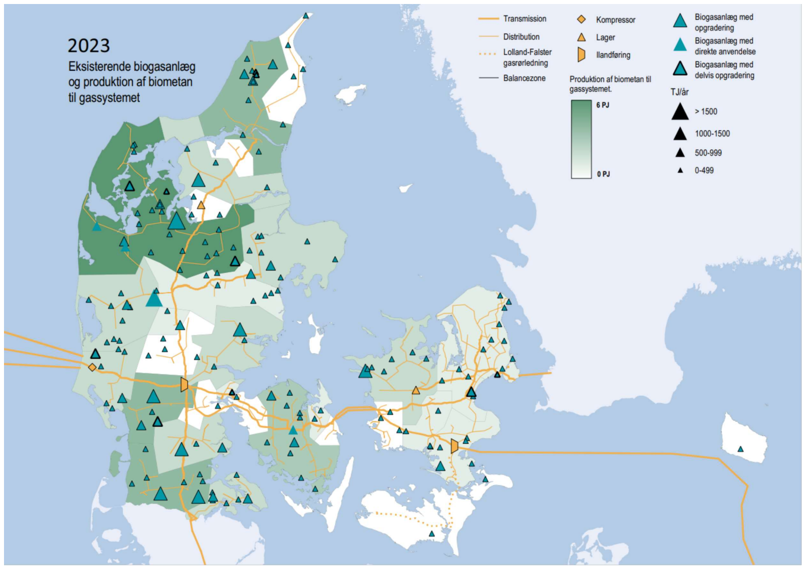

Figure 2.12: Biogas plants in Denmark that is owned and operated by Bigaden, (Bigaden n.d.)

slurry would according to the Ellen MacArthur be cascading. Cascading is the principle of using bio-based materials as efficient as it allows (Koosila 2022), (Ellen McArhtur Foundation n.d.). Biogas production from renewable sources has enormous potential and has potential to reduce LC GG emissions to 90 %. The full potential of closing the loop is reached as the process is by-products processed into energy and by-product that can be used for fertilizer. Biogas production will be an significant enabler of transitioning towards carbon neutral and renewable energy sources (Gasum 2023). It is important to consider the biogas production as well in a LC perspective. The source in itself might be renewable and potential for being carbon neutral, but in a LC perspective i.e. harvest and transportation must be considered. If transporting the biomass over longer distances, the footprint will naturally be larger. Same goes for the energy sources used for the transportation, etc. But the transportation of the biomasses should be seen as a phase-in of transporting renewable sources, while a concurrent phase-out of fossil-fuels, where it is considered to cause a lower carbon foot-print.

Despite the fact that the biogas production from by-product biomasses is considered to be an efficient process to improve sustainability, there must be considerations to the type and content of biomasses used in production. This is important in a risk perspective to fully understand long term impacts, ecologically and socially, in regards to ex. accumulation of unwanted substances. The importance of having a LCA approach to the development of biogas production is important in order to enable biogas CBE and continuous improvement of sustainable development (Feng et al. 2023). The study suggest different approaches to address impact of use of biomass. It suggests; identification and monitoring, occurrence and interaction of toxic contaminants, LCA approach and risk identification, and integration of assurance processes in biogas production and not a separate activity, to efficiently minimize ecological and social risks.

2.5.2 Logistics of biomass

The high cost of logistics and as well increased demand for biomass does not add up and causes severe challenges. Improvement of the logistics can be approached from different angles. Pre-treatment of masses and coordination between actors in B2E networks is one approach to overcome the obstacles (Svanberg 2016).

To fully facilitate large scale development of the biofuel industry, efficient and effective supporting logistics and supply chains are necessary, but are often challenged by disconnection geographically or circumstances that creates non continuous flows (Lin et al. 2016). Efficient design of biomass supply chains is critical to establish large scale biofuel production. Pre-processing biomass before transportation might reduce transportation costs, while at the same time, transport of biomass in longer distances biomass, pre-processed mass, like pellets, leads to decreased costs compared to over shorter distances due to the same amount of processing costs. (Lin et al. 2016).

A study of biomass transportation in Switzerland (Schnorf et al. 2021) presents break-even distances for transportation of different kinds of bio mass. The analysis is evaluating transport solution based on 3 parameters; economic, environmental impact, and energy used for transportation. The study showed that cost was the only barrier of transporting biomass for energy production, and amplifies why economic viable solutions must be found to gain environmental aspects the circularity of biomass can provide. Furthermore, truck was the only used transport mode, as the movement of biomass was only within Swiss borders. Transportation costs of the biomass, especially over longer distances is a severe economic barrier ("Barriers to the wider implementation of biogas as a source of energy: A state-of-the-art review" 2019).

As biogas production expands in the western countries and especially Northern Europe, European markets for biomass starts to fall shorter. This means importing biomass from other production areas to energy importing regions and the need for long-distance international transport solutions. The structuring and enabling of the international logistics network for biomass transportation will imply new logistics solutions, increased costs, more energy consumption, and increased material loss compared to local, national or regional supply (Hamelinck, Suurs, and Faaij 2005). Long distance transportation of biomasses can imply increased pre-treatment, or after treatment, more handling and mode changes. Volumes and masses is an important parameter for decision making to compare economic viable solutions. Large volumes are necessary in large scale systems and to keep prices down (Hamelinck, Suurs, and Faaij 2005). The study of Hamelinck, Suurs, and Faaij 2005 proposes a model of variations in options and key variables in the logistics decision making, this is displayed in appendix A.10.

Biomass bulk is the largest contributor to total costs in terminals no matter the size of the terminals. The reason for this is the requirement for temperature monitoring, specific equipment, and enclosed storage space, leading to increased costs (Dafnomilis et al. 2018). Storing bulk in terminals is shown to have an opposite economics of scale effect, showing the larger the terminal the larger cost contribution does the bulk storage have, (Dafnomilis et al. 2018).

Svanberg (2016) suggests three cornerstones for the physical flow of biomass in B2E supply chains. These are; 1) the supply chain attributes that determines the physical flow, 2) pre-treatment technology that can improve the flows, and 3) actor coordination which can also improve the physical flow. The author identifies a lack in literature of biomass logistics research that provides elaborate descriptions of attributes and characteristics of biomass supply chains. The pre-treatment technology treatment of the biomass that can contribute to ease of logistics or impact price of biomasses. Coordination considers sharing of data and how activities can be coordinated to improve the physical flow.

2.5.3 Market challenges and cost of transport of biomass in the Nordics

The document of Kjärstad et al. 2023, describes how processes, infrastructure, and logistics support to the objectives of achieving a climate neutral industry in the Nordics, by 2045 in 7 large industries in Sweden. The cascading principle of biomass is an important step to facilitate more efficient resource use and renewable energy sources. It is expected that the increased need for electrified industries and increased demand of available biomasses to use within a range of different sectors will drive prices up and as well contribute to challenges of distributing enough biomasses. Different sectors fighting about access to the same biomass can cause challenges as many sectors will require different forms of biomass for running industries of renewable sources. The constantly increasing demand for bioenergy supply in industries, put as well a great pressure on the gas distributions networks to have access and other adaptations the infrastructure need to go through to make the biogas accessible for the industries (Kjärstad et al. 2023).

An aspect of the report highlights how investments in climate neutrality needs to be profitable. In order to be profitable and viable, structures and processes needs to be in place to support it. If they are not, they will not be profitable, and investments and changes will not be made. Many investments in climate neutrality are shown to be profitable only in the long run and not on short term, which can become a barrier for investments. Investments made by the industry are as well based on the institutional risk of politics and expectations of future markets and prices. Many of the necessary investments lies without the area of influence by the industries. The optimal functionality of climate neutral industries requires industrial symbiosis, support systems and structures to enable the full potential and purpose (Kjärstad et al. 2023).

Biomass has enormous potential in many different sectors, but it is not possible to state how much biomass is available globally (Comission n.d.). As the demand for biomass will increase, and prices too, it is concluded that there will not be sufficient biomass available [1] if there is requirements from which sources the biomasses are restricted to come from. If legislation and directives to biomasses are becoming too strict, it will create constraints to access of the biomass, making it a limited resource and in turn mean that the full transition to climate neutrality is not possible. The report analyses 7 different industries; CHP plants, waste-to-energy plants, steel, iron and metal industry, petrol-chemistry, cement and mineral industry, mining, and paper pulp industry. 5 out of 7 [2] of these large industries in Sweden are concluded to be in need of bio based fuels to be able to shift into a climate neutral production. Biomasses are in the report concluded to be a limited resource due to restrictions there is on the Swedish market i.e., (Kjärstad et al. 2023).

2.6 Conceptual Model

Below in fig. 2.13, the literature study is captured in a conceptual model that creates the foundation for the research problem and the context it exists in.

The model is divided into four main categories, with key themes of each category listed. The connection between them is marked with arrows. Furthermore, the purple box, shows how the market trends and challenges are impacting all four categories.

[1] Within national Swedish borders.

[2] Waste-to-energy and paper pulp industry are the exceptions

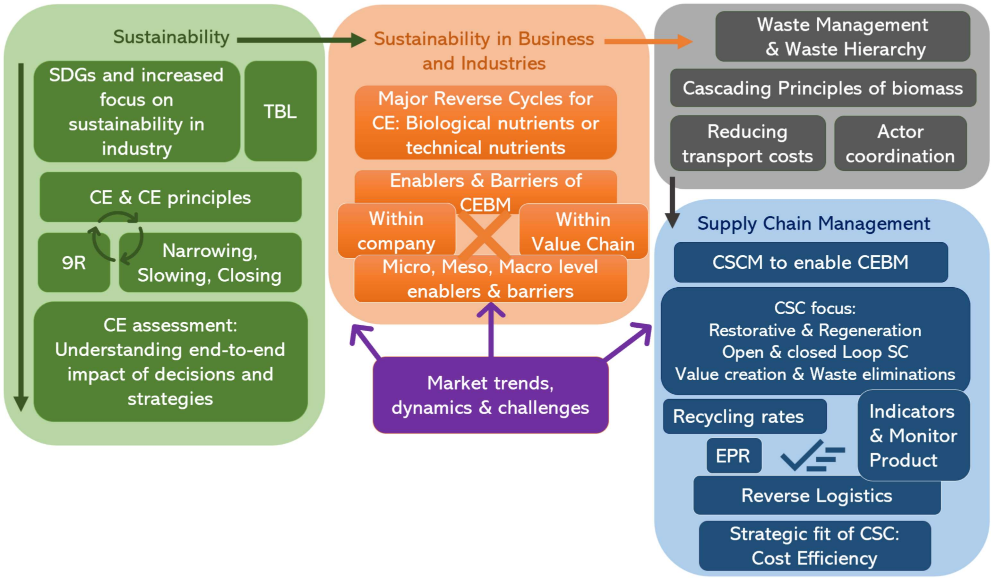

Figure 2.13: Conceptual Model of the Theoretical study.

Chapter 3

Methods

This chapter covers a description of the method applied in the study. A motivation of research strategy is explained, followed by description of the research process, research design and data collection is presented. Lastly a brief discussion of the trustworthiness of the research is presented.

3.1 Methodology

An overview of the research design is illustrated below in fig. 3.1. An elaborating description and motivation of each step will follow in the chapter.

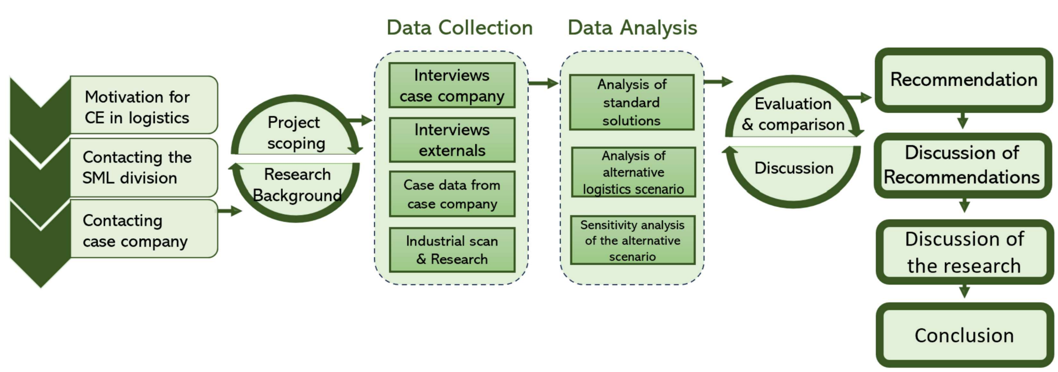

Figure 3.1: Overview of Research design and process. Own figure.

3.2 Research Strategy

The applied method in this thesis is categorized as a business research where two general approaches are applicable; qualitative and quantitative (Saunders et al. 2019). The qualitative research approach emphasizes collected data obtained from literature, interviews, graphical or pictorial (Yin 1999). The strength of the qualitative approach is that you are able to gain insights and in-depth understanding of complexities and issues that are not able to be quantified. The aim of qualitative research is obtaining a strong all-round understandings of the context and specifics to enable answering the many what and whys (Crowe et al. 2011). The quantitative on the other hand is applied as collected data from the case company and as well theoretical data to develop potential logistics scenarios to be evaluated and compared according to functionality and estimation of logistics costs.

Qualitative research can be categorized as explanatory, exploratory or descriptive research (PB Pressbooks 2020). Explanatory research aims to answer cause and effect relations through elaborating *why* a relation exists and is descriptive research to answer phenomenons or tendencies within the chosen topic. The other category is the exploratory. Exploratory research design is defined through an often existing lack of previous conducted research or that the research is in an early stage. This thesis can be argued to be an exploratory research. The argument supporting this would be the that there is little previous research exploring supply chain strategies and logistic solutions for the specific type of biomass as input to biogas production, hence it is considered that there is a research gap in this specific context. Furthermore, as described above, the topic in the company was still very much in an exploratory state and does not have much data nor experience with the business cases.

Furthermore, the research strategy can be described to be both deductive and addictive. Deductive in the sense of analysis of the supply chain of the case company. For the scenario and quantitative analytical part, the data and relevance of the quantitative data was not clear, which it can still be in an deductive research. As well there is characteristics of abduction, in the sense of being a puzzle tried to be solved, where there is either no direct theory to be applied nor any theories to be developed from it, as it is a unique case with unique factors explaining and impacting the case (Bell, Bryman, and Harley 2019).

The strategy of conducting this thesis research was as well with a problem solving approach, and to have an iterative approach where the structure and specificity evolves as more knowledge was gained step-wise. In an iterative approach the scope is demarcated as data and knowledge is gained, with not having a very specific theoretical starting point, but allowing the available empiric matter to set the frames of research scope. This is in line with the idea of throughout the research achieve an increasingly more comprehensive research and results (Saunders et al. 2019).

3.3 Research Design

The research design is the conceptual design of how this research is conducted with the aim to answer the problem statement. In the design there has to be a stepwise approach on how to enable understanding and hopefully an answer to the research problem. The design of the study is both to emphasize literature and collection of case data for scenario development, analysis and evaluation. The research design can be stated as a case study design (Bell, Bryman, and Harley 2019). The case study design emphasizes a detailed analysis of a single case with the specific scope in this case of a specific business case within one organization, where the complexities of both internal and external matter, and the nature of the research scope are attempted to be understood and explained, analyzed and potentially improved (Bell, Bryman, and Harley 2019).

As the case study approach of business research investigates a very specific case, reliability, replicability, and validity are important matters to consider, as findings might be only relevant for the specific case study. The case study in this research have characteristics of a intensive analysis as it relied on developing the specific narrative of the case and as well focusing heavily on the situational details. At the same time the case was attempted to be analyzed from a very general and theoretical fundamental supply chain framework, hence the deductive approach as mentioned above. The focus of the findings is not specifically if they can be generalized or universally applied (Bell, Bryman, and Harley 2019).

In order to understand the current state of the topic in theory and practise, applications of literature creates the foundation. The literature study started in a wide context, and became more specific, to gain both a deep and wide perception and understanding of the topic. Literature enables to understand current state and role of logistics in circular business models in general and specifically concerning transportation of biomass for biogas production. As well the literature can enable to understand the gaps in literature, which can bring a motivation to explore this gap, even if it is in a specific context.

The empirical design of the research was exploring the case company, and obtaining qualitative and quantitative data from a single case study to deduct the research theories. This thesis is built on a single case study of how the case company ought to design their logistic solutions for biomass with high melting points for biogas production. The case study is through three different business cases within the case company, but dealing with the same issue; biomass for biogas production in an international context with similar logistics challenges. The case study had an entry point in identifying the current barriers and challenges, and understanding why a viable business case had not been found yet, to explore how to overcome the barriers that currently makes it not viable.

The current possible standard solution provided a baseline for the analysis in both functionality and cost. From this an alternative scenario was analysed based on the company's own take on how to reduce costs and overcome the practical barriers. A sensitivity analysis was developed for the alternative logistic scenario. The reasoning behind conducting a sensitivity analysis, was due to the fact that the data was rather limited and many assumptions had to be made regarding it. The sensitivity analysis was as well based on assumptions and took a negative approach to test the alternative solutions robustness. Assumptions and estimations was important to enable the analysis, but also means that the results had its limitations which will be explored in the final thesis discussion. At the same time, this approach seems reasonable and very real-life like when dealing with cases of complex nature, and is considered a feasible approach to enable better informed decision making on uncertain information. With the data provided by the case company it made sense to conduct a cost scenario analysis. Cost analysis and research of either improvement of logistics related technology or comparison of alternatives is a widely used approach to transport research (Fjeld et al. 2021).

Interviews with external parties enabled an even wider exploration of potential solutions to overcome the company's challenges. This was considered important as one otherwise can be stuck or locked in a way of thinking solutions within similar frames, and not enable real improvement via radical change.

Gaining case knowledge and case data, qualitative interviews with the case company have provided the foundation, general understanding, and an extensive discussion of their current issues and tested scenarios. Quantitative case data for three different but similar business cases provided a baseline and input to the scenario development and analysis. The case data is from a fairly new and still at a pilot level from the company's side, which means as well that the interviews was a lot about browsing of potential new solutions, and due to the relatively limited amount of data, a lot of the discussion and development of scenarios is at a very theoretical level. The quantitative case data was not extensive, which brought some limitations, hence assumptions and estimations was required. The qualitative data that was attained to support analysis was based on their cost data for transport scenarios.

3.3.1 Research Process

The over all research process can be described as highly iterative, as it was not possible to look many steps ahead. The scoping of the project went hand in hand with familiarizing with the company and the specific research case study. The process was as follows; problem identification, research design, review of literature, understanding availability of data, data collection of both quantitative and qualitative data, scenario mapping, cost data analysis, and ending with presentation and evaluation of the findings. Business research is described as being 'messy', which requires a flexible approach to adapt the research into what opportunities and problems that emerges in the iterative process (Bell, Bryman, and Harley 2019). The approach in this research was indeed flexible, and had many detours as the process went on, before settling on a specific scope. The mentioned case data and knowledge limitations caused some research challenges that was accounted.

The initiative of the research was made by the researcher of the thesis contacting the SML (Service Management and Logistics) department at Chalmers due to interest. The institute was initiating a 3 years research project, Circ:Log (Vural and Halldorsson 2023), researching improvement of circular logistics. This was the entry point to the subject, even if the final scope of the project is not directly linked to this overall research. After this it was the researchers responsibility to find an empirical area. This was when the Danish 3rd party waste management company was contacted. The reason for the initiation of contact to this company was due to their circular business model centering around global waste management and logistics solutions for this. The core of the company is driven by circularity, and the question to how logistics was managed was interesting to discover. Contact was initiated an the company was onboard.

From this state it progressed to defining a scope, which was a time consuming process, as the possibilities within the company was extensive and not clearly defined to a beginning. This was a privileged degree of freedom, but as well caused challenges of attaining specific enough data and actually grasping if the issues the companies had. Parallel with the scoping, literature of current studies of circularity, waste management, logistics including circular logistic and reverse logistics was conducted. This helped to understand trends, challenges, barriers and enablers and most importantly gaps in current literature. The literature study stressed that circular logistics solutions are fairly new and undiscovered which was a large motivation for the study, but also created uncertainty and free frames for the study's exploration further. To explore the possibilities further than what was discussed with the case company, interviews with external actors was conducted, and as well industrial browsing on the internet to gain in-depth understanding of current logistic and especially transport-wise possibilities for products with the specific characteristics and requirements.

Demarcation of the research was an important a challenging step. The final demarcation is explained previously in the *Introduction*. During the interviews it was discovered the complexity and potential broad scope of the topic, and that the importance of a strict demarcation was very important. After some initial interviews and parallel discussion with the supervisor, a business case was suggested by the company. The business case from the company that was settled on was concerning a rather new and unexplored business case for the company, that had sustainability aspects in several ways and at the same time cost and logistical challenges. This as well narrowed the scope and what kind of data the company had available to provide for the research. The availability of data shaped the direction of the research problem.

3.4 Data Collection

Collecting data for a research study there are two types; primary and secondary data (Bell, Bryman, and Harley 2019).

Primary data is data collected for the purpose if the specific study (Saunders et al. 2019). This can be as described company, industry, case data etc. The collection of primary data is through interviews with the case company and the associated quantitative data that is relevant for the case to provide quantification in proposed scenarios.

Secondary data is data gained from other sources collected for a different purpose than the specific study, that then can be applicable for the current study with the knowledge and insight it has provided (Bell, Bryman, and Harley 2019).

3.4.1 Primary Data

Primary data for this thesis has been collected from interviews with internals from the case company, mainly project managers. As well interviews with the COO of a danish port and as well researchers within the field has been conducted to gain a wider understanding of the challenges.

The collected quantitative data collected through interviews with internal and external actors, is presented in the chapter of *Findings*, providing foundation for the analysis. The interviewees are presented below. Primary data in quantitative form is provided by business case data from the company. The data presented in *Findings*. The empirical background described in the *Introduction* is also attained from the interviews.

Interviews

An initial interview was conducted early in the project. The purpose of this was to understand the business model and development of the business model of the company, their business sectors, and lastly, the role that logistics are having to support their CEBM. The purpose of this was to scope the project. This first interview can be described as unstructured.

Following the initial interview, a number of interviews was conducted throughout out the research period. The interviews was building on top of each other and iterative contributing to a greater understanding of the case and case challenges. According to (Creswell 2009), all interviews with the case company can be defined as semi-structured interviews. Before interviews, questions and topics were prepared but with allowance for flexibility in the interviews to enable a more curious discussion and possibility to follow the discussion where it led. Allowance for interviewees to speak freely creates more opportunity for taking the discussion unexpected ways, instead of sticking to a, perhaps, biased idea of where the discussion should go (Bell, Bryman, and Harley 2019). The following interviews became more structured as the scope became more clear, while still keeping the degrees of freedom to be open to new inputs. The last interviews can be categorized as structured, as the project progressed it became clear what data and information was lacking to understand analyse the full picture and context.

The interviews with third parties, such as the interview with the port, can be categorized as structured, as the issues they were wanted to cast light to was very specific. The interview with a Chalmers material engineer, was unstructured, as it was unclear from before what could be contributed with, but it turned out to be a fruitful discussion, and as well provided a very problematic and important context understanding of market challenges of biomass.

It was preferred to have physical interviews as it have another effect sitting face to face, but due to the distance, most interviews was conducted online. Teams was applied as the online interview channel. Fortunately all interviewees was used to online meetings and all were very well prepared, as some topics and questions were some times send beforehand to allow interviewees to prepare and collect material to ensure time efficient once interviews was conducted. All company and external contact persons were always available at mail, which could clear up misunderstandings etc. effectively afterwards.

In Table 3.1 the interviews, interviewees and a statement of their role in the organization is presented.

Organization	*Position*	*Date*	*Duration*	*Channel*
Case company	CEO & Sustainability Director	5th October 2023	1,5h	Physical
GIAB Nordic	Sustainability Advisor	26th October 2023	1h	Teams
Case company	Project Manager	6th November 2023	1,5h	Teams
Case company	Project Manager	14th November 2023	1,5h	Teams
Case company	Two Project Managers	24th November	2h	Teams
Kalundborg Havn	CCO	6th December	1h	Teams
Chalmers	Jan Kjärstad	11th December	1 h	Physical
Case company	Project Managers	15th December	1 h	Teams
Case company	Project Manager	9th January	0.5 h	Teams

Table 3.1: Sources of primary qualitative data. Interviewees and interview information.

Business Case Data

Quantitative data was requested as the project progressed. The case company provided data from 3 different business cases. The cases was concerning different products but with same characteristics and challenges, but from 3 different origins globally. The data was received rather late in the process, and before that many potential idea of analysis was browsed before understanding what was actually possible. Quantitative data was even gained from industrial analysis on the web, to gain estimations of costs of other logistic options that the case data did not provide. As well the port provided data in form of prices of their services and logistic options.

The quantitative data provided by the company regarding the three business cases is listed below and stated in chapter 4, Findings.

- Product data and volumes
- Transport data for agreements
- Economical data for standard transport solutions & estimations of costs of to an alternative scenario

3.4.2 Secondary Data

The secondary data for this study was gathered through specific searching of key words within the broad topic on online libraries and scientific research sites. The secondary data contribution is seen as a necessary complementary to the primary data. Secondary data is required to understand the current state and development of the research area and as well to gain understanding of the terminology and specifics in research and the studied industry. Literature will assist to the broad and specific understanding of the topic and will clarify potential gaps in literature. Furthermore, the secondary data can provide frameworks and tools for analysis of the primary data. Lastly, the secondary data will hopefully enable to see if and how theory separates from practical and real-life business cases, to fully understand what the obstacles are to have fully functional and economically viable reverse logistic services within waste management.

3.5 Data Analysis

Different analysis methods was applied to conduct the research. As for the data, the analysis methods can as well be separated into a qualitative and quantitative approach. Both was applied to understand logistic barriers and cost drivers.

The analysis in the thesis is a cost analysis of 2 different logistics scenarios. Primary data in qualitative and quantitative form, as well as collected primary data from the other sources as described above, enabled a scenario mapping. The first analysis was an analysis of the current standard solution, the second analysis conducted a scenario analysis of an alternative logistics solution. The alternative logistics scenario was further analysis via a sensitivity analysis. Data for the scenarios is based on cost estimations provided by the company as listed in Findings, chapter 4, and data from alternative sources if data to make estimations and assumptions was required. Through interviews with a port an alternative scenario is analysed in a qualitative sense to be applied in the recommendations. The recommendations of the scenarios was put into a context of a supply chain strategy framework with focus on the three logistic drivers (Chopra and Meindl 2013). The framework presents three logistical drivers; *Inventory, Facilities* and *Transportation*, as drivers for structuring the supply chain strategy according to the degree of cost efficiency or responsiveness that creates the optimal strategic fit.

Discussion of the scenarios and their respective cost implications were to round up the analysis, and lastly the analysis aimed to to put this case into a larger industrial perspective, as well in an environmental and social context.

There are many variables and uncertainties regarding the cost estimation of the alternative scenario, and the data provided can not cover the full complexity of it. The aim of the cost analysis is to provide a comprehensive understanding of the complexities that is impacting the cases and stress that estimations and assumptions was needed to be made to enable the analysis. The full list of assumptions are seen in appendix A.15. The results of the cost analysis is not a complete guideline to the costing, and that is why the sensitivity analysis conducted after, attempts to cast light to the uncertainties and complexity of the matter. Based on the findings from the analysis of the alternative logistics scenario, the identified challenges will be discussed and via industrial research and discussion with externals discuss how logistics can be improved further in a practical sense.

3.6 Trustworthiness of findings in the research

The strength and interesting part about this research having a degree of exploratory features is that the frames are fairly free, and is based primarily on the company's experiences assisted with inspiration from literature and external sources. The weakness and challenge of that kind of research is that the data, both qualitative, quantitative and experimental was limited. This makes it challenging to evaluate, especially if proposed scenarios are feasible in reality. Assumptions and estimations does not necessary make the research less trustworthy, but applicability in a broader context might not be great, only for the specific case. As well follow-up tests to confirm or reject proposed solutions would have been great for the research trustworthiness. Unfortunately this was not possible within the time frame nor economical scope of the research. Being aware of these weaknesses or limitations can strengthen quality of the research.

Evaluating trustworthiness and quality is critical, and quality of a study is closely related to the trustworthiness of a study (Y. S. Guba and E. G. Guba 2013). Quality is present if findings and interpretations is the result of a stringent research being systematic and critical. The four criterion's of credibility, transferability, dependability and confirmability are four dimensions that needs to be discussed and considered when evaluating trustworthiness and quality of a research (Y. S. Guba and E. G. Guba 2013). Below these four criterion's are briefly discussed.

Credibility is about establishing confidence in analysis outcome. Lincoln and Guba (2013) suggest different approaches to obtain this. A continuous discussion with the supervisor and interviewees as well provided persistence in data collection. As well, as the company has clear priority of solving this case, it is considered that they have been honest and credible in their data sharing.

Transferability refers to the extent that the current study can be transferred and applied in other research. The more in depth the research background and methodology is described, the more it enables other researchers to transfer gained knowledge to other similar researches (Y. S. Guba and E. G. Guba 2013). It has throughout the research been the focus to stay strict and committed to the scope and demarcation, and as well describing this thoroughly. Together with a extensive explanation of methods applied, it is considered that it should be possible for other researchers to evaluate of this research is applicable in other but similar research contexts. The topic of this research is despite its specificity considered to be relevant for others due to the rather unexplored yet very relevant topic for society. The specific transferability of the results is due to the limitations of the study limited as well. But general industrial considerations are considered to be relevant for other studies.

Dependability defines if the outcome of the study, meaning the findings follows a line of a reliable and steady research method and process (Y. S. Guba and E. G. Guba 2013). Consistent discussions both with supervisor and company contacts is considered to provide dependability. Critical discussions with both parties ensured that there was a linkage between idea and actions and the practical conduction and execution of the research. The discussion ensured that the research followed a line of consistent process. It is considered that it would have been a benefit from the beginning to have a clearer project scope, but it is not considered that it reduced the dependability of the research.

Confirmability is following the dependability and determines if the results, findings and proposed solutions is a outcome of the line of research process applied and the collection and analysis of data (Y. S. Guba and E. G. Guba 2013). When applying the qualitative research as an approach, objectivity is required, to remove bias of preceding perceptions as much as possible. A critical approach to the qualitative aspect of this study, as well as the quantitative, is required to enhance quality of the research. As the quantitative data was limited due to the nature of the company case, it certainly requires both objectivity and critical approach before deciding on the degree of confirmability.

Chapter 4

Findings

The findings are gained through interviews, as well as quantitative data provided by the case company. Summaries of the interviews are found in appendix A.11-appendix A.14.

4.1 Logistic challenges for a biomass supply chain

As presented in the Introduction, the case company are struggling to find a suitable solution for transporting biomass residues from respectively Argentina, Oman and Ukraine to transport it to Denmark for biogas production. The company has tested a few shipments from Ukraine. But the importing from Argentina and Oman has not been tested and is so far merely theoretical prospects to import the biomass from. The by-products from each source is different but has similar characteristics. All the biomasses considered in this case are categorized as non-ADR products, meaning the products are not considered dangerous waste. This means that there is no specific legislative compliance as there would be for dangerous waste transportation, which would potentially complicate and restrict logistics further.

The challenges are related to finding a practical possible solution that as well is economically viable. So far the company has only considered options without pre-treatment before transportation. This means that the product is transported 'as-it-is' as a by-product residue from the respective organic productions. Having no pre-treatment means that the biomass to begin with is pumped from its respective productions into the containers at the origin at a temperature where the product is able to being pumped. After temperature drops, it will be solid, or very thick, meaning heating is necessary before being able to pump the product after arrival at the plants. So far, the company has considered the heating to take place at a truck washing station in Kolding, where steam can be infused to the tanks.

The logistic challenges appears due to the characteristics of the product. The product solidifies during transportation, and needs to be heated to a certain temperature at arrival at the plant or close to it, to be pumped into the plants. The hurdle to solve the logistics is a challenge for the company as the biomass is very potent for biogas production and the biomass markets for biogas production in especially, Denmark, Sweden, and Germany, is under high demand due to the need for biogas.

All the three products has densities around 1 (g/cm^3) as seen in the table 4.1 below.

Origin	Product density
Argentina	1,05 g/ml
Ukraine	0,92 g/ml
Oman	1,006 g/ml

Table 4.1: Product densities.

The plants are dependent on a certain quality and consistency in the product contents, as they need to know what comes into the plants. Quality checks is the responsibility of the company. Quality checks concerns assurance that the product does not exceeds a minimum allowed content of 'impurities' such as sulfur and salts, that the plants are sensitive to. The suppliers agree to deliver the biomass within the limit values, but as the product is a by-product from another prioritized main production, variations can occur. Collaboration and transparent communication between the suppliers and the company is necessary to be able to maintain consistent delivery and product variations within the allowed margin. It is the company's responsibility to ensure that the quality of the product remains within the accepted limits. They do quality checks and are expecting the suppliers to inform if changes are made to the main production.

There is no specific biogas plant in Denmark that is considered to be the receiver of the biomass. It is considered that if prices can be kept down and logistics can be solved in a practical matter for the plants, the company considers many potential plants to be interested in buying the biomass as it is generally under high demand. The potential for selling the biomass at good prices is also why the company is very interested in finding a viable logistics solution to import the biomass. As they are convinced to be able to sell the biomass, solving the logistics around it has high priority.

In figure 4.1 below, the global logistics of this thesis scope is illustrated. The company has considered the standard solutions of shipping the product to the port of Aarhus, loading to trucks than are taken to the washing stations where heating of the product is made, and after this shipped by the same trucks to a biogas plant within 1 hour drive. The product shipped from Ukraine will go straight to the washing station for heating and then being send to the plant.

Figure 4.1: The biomass to be transported from Argentina, Oman, and Ukraine.

4.2 Sunflower oil residue from Ukraine

The case of sunflower oil residue is so far the only case within this type of product that has been tested practically, and the solution tested by the company will provide the case baseline later in the analysis to evaluate improvements from this baseline through different scenarios.

The biomass to be bought is a biomass byproducts from sun flower oil production in Ukraine. In fig. 4.2 the product when being pumped is seen.

Figure 4.2: Sunflower oil residue from Ukraine. Source: Combineering.

4.2.1 Product Data

The product data from the Ukraine business case is displayed in Table 4.2 below. The transport and economical data is providing the scenario baseline and is the only tested scenario to transport the product. This baseline is for comparison to other non-tested scenarios.

Sunflower Oil Residue	
Producer location	Kyiv, UKR
Product	Residue from sunflower oil production (Not ADR)
Pumpable temperature	+52 degrees celcius
Load temperature	+60 degrees celcius
Loss of temperature during transit	-20 degrees celcius
Volumes	1500 tons / 10.000 tons

Table 4.2: Product data for Ukraine business case.

The yearly volume from the producer is 1500 tons of residue, but it is possible to upscale to 10.000 tons from other producers in the area.

The transport data for the Ukraine case is displayed in Table 4.3

Transportation	
Standard transport	tank truck
Volumes & weight	22 Tons pr tank truck
Transit time	5 days (120h)

Table 4.3: Transport data for Ukraine business case.

The cost data of current logistics solutions for the Ukraine case i displayed in Table 4.4

Economy	
Product price DK	360 EUR /t
FCA price	130 EUR/t
Customs procedures	10 EUR/t
Transport in tank truck	3700 EUR / shipment (22t) - 168 EUR/t
Heating w. steam at washing stations in DK	60 EUR/t
Heating time at washing station in DK	16 h

Table 4.4: Economical data for Ukraine business case.

The customs procedures includes export, transit and import. At the moment[1] the border between Ukraine is practically closed with a blockade from Polish truckers, so the above mentioned prices, which were valid for half a year ago are in fact much higher now. When the border is expected to be opened again in a few months, the prices should come back to the level displayed in the table above.

[1] noted the 13.12.2023

4.2.2 Transport

The tested logistic solutions from Ukraine to Denmark, the company has transported the biomass in tank trucks that can be heated and kept warm during transportation. The heating can be done with having steam in the pipes surrounding the tank, or transferring the exhaust gas from the tailpipes to the heating system of the truck. In Figure 4.3 the type of heating truck they have applied is illustrated. As seen in Table 4.4 the heating process the company has tested is applying steam directly into the tank of the truck at a washing station for trucks in Denmark as the heating of the truck during transport did not function satisfactory.

Figure 4.3: Tank trucks with heating system. Source: Combineering.

The heating trucks was provided from Ukraine but was too old or too bad quality for the heating systems to be operating with satisfactory. This means that the product was not able to be pumped at arrival in Denmark and the heating processes needed to be performed before being able to be pumped. This was done by applying steam to the pipe-system and as well by pumping steam directly into the tank. Doing this was time consuming as the product mass took a long time to heat to a consistent temperature and then be ready to pump. This was an extra activity that was not planned, which means more time, money, equipment, and man hours. It was concluded by the company that this transportation solution was too expensive and too uncertain due to the heating process. Internal analysis in the company discovered that transportation with heated trucks could only reach above a break even point if backhaul transportation of the heating trucks was applied. Finding heating trucks to use in a backhaul system, meaning finding a heating tank truck going to Ukraine from Denmark or Scandinavia had to be in place, in order to be able to use it in a reverse flow from Ukraine to Denmark. This has not yet been possible to find by the company. The expensive and unsuccessful attempts with the heated tank trucks from Ukraine, eliminated the option of using heated tank trucks. This scenario will be illustrated in the Analysis chapter to provide a logistic wise and economical baseline to compare the alternative scenario against.

4.3 Alternatives Transport Scenario

The company has investigated several alternative options regarding transport modes, means and facilities, and heating options depending on the logistic solution. Preferably, but depending on volumes they wish to transport it on either curtain side trailers, as this is the by far cheapest mode on road transport. Transporting in by this would as well set requirements to the type of containers that are possible to apply for the products as they should fit into such a trailer. Handling, load and unload should be eased according to the chosen transport mode. Having larger volumes and ability to transport in 20ft TEU or 40 ft TEU train is also an option, but requires the product to be in smaller containers that are suitable to fit in 20 or 40 ft TEU containers. In other business sectors in the organization, the company has agreements with Deutcher Bahn. Finding a suitable train line going from Ukraine to Denmark could be an option, but this option is considered to several load an unload operations. Adding more handling to the process is not considered attractive for the company, but of course it all depends on volumes and prices. The fit of trains across borders can cause complications as the railways systems are not always compatible.

From Oman and Argentina there is not many alternative options than ship for transportation modes. Optimization of these solutions are related to equipment, containers, handling and process optimization.

4.3.1 Means & Equipment

The product types can be transported in different containers. The company has so far considered IBC tanks and flexitanks as potential containers for the product for two reasons: they are compatible in containers and curtain side trailers. Regarding heating of the units, seemingly the only possible options is unit wise heating at the washing stations as the company has explored. Looking in to the future, the company hopes to enable an option that does not contain unit wise heating at the washing stations, but perhaps a large sauna where the units can be stored and heated simultaneously. This does not exists in Denmark yet. A further exploration of the issues of heating will be made in the analysis.

In Figure 4.4 below, the two considered alternative means of containing the product is illustrated. Both these types of containers are considered to be compatible to have in a 20ft TEU container on either a train, vessel, or curtain side trailer. A curtain side trailer is the cheapest mode for road transport and is by the company considered preferable also compared to the otherwise often cheaper rail transport. The reason for this is that having the product on trucks is more flexible and since first and last mile anyway needs to be made by truck they wish to reduce loading activities to a minimum to keep prices down.

Figure 4.4: IBC tank (L) and flexitank (R). Source: google

The IBC tanks can be put in some heating elements that by time will melt the mass, the same can be done in flexitanks with heating pads that are compatible for containers. This is seen in Figure 4.5. As well steam can be applied and send into the tanks to make the masses change to liquid state.

Figure 4.5: IBC tank heating element (L) and flexitank heating pads in a container (R). Source: Combineering.

If the product is send by ship it is considered possible to use IBC tanks and flexitanks as well as they fit in standard 20ft TEU containers that can be loaded to vessels. Figure 4.6 below illustrates an ISO tank in a container.

Figure 4.6: ISO tank. Source: Combineering.

4.3.2 Handling

Depending on the different alternatives for transportation, means, and equipment, there are different handling activities associated to each of them. The loading processes are considered rather similar.

IBC tanks

For the IBC tanks the main handling processes are described to be; heating, unloading and cleaning. The heating can be done either by unitwise heating in a special fitted heating grid for IBC tanks. It is considered that the optimal option for heating should be at the plant. For unloading to the tanks special equipment is required. Either the product is being pumped when ready, or the flexitank is turned upside down. Both will require special equipment at plants.

Depending on the transport mode and where the heating takes place, different handling processes are required. For road transport, which is considered the most flexible one, there will be either one or two steps of handling. The options considered preferable for the company is to unload it once at the plant, before heating. If the IBC tanks are loaded to containers or trains, there are more handling activities, and the IBC tanks should either way be transported first and last mile by truck.

For cleaning the IBC tanks this is considered to be done either at the plant or at centralized facilities. As for the heating, it would be less processes and handling if it is done at the plants, but this as well requires the plant to have both equipment and ability to do it satisfactory.

Flexitanks

The same processes goes for the flexitanks as for the IBC tanks. The heating of flexitanks as well has the options for single unit heating with specific flexitank heating pads to cover the flexitanks. If the heating is done at the plants the plants should have either the heating pads or ability to steam the units as in the washing stations. Unloading of the mass in flexitanks to the biogas tanks at the plant is considered only to be done by pumping, which as mentioned require sufficient equipment.

The flexitanks are non-solid which makes the requirement for ability to handle the maybe challenging sizes and materials of the large bags necessary, as they as well are considered a little fragile of their material.

The cleaning process is eliminated with the use of flexitanks, but instead disposal of the large bags are required. As the product is organic, there are not considered to be any complications with doing this, except that it will add an expense.

4.3.3 Inventory & Facilities

The biogas plants are able to process (digest) many different kinds of bio-masses. The usual kinds of agricultural waste and substrates are easy to handle, as they are either in liquids, pellets, or solid forms. Many of them are good but not very energy dense, such as straw residues, having big volumes bot low energy density. Often the products are collected from nearby farms, which means little transportation and limited resources spent for logistics. The product types are easy to handle and does not require extraordinary handling, processing etc., before being loaded to the plants.

What is attractive for the new product being investigated is as mentioned its biogas potential and high energy density. But on the down side the product sets many challenges for the facilities in the supply chain. The plants takes time to adjust to a new kind of substrate with this high fat content products. The handling challenges means that the plants need specific facilities to manage and handle the product efficiently and with ease. Several large investment costs. If heating is done at the plants heating facilities or equipment is required. This could cause a considerable barrier for the company's ability to sell the product. If else, 3rd party heating facilities should be organized. Currently a 3rd party solution does not exists with any partners. Pumping facilities is required, which can also be equipment the plants needs to invest in, if they are not currently operating with liquids in their plant. It is required from the plants to have ensured a flow of the biomass once digestion with the specific substrate is initiated. To company has currently no option to store it externally and consider it optimally if the plants can store it locally and for free at them selves.

4.3.4 Challenges with alternative solutions

The primary challenges the company sees with these two options of equipment is that both flexitanks and IBC tanks will require much manual handling, and as well with many smaller units it increases the amount of manual handling further. This is why the company considers big saunas as the best option for heating as the unitwise heating seems complicated and expensive. As well it can be difficult to control how long time the heating process will take for both alternatives. As it is considered optimal to have the heating process as close to the plant as possible or preferably at the plant, it is considered that the plants need equipment and facilities for this. This will of course be expensive and be a large barrier for the plants. If centralised heating facilities could be found close to the plant this is considered to be preferable, but it as well will add another step to the process and handling.

It is considered that there will be a significant amount of leftover/spilled residue of the product when being pumped as the product is very thick even when 'fluid'. This adds another issue with IBC as they are considered to be reusable at least 2-4 times. They will need cleaning, which will add another process and another expenditure to the process. As well for the flexitanks there is the challenge of a large product waste when being pumped. The flexitanks on the other hand is a single use equipment which means that disposal of the bags is an added process. The flexitanks as well is considered under risk for puncturing and spillage, and can add a safety risk during transport. It could also be considered to be requirements for this kind of transport equipment.

The unload process of IBC tanks is considered to be most efficient to turn it upside down. The other options is to pump it. Both options needs specific equipment at the plants. Both approaches as well implies cleaning of the containers completely. Another option which is seen in the industries is simply to destroy the containers to more efficiently get the masses out. But this is not considered a preferred option of the company due to both economical and environmental reasons, and inefficient use of resources.

Data for considered alternatives

An industrial analysis and estimations of prices provided by the company puts a number to the alternative solutions that the case company has considered. In Table 4.5 below costs of alternative means to transport are displayed.

Data for alternative solutions	
Curtain slider truck (w. IBC or flexitanks)	2600 EUR/t for 22 tons 119 EUR/t
IBC	30 EUR pr piece in UKR
flexitank	70-230 EUR / piece

Table 4.5: Cost data of alternative transportation and equipment.

4.4 Oily residue from Oman

The business case in Oman is so far an unexplored business case in a practical sense, meaning there have been no pilot attempts to transport the product from Oman. But as the products have similar characteristics, the solutions across the products and origins are considered to be likewise applicable in other business contexts from other origins but similar product characteristics and hence similar logistic challenges. The producer is situated in Sohar, Oman. Below in Figure 4.7 the product from Oman is illustrated.

Figure 4.7: Oily organic residue from Oman. Source: Combineering.

4.4.1 Product data

Below the findings from the Oman business case is displayed in Table 4.6

Oily Residue	
Producer location	Sohar, Oman
Product	Oily Residue (Not ADR)/ not waste
Pumpable temperature	+43-47 degrees Celsius
Load temperature	+48 degrees Celsius
Loss of temperature during transit	-25 degrees Celsius
Volumes	600 t /year

Table 4.6: Product data for the Oman business case.

Above the Table 4.6, illustrates a yearly volume of 600 tons. This is the potential volume of the specific production the company has been in contact with. It is possible to upscale to 2000 t pr year from near by producers of the same product.

The transport specific data is displayed in Table 4.7

Transportation	
Standard transport	ISO tank container
Volumes & weight	24 Tons pr container
Transit time	N/A

Table 4.7: Transport data for the Oman business case.

The cost specific data for the Oman case is displayed in table 4.8

Economy	
Product price DK	500 EUR /t
CIF Aarhus price	360 EUR/t
Customs procedures	5 EUR/t
THC /Terminal handling costs	270 EUR / load
Last mile (ISO container loaded on truck chassis	40 EUR / t
Heating w. steam at washing stations in DK	60 EUR/t
Heating time at washing station in DK	20 h

Table 4.8: Economical data for the Oman business case.

4.4.2 Current possible logistics solution

The producer is only able to load the product in ISO tanks when it is warm enough in Oman, in the period from end of April to mid October. The product in this period is stored in IBCs, gets too solid at cannot be transferred into ISO tanks. It is at winter times the prices for the product is the best in Denmark for this product as the demand for substrates is on top. The current theoretical discussion to transport it in ISO tanks and the other restrictions from the producer is not a very flexible solution and expensive, which strengthens the incentive to find another one. The given price above is if the ISO tank containers is delivered liquid to the plant. The given price above for the CIF Aarhus at 360 EUR/t, is what the company pays for the transport and it includes cost of the product and transport to Aarhus harbour.

4.4.3 Logistics Alternatives

The only option that has been considered is to transport the product from Oman by ship, in ISO tank containers on vessels. The ISO containers does not have a heating source when being on the vessels. It is isolated but it does not not prevent the temperature from falling. It is expected that the temperature of the product will drop 25 degrees. The product can be sold when delivered liquid in an ISO tank to a biogas plant. The ISO tank containers are shippers owned, meaning they need to be delivered empty back to the port of Aarhus in Denmark. As described under *Challenges* above, this solution is considered too expensive and inflexible which makes it less attractive.

As for the Ukraine business case, the company are considering other options to solve it that can make it a profitable and viable business case in the long term. The company is as well considering IBC tanks or flexitanks, both contained in sea containers on board could be an option. A benefit of using the IBC tanks is that the Oman producer can supply them to the company free of charge, as this would also be how the product is stored in the mean time.

4.4.4 Challenges

The challenge and drawback of both IBC and flexitanks is extensive manual handling and it is many single units handling processes. For IBC tanks, as described for the Ukraine case challenges, the heating obstacle as well applies for this case and sauna seems like the most efficient option but still the challenge is the limited centralized offerings of this in Denmark. It is not considered that plants can provide this kind of facilities themselves. The barriers of cleaning the IBC tanks applies to this case as well, and if using flexitanks, the disposal of these applies too. It is not considered that the IBC tanks should be used again in the same transportation as sending them empty back to Oman does not seem like a viable solution. But if they could be cleaned and resold on the 2nd hand market it might be a solution.

As for the flexitanks they need to be heated, possibly with heating pads. This can be done at the plant as is is considered too expensive to keep heating consistent during the entire transportation. The company acknowledge that there might be other heating options even for the flexitanks. There is a high risk that there will be a significant leftover/residue which will be difficult to take out of the flexitank. The loss of product due to difficulties of pumping the product efficiently, once again lead to the issue of low utilization. Safety and risk of spillage which tranporters are considered to want to avoid, is a risk with the flexitank with the slightly fragile and soft material.

The company considers the solution with IBCs to be best and the most logical solution. IBCs in this specific case do not cost anything, the producer stores the material in IBCs anyway and the sea transport should be a bit cheaper than for ISO. Theoretically we can also store IBCs is DK as long as we want before we heat them and sell them.

4.5 Glycerine from Argentina

The product is crude glycerin from a producer situated in Buenos Aires, Argentina. The challenges of logistics for the Argentina business case is similar to the ones for Oman as both have seafreight as a standard transportation option. In Figure 4.8 below the product from Argentina is illustrated.

Figure 4.8: Crude glycerin from Argentina. Source: Combineering.

4.5.1 Product data

Below the findings from the Argentine business case is displayed in Table 4.9.

Crude Glycerin	
Producer location	Buenos Aires, Argentina
Product	Crude Glycerin (Not ADR)
Pumpable temperature	+35-40 degrees celcius
Load temperature	+50 degrees celcius
Loss of temperature during transit	-25-30 degrees celcius
Volumes	1200 t/year

Table 4.9: Product data for the Argentina business case.

The transportation data is illustrated in Table 4.10.

Transportation	
Standard transport	ISO tank container on vessels
Volumes & weight	26 Tons pr tank truck
Transit time	approx. 6 weeks

Table 4.10: Transport data for the Argentina business case.

The cost related data is displayed in Table 4.11[2] [3].

Economy	
Product price DK	510 EUR /t
FOB Buenos Aires price	230 USD 210 EUR/t
Customs procedures	5 EUR/t
Transport in ISO tanks on vessels	6600 USD 5995 EUR/t pr ISO container
Heating w. steam at washing stations in DK	60 EUR/t
Heating time at washing station in DK	18 h

Table 4.11: Economical data for the Argentina business case.

The given tonnage price in Table 4.11 is for when the biomass is delivered in liquid form in ISO tanks at the plant in Denmark. The given price to FOB Buenos Aires involves that the producer deliverers in filled containers onboard of a vessel in the port of Buenos Aires. The given transportation cost includes seafright, handling in the port of Aarhus, delivery to heating facilities in Kolding, and the last mile delivery by truck to the plant[4]. The full list of what the price of transport are including is given below.

- Seafreight
- CAF
- BAF

[2]The given prices are from June 2023
[3]The conversion from USD to EUR prices are from 2nd January 2024
[4]Under the assumption that the plant will be located in mid-Jutland within 1-2h drive from Kolding

- THC Destination
- Wharfage Destination
- Trucking to heating
- Trucking to discharge(incl. Vehicle with compressor)
- 2 hours free for discharge—thereafter DKK - 450   60 EUR/hour
- Cleaning after use (max residue 20 litres)
- Tankhire Origin—10 days free
- Tankhire Destination—10 days free

The fee is *excluding*

- Trucking to load
- ISPS Origin
- Wharfage Origin
- THC Origin
- Customs Documentation/handling
- Storage and related costs
- Product heating(steam)—DKK 345,-/hour (OLD price from 06.2023)
- Product insurance
- Tankhire after free days—USD 50,-/day

4.5.2 Current possible logistics solution

The same standard transport solution is the same for the Argentina case as for the Oman business case. The standard transport option sea for products that are loaded liquid is by ISO tank containers on vessels. The ISO containers does not have a heating source. It is isolated but it does not prevent temperature from dropping. The ISO tanks are shippers owned containers are shippers owned and must be returned empty to the port of Aarhus.

The current standard solution with ISO tanks is too expensive to be economically viable at the moment. It is as well expensive to store ISO tanks, meaning that it is preferable to unload directly at the plant.

4.5.3 Logistic Alternatives

The IBC tanks and flexitanks have as well been considered as alternatives to the standard solution. It is the same considerations that goes for these alternatives as described above. The price for IBC or flexitanks on vessels is not known, but it is considered to be cheaper than ISO tank containers.

It is the same challenges as described for the Oman and Ukraine case that goes for the IBC and flexitanks solution, considering extensive handling, many units, heating, unloading, cleaning and disposal. As well it is not yet explored if i.e. applying the flexitanks would The transportation time is long and very inflexible. As seen in the list presented above, there is quite many expenses that are not covered in the already very expensive solution pr ISO tank.

The case company are facing severe logistics challenges but if solved, it could become a great business opportunity, and contributor to development of the green transition. As they have done very little transport wise testing with the specific type of product, there is only limited experience to develop practical and theoretical solutions. The case data is as well limited which are bringing some limitations to the scenario developing, but opens up for exploratory opportunities to find a economical viable solution that at the same time can be scaled and applied in practical sense. Reducing costs of the logistics is priority.

Chapter 5

Analysis

This entire Chapter 5 is dedicated to answering the overall research problem of this thesis;

How can logistic and cost barriers for circular supply chains be overcome to enable viability and full potential of CEBMs?

In Figure 5.1 below the specific structure of the analysis and structure of this chapter is illustrated.

Section 5.1-5.2 aims to answer Research Question 1 proposed in Chapter 1, regarding mapping of current logistic possibilities for the company, proposed by the company itself. The two sections will cover a logistics scenario and cost analysis, based on the findings in chapter 4. These two sections will first conduct an analysis of the standard solution, then an alternative scenario, and lastly a sensitivity analysis of the alternative scenario. Each analysis will be followed by a discussion and evaluation of the results.

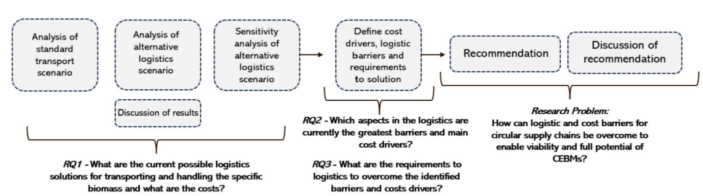

Figure 5.1: Overview of the analysis and the stepwise approach to answer the research questions and overall research problem.

Section 5.3 aims to answer Research Question 2 and Research Question 3, also proposed in Chapter 1. The section will cover an identification of the main logistics barriers and cost drivers. The analysis of the scenarios, interviews, and theory, is the foundation for answering Research Question 2 and Research Question 3.

The analysis as a whole will lead to a recommendation in section 5.4, and based on Research Question 1-Research Question 3 this section will aim to answer the Research Problem stated above. This is followed by a discussion of the recommendations in section 5.5

To enable the analysis, it was required to make some assumptions due to the limited amount of data and to keep the analysis specific. The assumptions are listed in appendix A.15.

5.1 Cost Analysis of Standard Logistics Scenario

This section will cover a cost analysis of the standard logistics scenario. Full data and calculations are shown in appendix A.16. The costs of the standard scenario enables to establish a baseline in economical and functional sense. The standard solution of transportation of the products from the three origins in the business cases are illustrated below in Figure 5.2.

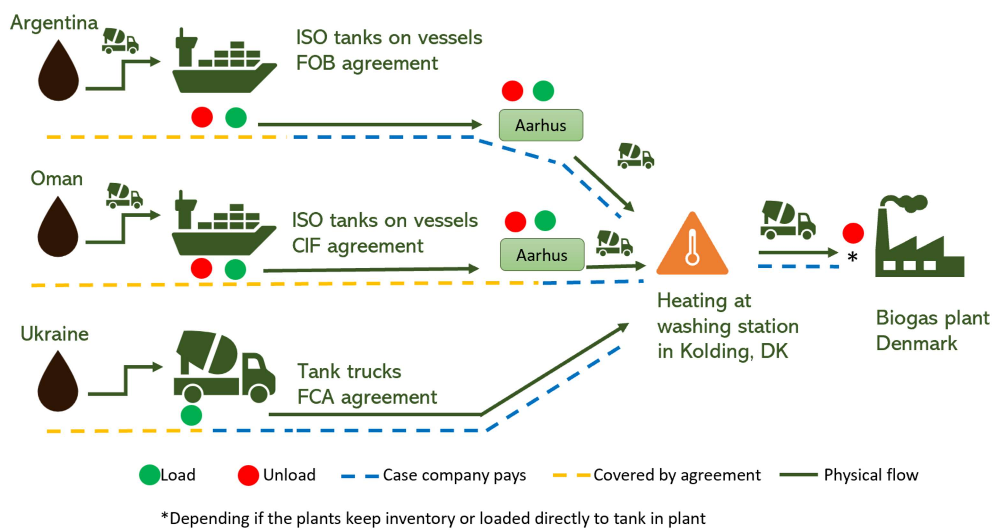

Figure 5.2: Standard transport solution overview.

The standard scenario for transporting the sunflower oil residue from Ukraine is by shipping the product in heated tank trucks with an FCA agreement. The FCA agreement implies that the company pays for the product and for the producers to load the production in Ukraine to the trucks. The trucks' ability to keep the product warm was unsuccessful and moreover heated tank trucks are considered too expensive by the company. If the heated trucks were a part of a reverse logistics design, the price would be reduced and make the solution more attractive, but this has not yet been possible for the company to find a reverse flow of tank trucks that returns empty to Ukraine after delivery in Denmark, as the amount of bulk exported from Denmark to Ukraine is limited and therefore also reverse flows. As heating by the trucks was unsuccessful, it was tested to inject steam to the tank after arrival in Denmark at a truck washing station placed in Kolding at an hourly costs. The ambition of the company is to improve this business case, meaning reducing logistic costs and as well the practical aspect of heating the product. All transportation that are not included in the Incoterms, are handled by agreements with 3PL providers.

The two other potential business cases of importing similar products from Oman and Argentina has not yet been tested and there is no practical experience. The standard transport solution from Argentina to Denmark is by ISO tanks on vessels. ISO tanks are in general an expensive type of container, and is considered being too expensive for the company based on the cost estimation data the company has. In this case the company is given an estimation of an FOB agreement, meaning the product is loaded on trucks from the producer and unloaded at the port in Buenos Aires. For the Oman case, the standard solution is as well in ISO tanks on vessels, but in this case with a CIF agreement. That means that the price also includes transport to Denmark and unloading in the port of Aarhus. In both scenarios there is a consolidation in Kolding where steam is injected to the tanks. The remaining transportation that is not included in the Incoterms are handled by 3PL providers.

What is included in the respective Incoterm agreements is illustrated in Figure 5.3 below, together with the other types of Incoterms to have an overview of the different options there is. The relevant agreements are highlighted in blue; Ukraine (FCA), Argentina (FOB), and Oman (CIF). Note that for the Oman case the company have included unloading of product in Denmark in the price.

INCO TERM	Loading delivery to port & customs	Unloading	Loading at port to export	Transit to destination	Cargo insurance	Unloading at port of import	Loading truck at port of import	Carriage to destination	Import customs clearance	Import Duties
EXW	Buyer	Buyer	Buyer	Buyer	Buyer	Buyer	Buyer	Buyer	Buyer	Buyer
FCA	Seller	Buyer	Buyer	Buyer	Buyer	Buyer	Buyer	Buyer	Buyer	Buyer
FAS	Seller	Seller	Buyer	Buyer	Buyer	Buyer	Buyer	Buyer	Buyer	Buyer
FOB	Seller	Seller	Seller	Buyer	Buyer	Buyer	Buyer	Buyer	Buyer	Buyer
CFR	Seller	Seller	Seller	Seller	Buyer	Buyer	Buyer	Buyer	Buyer	Buyer
CIF	Seller	Seller	Seller	Seller	Seller	Unload incl. (Negotiable)	Buyer	Buyer	Buyer	Buyer
CPT	Seller	Seller	Seller	Seller	Seller	Negotiable	Seller	Buyer	Buyer	Buyer
CIP	Seller	Seller	Seller	Seller	Seller	Negotiable	Negotiable	Seller	Buyer	Buyer
DAT	Seller	Seller	Seller	Seller	Negotiable	Seller	Buyer	Buyer	Buyer	Buyer
DAP	Seller	Seller	Seller	Seller	Negotiable	Seller	Seller	Seller	Buyer	Buyer
DDP	Seller	Seller	Seller	Seller	Negotiable	Seller	Seller	Seller	Seller	Seller

Buyer Seller Negotiable

Figure 5.3: Incoterm agreements. Those marked in blue are the ones that the case company has provided data for in each case. Source: Own figure.

As the case is considered to not involve any inventory costs due to the assumptions described in the methods chapter, the costs are divided into transport costs, handling costs, and cost of the Incoterm agreement. The Incoterm includes the price of the product and the activities illustrated above. In Figure 5.4 the cost distribution for the standard transport solution for the three cases respectively is illustrated. The reason for the Incoterm agreements to be estimated separately is due to the fact that it is considered to be both transport and handling costs covered in the price and as well the product price that can not be isolated.

Figure 5.4: Cost distribution pr. shipment per origin. Own figure.

The shares of the cost contribution are between the Ukraine case and the Argentina case rather similar. The cost distribution for the Oman case differs significantly, due to the high cost share of the Incoterm agreement. In this agreement the product, some transportation, and handling are included which reduces these costs elsewhere. The company operates under the assumption that inventory is kept at the plant. But there is a storage cost for the Argentina case. The FOB agreement covers 10 days offree storage and after this 50 USD is paid per day (€46 per day [1]). Looking at the cost distribution, in general the handling costs takes a rather small share, but again it should be noted that some handling is covered by the respective agreements.

Combining the costs of transport, handling, the price of the Incoterm for each business case, and the selling price, the profit for each standard solution *per shipment* from each origin is calculated and illustrated in the table below.

Cost per shipment			
Origin	Ukraine	Argentina	Oman
Tons per shipment	*22 t*	*26 t*	*24 t*
Revenue per shipment	€7.920	€13.260	€12.000
Cost of agreement	€2.860	€5.460	€8.640
Transport cost	€3.700	€6.030	
Terminal Handling Cost			€268
Last mile Cost			€984
Heating Cost	€960	€1.080	€1.200
Customs	€10	€5	€5
profit	**€390**	**€683**	**€903**

Table 5.1: Costs and profit per shipment per origin.

The company has stated that as long as the business cases is profitable, and at the same time has potential to be optimized, they are interested in exploring the options further and hopefully initiating an import to Denmark. The company considers that there will always be options for negotiating prices and optimizing logistics to increase profits. The first case of Ukraine is calculated to make a profit of just below €400 per shipment. The Argentina case makes better profit, but the business case is very sensitive to the mentioned storage cost at the origin. 10 days is included for free at the origin of the Port of Buenos Aires. If storage days exceed 10 days, a daily fee is paid, and calculations shows that if the total waiting time in the Port of Buenos Aires, meaning 25 days or more in total, the business case is sensitive to the extra cost that the storage of products adds. The loading to the port in Buenos Aires should therefore be timed and planned in order to reduce the amount of storage days before shipments leaves the port.

The assumption is that cost functions for the transport solutions follows a linear function, meaning *no* economics of scale, which is the only assumption that can be made based on the given data provided by the case company. The company considers to import large volumes from each origin, and even in two of the cases they have the opportunity to upscale from other producers. Therefore it makes sense to look at the costs in a yearly aggregation. The company has provided data of approximation for yearly volumes from each producer. As it was assumed above, there is not considered any economics of scale in the provided data. Assuming the company decides to buy all tonnage possible and taking advantage of up-scaling possibilities from nearby producers in Oman and Ukraine to increase the yearly volumes. A calculation of the required number of shipped containers per origin

[1] As converted the 17th of January 2024.

considering the maximum of yearly volume is seen below, and as well the estimated profits is calculated.

Summary yearly for shipping all possible tonnage from each origin			
	Ukraine	**Argentina**	**Oman**
Tons per year	10.000 t	1.200 t	2.000 t
Tons per shipment	22t t	26 t	24 t
Nr. containers	454 truck shipments	46 containers	83 containers
Yearly profit	€179.620	€34.090	€75.741
Nr of shipments	454 trucks	46 containers	83 containers

Table 5.2: Yearly cost, number of containers and number of shipments considering the full up-scaling of producer agreements.

It is a considerable amount of trucks going between Ukraine and Denmark if the potential maximum of 10.000 tons is to be imported. If choosing not to upscale from other producers and only buy the 600 tons, it would instead be 27 trucks. Regarding shipments from Argentina and Oman, an estimation by the company showed 20 units of 20 ft TEU containers per ship, going 1-2 times per month from both Oman and Argentina. A total of 83 containers are required to ship the 2000 tons from Oman, meaning that it will take a maximum of 4 shipments, rounded down, to transport it all. Considering that in Oman they are only able to deliver it in the months from April to October it means that it is possible to ship it all within the time frame of 7 months, as is would be done in either 2 or 4 months depending if there will be 1 or 2 shipments per month. For the Argentina case, the volumes are smaller and the 1200 tons could be distributed on 46 20 ft TEU containers of 26 tons of product each. This would mean that it all could be shipped with a maximum of 3 shipments divided as well across 2-3 months.

After arrival to Denmark the standard scenario in all three cases suggest to transport the product in tank trucks to the heating station in Kolding, about 2 h drive from the port in Aarhus. Here steam would be injected to the tanks and the heating procedure is estimated to take 16 hours for the Ukraine product, 18 hours for the Argentina product and 20 hours approximately for the Oman product to make 1 shipment pumpable. After this the company expects to have the maximum of 1 hour transport to the potential biogas plants and pump the product directly to the tanks while it is still able to be pumped.

5.1.1 Discussion of Standard Logistics Scenario

The standard scenario is not considered to be very attractive for the company, as they are convinced it could be done cheaper. Regarding heating, a first consideration of the process is that it is considered inefficient and inflexible when using the washing stations for heating with steam. The extra consolidation point in Kolding means 16h-20h extra 'process time', before the product can reach the plant. In this aspect it seems more optimal if the plant could control this part of the process themselves in order to have the most flexibility regarding their biogas production. In general the heating procedure is circumstantial. Having an extra consolidation point in Kolding adds time. Investigating another better solution for this part of the supply chain should be priority as it seems to add an unwanted inflexibility and dependency.

The company has not yet been able to find any reverse logistics options via i.e. backhauls for the truck transport between Ukraine and Denmark. An option is to transport it part of the way, i.e. to Germany, and reload to other trucks in a reverse flow and by that lower the transport price. Looking into if the railway connection from Germany to Denmark could also be an attractive option to lower costs. At the same time, this would mean more consolidation and more handling. The fact that the company have agreements with DB in other of their sectors already, could open up for the possibility of exploiting already existing and established transport networks.

Planning and scheduling the shipments from Oman and Argentina is important as the flexibility is low, lead times long, and the requirement of product availability is important for the plants. What can be reduced in costs is simply how the product is contained and as well negotiate better prices and perhaps economics of scale if the company decides to import respective 46 and 83 containers of product. Another parameter is also re-negotiating the Incoterm agreements and make a clear mapping of which parts could perhaps be done cheaper externally or if a higher level of Incoterm agreements should be made and more included to a higher price. In dialogue with the plant it should be discussed how frequent they would need to receive product and as well willingness to store and potentially heat the product.

Despite the assumption based on the given data that the cost function of the scenarios is linear, it is considered that it should be possible to negotiate price to gain benefits of scale in each of the solution. The profit is sensitive to the selling price in Denmark. Considering the predicted increased demand for biomass, the company could operate from a scenario that the prices will be stable high or even increase. But it is important to construct a solution that is robust enough to also tolerate occasional price fluctuations.

If the company wants to make better profits it is important to look into ways of reducing the different cost contributions in the scenarios. Furthermore the heating situation is not considered optimal and the practical matter needs to be solved. For all three cases the company has considered IBC tanks and Flexitanks as cheaper alternatives for product storage during the transportation. Regarding heating, the company have only provided data for the option to heat it at the washing station in Kolding, in mid-southern Denmark relatively close to the German border south. In the following section an analysis of an improved logistics scenario is conducted.

5.2 Cost Analysis of Alternative Logistics Scenario

The company has proposed the idea of changing the equipment the product is stored as a way to reduce costs of in another logistic scenario, to explore if the barriers of too expensive standard solutions and the practical complications with heating the product can be lowered. Full data and calculations are shown in appendix A.16.

For all three cases, the company wants to have analysed the use either IBC tanks or flexitanks for storing the product during transport, instead of respectively ISO tanks and heated tank trucks.

The changed logistics scenario is illustrated below;

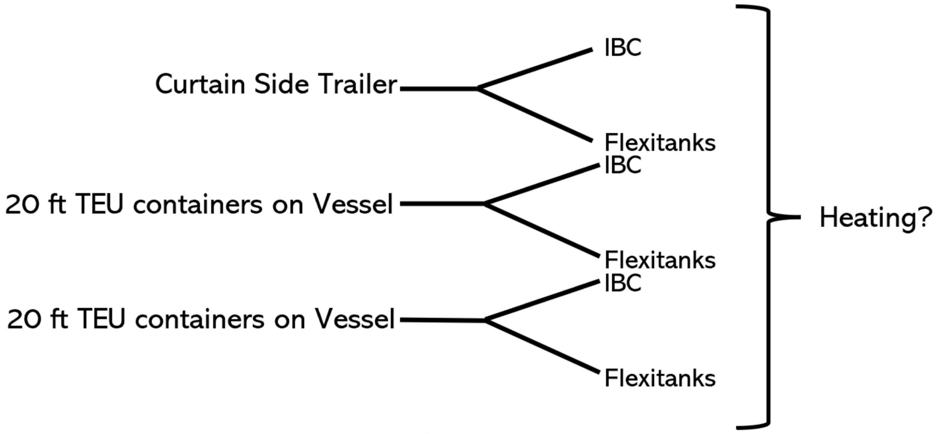

Figure 5.5: Alternative Logistics Scenario proposed by the company. Own figure.

For the Ukraine case, the alternative solutions is the change of road transport mode from tank truck to curtain side truck in combination with the IBC or flexitank. It is an attractive solution especially for the Ukraine case as the company could get the IBC tanks for free from some of the producers. The company can get an unknown amount of IBC tanks from producers in Oman and Ukraine, so the amount they would need to purchase beside these, are unknown and depending on how much they scale import from other producers, and if these producers also would be able to provide a certain amount for free. In the Alternative scenario it is considered that they can get 600 IBC from the original producer in Oman, and 1500 from the producer in Ukraine, equivalent to volumes they purchase from original producers, and they would need to purchase the remaining at a cost of €30 per piece. The cost of cleaning the tanks are added too, as they are considered to be able to be reused 2-4 times. For the flexitank there will also be an additional cost pr. tank for both acquiring and disposal. The IBC tanks does not necessarily need to be returned to sender and used in the same context, as sending them back to the origin implies a cost too. They can be used internally.

The company was not able to provide a price of flexitanks, but industrial research suggests that the price of flexitanks variate between 80 USD to 400 USD depending on size and quality (Insights n.d.), (Flexitanks n.d.). On average an estimation is set to be 250 EUR cost per flexitank in the cost analysis. It is considered to be worth investing in some of durable materials due to leakage risks and equipment damage as described in chapter 4.

Both IBC tanks or flexitanks fits in standard 20 ft TEU, that as well are considered cheaper than ISO tanks. The cost of container hire is estimated to be €2000 per container (Freight n.d.)

Application of the flexitanks can be either single or multiple use, where single use is more common to avoid cross contamination between products. Single use is also considered preferable in this case as shipping the tanks back to the origins seems circumstantial. Furthermore there could be considerable amounts of residue left in the flexitanks that would mean it could only be used in the same context. If using single use flexitanks, a potential cost of disposal must be considered to be placed at the company too. As mentioned in findings, there are some risks of using the flexitank in case of example puncture and leakage from the tanks. There could as well be scenarios where the flexitank is paid for via the Incoterm agreement or 3PL serviced such, as DHL, that promotes the flexitanks as *"An innovative non-hazardous bulk liquid transportation solution"* (DHL n.d.[a]).

For the Oman and Argentina case the mode is vessels, and is the only option of mode from these origins. The units should be loaded to standard containers, being 20 ft. TEU. In one 20ft TEU it fits one flexitank. According to websites a flexitank should fit 16.000-24.000 litres. It is assumed a volume of 20.000 liters on average in the analysis (Group n.d.). Based on the given densities provided by the company, it is assumed that there would fit 20 tons of product in the flexitanks and 1 ton in each IBC tank of the product from Oman and Argentina. The density of the Ukraine product is lower and more IBC tanks are required, as 1 IBC can only contain approximately 920 kg. For the flexitank the assumption is that it as well fits 2000 tons (20.000 liters) of product from Ukraine, as the flexitanks can have between 16.000-24.000 liters. Regarding IBC tanks, the amount that can be fitted into a container depends on the stacking. Industrial research shows that 18-20 as a maximum can be fitted depending on the stacking(Foreverest n.d.). The stacking is illustrated below;

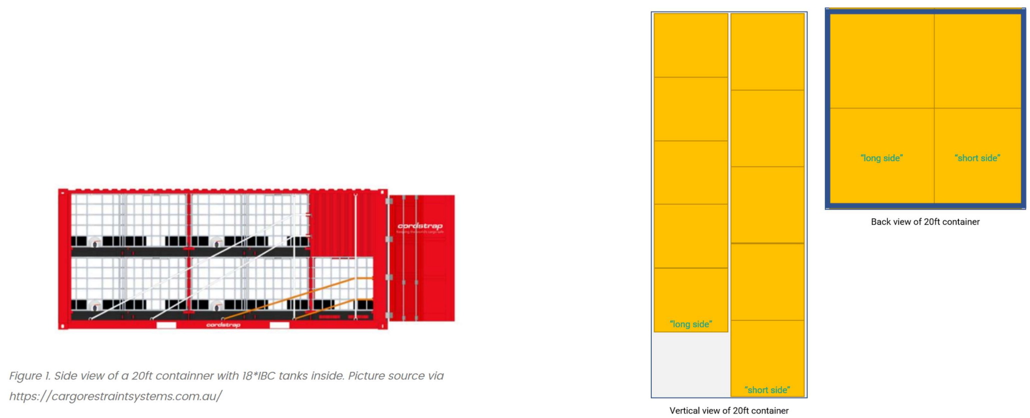

Figure 5.6: IBC tank 18 stack in 20 ft. TEU (L) and IBC tank 20 stack in 20 ft. TEU (R). Source: (Foreverest n.d.).

The THC and the customs handling cost is considered to be the same as in the standard scenarios, even if changes amount of units could impact the price. The alternative scenario does not suggest a specific method for heating but highlights the steaming at the washing station as an option. The change is that now the heating would need to be made unit-wise per IBC tank of flexitank until the product reaches a pumpable temperature. If applying the specified heating equipment as illustrated in chapter 4, either a heating cover or heating pads for respectively the IBC tanks or flexitanks, heating would as well be made unitwise. If applying the specialized heating equipment for IBC or Flexitanks it is considered an upfront and one time investment. The uncertainty is then how many heating pads or heating covers should be invested in. The challenge with this rather circumstancial solution is that it is unit-wise heating, and depending on the size of the plant and production volumes unit wise and hour long heating might not be an attractive solution either. Large scale heating seems more optimal. Where the heating should be placed and when in the supply chain is also a critical aspect. Optimally the heating should happen as close to the plant as possible and preferably at the plant as this would provide the most flexibility for production. The company does not have a centralised storing facility meaning that the product also should be stored at the plants. This makes heating at the plants even more attractive and optimal.

This is why in the the analysis of the alternative logistics scenarios, it is considered that heating is placed at the plants and as well the related investment costs of equipment. It is not known how long time the heating will take when the units are smaller and how many man-hours spend on facilitating it. In general individual heating of IBC tanks with steam at the stations is simply considered too inefficient and circumstantial. Other options should be discovered to overcome the barrier that the heating so far is. Other equipment needed for loading the product at the plant is also considered to be at the plants.

Regarding the agreements of either IBC, FOB, or FCA, it is assumed to be the same type of agreement for each case as in the standard solution.

Below the alternative logistics scenarios are calculated applying either only IBC tanks or only flexitanks.

Cost scenario of alternative logistics scenario (EUR)			
	Ukraine	**Argentina**	**Oman**
Total tons	10.000	1200	2000
Required IBC / Flexitanks	10.000 / 500	1200 / 60	2000 / 100
Nr. of shipments for IBC /Flexitanks	540 trucks per year	20 containers 3 times per year	20 containers 5 times per year
Tons. per shipments for IBC /Flexitanks	18,4 tons 20 tons	20 tons 20 tons	20 tons 20 tons
Total revenue Denmark	3.600.000	612.000	1.000.000
FCA / FOB / CIF	1.300.000	252.000	720.000
IBC	255.000 (1500 for free)	36.000	42.000 (600 for free)
Flexitank	100.000	12.000	20.000
Curtain Side truck	1.300.000		
Container rent		120.000	
Terminal Handling Costs			26.800
Last mile			82.000
Customs	5000	300	500
Cleaning IBC	54.000	6.000	10.000
Flexitank disposal	2.500	300	500
profit IBC scenario	**453.600**	**197.700**	**118.700**
profit Flexitank scenario	**649.100**	**227.400**	**150.200**

Table 5.3: Analysis of costs per year per origin for the alternative solution.

5.2.1 Discussion of Alternative Logistics Scenario

The cost calculations is based on the assumptions that the heating is considered to be done at the plants including the equipment it requires. Hence, the costs of this is not considered in the alternative scenario, and the issues related will be analysed in the sensitivity analysis later.

In Figure 5.7 the yearly costs of the business case in Ukraine for each of the standard solution and the alternative scenario is illustrated. The switch in mode accounts for nearly €280.000, where the saving of this is seen to be cancelled out if purchasing the remaining estimated 9300 IBC tanks, if 1500 is given for free. Use of the flexitanks suggests a €144.000 less of an expense than IBC tanks. The added costs of cleaning or disposal accounts for much less, than the removed yearly expense of approx. €435.000 for heating at the washing station. This can be misleading in the interpretation and will be taken into account in the sensitivity analysis of the scenarios later. In case heating was added to the alternative solution, the case would make a profit of just €18.000. The alternative logistic scenario, would require more shipments due to smaller unit loads than the standard as seen in table 5.2 and 5.3.

	Standard	*Alternative*
Tons	10.000	10.000
Sales price DK	€ 3.600.000,00	€ 3.600.000,00
Tank truck	-€ 1.680.000,00	
Curtain Side Truck		-€ 1.404.000,00
IBC		-€ 279.000,00
Flexi		-€ 135.000,00
FCA	-€ 1.300.000,00	-€ 1.404.000,00
Heating	-€ 435.840,00	
Customs	-€ 4.540,00	-€ 5.400,00
Cleaning		-€ 54.000,00
Flexitank disposal		-€ 2.500,00
Profit Standard	€ 179.620,00	
Profit IBC		**€ 453.600,00**
Profit Flexitank		**€ 649.100,00**

Figure 5.7: Yearly costs for the Ukraine business case of respectively the standard and alternative solution

The Argentina case on a yearly basis for the standard and alternative scenario is illustrated in Figure 5.8

	Standard		Alternative	
Tons		1200		1200
Sales price DK	€	612.000,00	€	612.000,00
IBC			-€	36.000,00
Flexitank			-€	12.000,00
FOB	-€	252.000,00	-€	252.000,00
Container Transport			-€	120.000,00
ISO tank transport	-€	276.000,00		
Heating	-€	49.680,00		
Customs	-€	230,00	-€	300,00
Cleaning IBC			-€	6.000,00
Flexitank disposal			-€	300,00
Tankhire after 10 days				
Profit Standard	€	**34.090,00**		
Profit IBC			€	**197.700,00**
Profit Flexitank			€	**227.400,00**

Figure 5.8: Yearly costs for the Argentina business case of respectively the standard and alternative solution

For the Argentina case, the cost differences is again very large. Once again it should be stressed that about €50.000 for heating in the standard solution is not accounted in the alternative scenario. Despite purchase of equipment, the solution of charging standard 20 ft TEU containers instead of ISO tank containers, is about €150.000 cheaper according to the average cost in 2023 (Freight n.d.), even with 14 shipments more. The difference on the bottomline is primarily due to the use of standard containers instead of ISO tanks.

The case of Oman and the yearly profits for the standard and alternative scenario is illustrated below,

	Standard		Alternative	
Tons		2000		2000
Sales price DK	€	1.000.000,00	€	1.000.000,00
IBC pr piece			-€	42.000,00
Flexi			-€	20.000,00
CIF	-€	720.000,00	-€	720.000,00
Heating	-€	99.600,00		
THC pr shipment	-€	22.244,00	-€	26.800,00
Cleaning IBC			-€	10.000,00
Flexitank disposal			-€	500,00
Last mile	-€	82.000,00	-€	82.000,00
customs pr shipment	-€	415,00	-€	500,00
Profit Standard	€	**75.741,00**		
Profit IBC			€	**118.700,00**
Profit Flexitank			€	**150.200,00**

Figure 5.9: Yearly costs for the Oman business case of respectively the standard and alternative solution

For the Oman case, once more there is a large difference. But the heating costs accounts for almost €100.000 in the standard solution, which in case it was added to this scenario would cancel out benefits and actually make it less beneficial. The THC increases a bit higher in the alternative solution due to the difference of 17 more containers to be handled. The CIF cost are the same in both solutions which might be misleading, as the discounting of switching to standard containers instead of ISO tanks is not considered.

For all three cases, an uncertainty and source of error, could be the price of the Incoterm for the alternative logistics scenario. First of all it could be considered that flexitanks and IBC tanks could be covered in the agreements too. For especially the Oman and Argentina case that the price would be cheaper due to not using ISO tanks anymore. For Ukraine, the services are already at a minimum and change of equipment is not considered to impact the FCA price a lot, but only slightly due to increased units handling if IBC is applied. Another uncertainty that would instantly mean the tipping point for the calculations is the elimination of heating costs in the alternative scenarios. This expense is large. Without having data to support it, the benefit of using the washing stations for heating with steam is not clear, and is not considered to be an optimal solution. At the same time, cutting the cost of heating completely in the scenarios is not realistic either. There are many benefits for both the company and plants to place the heating at the plants. Even if it would require some investment costs at the plant and extra hours, it would give the more flexibility and less dependency, but it makes sense to compensate for this in the price paid for the product by the plants. Another argument to discard the steaming at the washing stations is the fact that the units should not be loaded to maximum, but leave some room for steam injection. Another uncertainty is as well how the product behaves and potentially expands during heating, this is not taken into considerations in the filling rates of the units.

The increased number of units and changes equipment to contain the product would most likely have an impact on the handling costs and affect either THC or the Incoterms. For the FCA it does not seem like a big change in the service as with the FCA they just provide the product and loading it to trucks. Anyhow, it should be considered, that loading it to IBC or flexitank, and then to a truck, might cause slightly more handling time than pumping it directly to a tank truck as in the standard solution, and perhaps cause a smaller increase in the Incoterm cost. Regarding the FOB and CIF agreements for Argentina and Oman respectively, it is the same considerations that should be made. What impact does change in equipment have in price, and does the induced changes in handling activities and time, impact costs? For these cases, it could mean a reduced cost of the agreement, as the ISO tanks according to the company are an expensive container to use. Regarding the agreement type itself, it should be investigated if the agreement types could be negotiated to include more services. This would also depend on the rest of solution the company decides on, regarding heating, potential storage, delivery to plants etc., and how much flexibility they would want.

The analysis so far leaves uncertainties and many questions. The following section will try to explore sensitivity impacts of different cost aspects. Based on the uncertainties and variables discussed, a sensitivity analysis will be conducted in the next section. The purpose of this analysis is not to give an accurate price to each scenario, but to provide understanding how the costs are sensitive to the decision and perhaps to which degree.

5.2.2 Sensitivity Analysis of Alternative Logistics Scenario

To enable better decision making in a business case with many variables, uncertainties, and unknowns, this part of the scenario analysis will conduct a sensitivity analysis to try to understand how different variables impacts the scenarios. Calculations are shown in appendix A.16.

The changed variables will first be presented and discussed. To develop further on the alternative scenario, different parameters of the costs are tested in a sensitivity analysis. The sensitivity analysis in general takes a rather pessimistic approach. The choices of parameter changes are motivated below. It should be noted, that the sensitivity analysis is based on many assumptions and estimations. If prices are displayed that was not provided by the company, it is based on industrial analysis and data from external sites and not given by the case company as it was very limited the data they could provide due to the very unexplored nature of these potential business cases. The point of the analysis is to create an overview of how different choices and their costs implications will impact the revenue and overall solution, to support decision making. If more data is gained, the company will be able to make a more accurate analysis.

For the Ukraine case, the cost of the Incoterm could remain the same, and it is considered preferable to keep the agreement on the same level, as it is considered that the company can find 3PL solutions to get the biomass transported to Denmark at a competitive price. In the sensitivity analysis, the price of the FCA is estimated to increase by 5% due to the increased number of units in the loading that the producers are offering, whereas in the standard solution it was pumped directly to a tank. This increase is considered for both using IBC and flexitank.

It is assumed that the company will keep the IBC tanks for internal use and not sell them. This means, that in the analysis the company pays for cleaning them but keep them internally and hence, has no profit of selling.

Heating activity and costs are covered completely by the plants, so the sensitivity analysis assumes that there is a decrease of 15 % in the selling price to compensate of the extra handling costs and investment costs located at the plants.

For the Ukraine case there is a need for 10.000 IBC tanks which is a lot. Some producers are willing to give it for free, but in a longer perspective this is considered to be an extensive give-away. In the sensitivity analysis it is calculated that the company will pay for all 10.000 units to the price of €30. As the cost of flexitanks can variate greatly according to an industrial scan online, it is considered that the flexitanks needs to be of premium quality to reduce leakage risks of applying the large soft tanks. The more expensive ones on the market are about €400-450. In the standard solution the price of them were set to €250. In the sensitivity analysis they are set to €300. According to DHL (DHL n.d.[b]), the flexitanks can be disposed and the materials recycled. Due to both the product residue inside them and the cost or i.e. getting them picked up and recycled, a cost of €5 is added for each flexitanks that needs to be disposed.

To sum up, the sensitivity analysis calculates a new revenue under the assumptions;

- 15% cost reduction of product in DK as the plants are responsible for heating
- A cost of €5 per IBC tank for cleaning
- no IBC tanks are given for free and all IBC has to be bought (10.800).

- 5% increased FCA price due to more handling
- Flexitanks costs €300
- Disposal of flexitanks costs €5 per flexitank disposed

For the Argentina case, the assumption is as well a reduction of 15% in selling price in Denmark due to placement of heating at the plants. The same assumptions are made for cleaning of the IBC tanks and keeping them internally, and the disposal cost of flexitanks. As well the calculations considered that all IBC tanks are bought, as was the case in the standard solution for the Argentina case. The price of flexitanks are as well increased to €300 to ensure premium quality. The FOB goes up 5% due to more units handling. The rather expensive ISO tank transport is reduced rather much by instead using rented containers to the price of €2000 per piece as described earlier. To summarize, the sensitivity analysis estimates the following factors;

- 15% cost reduction of product in DK as the plants are responsible for the heating
- A cost of €5 per IBC tank for cleaning
- No IBC tanks are given for free and all IBC has to be bought (1200).
- 5% increased FOB price due to more handling
- Flexitanks costs €300
- Disposal of flexitanks costs €5 per flexitank disposed
- Transport costs for ISO tanks are replaced with a cheaper 20 ft TEU container charged from Argentina to Denmark.

For the Oman case, the product price is once more estimated to decrease by 15% due to placing heating at the plants. As for the two other scenarios, cleaning costs €5 per IBC tank and as well €5 for disposal of flexitanks. All IBC has to be bought, whereas in the standard solution, 600 was estimated to be received for free out of the 2000 if upscaling from other producers. Flexitanks are now set to cost €300 per piece.

The Oman case is the one with the most expensive Incoterm agreement but also more services are covered. It is difficult to estimate what using ISO tanks does to the price of the Incoterm agreement as it is not possible to isolate each cost of activities and services covered under the agreement. But since the cost of a charged 20 ft TEU container is much cheaper, the decrease is estimated to be 20%. Instead the THC goes up with 10% with more units handling in loading and unloading at the port. The last mile is considered to be the same.

- 15% cost reduction of product in DK as the plants are responsible for the heating
- A cost of €5 per IBC tank for cleaning
- No IBC tanks are given for free and all IBC has to be bought (2000).
- Flexitanks costs €300
- Disposal of flexitanks costs €5 per flexitank disposed
- CIF goes down 20% due to no use of ISO
- THC goes op 10% due to more handling and smaller units

The table below shows the estimations of impact of the sensitivity analysis is calculated. The table below shows the profit of respectively the standard scenario, the alternatives scenario and the sensitivity analysis.

	Standard	Alternative	Sensitivity
Tons	10.000	10.000	10.000
Sales price DK	€ 3.600.000,00	€ 3.600.000,00	€ 3.060.000,00
Tank truck	-€ 1.680.000,00		
Curtain Side Truck		-€ 1.404.000,00	-€ 1.404.000,00
IBC		-€ 279.000,00	-€ 324.000,00
Flexi		-€ 135.000,00	-€ 162.000,00
FCA	-€ 1.300.000,00	-€ 1.404.000,00	-€ 1.474.200,00
Heating	-€ 435.840,00		
Customs	-€ 4.540,00	-€ 5.400,00	-€ 5.400,00
Cleaning		-€ 54.000,00	-€ 54.000,00
Flexitank disposal		-€ 2.500,00	-€ 2.500,00
Profit Standard	**€ 179.620,00**		
Profit IBC		**€ 453.600,00**	**-€ 201.600,00**
Profit Flexitank		**€ 649.100,00**	**€ 11.900,00**

Figure 5.10: Yearly estimated profits of the Ukraine case of respectively the standard solution, the alternative scenario, and the sensitivity analysis applied on the alternative scenario.

The Ukraine case is as very sensitive to the reduction in price, to compensate for heating, and the other considerably large added costs. The price reduction of 15% accounts for a €600.000 where the heating in the standard solution was estimated to cost €435.000 . The purchase of heating equipment is not calculated, but is as stated a one time investment. So for the next years the selling price could probably be reduced less than this suggests. The FCA agreement is more expensive, which might not present. The reasoning behind the increase was here due to potentially more units handling, or to compensate for not using standardized equipment. But if i.e. flexitanks are used, which will be the same units as for the standard solution, and the operators have experience with the equipment, this increase might not be present.

The analysis suggests that the business case under the listed assumptions above wont be profitable if applying IBC tanks. Besides purchasing 10800 IBC tanks, the added costs associated to the IBC solutions as well contribute negatively. The negative approach taken in the sensitivity suggests the flexitank solution only to make a small profit, and much less profitable than the standard solution. Here it should be stressed, that between these two scenarios there is a 144.000 difference in the FCA price which as discussed above might not be present if using flexitanks due to the same number of units. This would make the profits of the standard solution and the flexitank solution in under uncertainty equal in profits.

For the Argentina case, both the IBC and the flexitank alternative scenario under uncertainty are performing better economically than the standard solution, and again the most profitable one between the alternatives is the flexitank, which is about €24.000 less than the IBC scenario. The reason for the standard solution to make approx. €60.000 and €83.000 less in profits, than the sensitivity analysis scenario, is as for the alternative scenario due to the fact of an estimated €154.000 for not using ISO tanks to contain the product. Standard 20 ft. TEU prices are much cheaper. Even with the added cost of new equipment this solution is still more profitable. A slight increase in the FOB agreements is estimated to compensate for using another type of equipment. There could also be a reduction, but it is not possible to suggests which way the price would go or if there would be a difference. The three case scenarios for the Argentina case is illustrated below.

	Standard		Alternative		Sensitivity	
Tons		1200		1200		1200
Sales price DK	€	612.000,00	€	612.000,00	€	520.200,00
IBC			-€	36.000,00	-€	36.000,00
Flexitank			-€	12.000,00	-€	18.000,00
FOB	-€	252.000,00	-€	252.000,00	-€	264.600,00
Container Transport			-€	120.000,00	-€	120.000,00
ISO tank transport	-€	276.000,00				
Heating	-€	49.680,00				
Customs	-€	230,00	-€	300,00	-€	300,00
Cleaning IBC			-€	6.000,00	-€	6.000,00
Flexitank disposal			-€	300,00	-€	300,00
Tankhire after 10 days						
Profit Standard	€	**34.090,00**				
Profit IBC			€	**197.700,00**	€	**93.300,00**
Profit Flexitank			€	**227.400,00**	€	**117.000,00**

Figure 5.11: Yearly estimated profits of the Argentina case of respectively the standard solution, the alternative scenario, and the sensitivity analysis applied on the alternative scenario.

The costs of the three scenarios for the Oman case is illustrated below.

	Standard		Alternative		Sensitivity	
Tons		2000		2000		2000
Sales price DK	€	1.000.000,00	€	1.000.000,00	€	850.000,00
IBC			-€	42.000,00	-€	60.000,00
Flexi			-€	20.000,00	-€	30.000,00
CIF	-€	720.000,00	-€	720.000,00	-€	576.000,00
Heating	-€	99.600,00				
THC	-€	22.244,00	-€	26.800,00	-€	29.480,00
Cleaning IBC			-€	10.000,00	-€	10.000,00
Flexitank disposal			-€	500,00	-€	500,00
Last mile	-€	82.000,00	-€	82.000,00	-€	82.000,00
Customs	-€	415,00	-€	500,00	-€	500,00
Profit Standard	€	**75.741,00**				
Profit IBC			€	**118.700,00**	€	**92.020,00**
Profit Flexitank			€	**150.200,00**	€	**131.520,00**

Figure 5.12: Yearly estimated profits of the Oman case of respectively the standard solution, the alternative scenario, and the sensitivity analysis applied on the alternative scenario.

Compared to the standard solution the gain on profit seems to be explained by the assumed reduction in CIF price when not using the expensive ISO tanks of about €145.000. The THC was assumed to grow in the sensitivity analysis based on the fact that it was either new methods or more units handling. If applying the flexitanks it means the same amount of units handling as the standard solutions number of ISO tank containers. Then the THC increase should merely be due to the fact that it is new kinds of equipment, which might not cause an increase after all. If partnering up with 3PL operators that have experience with these, such as DHL, the increase in THC cost might not be present at all. For the Oman case the pattern is the same, that the flexitank solution is less of an investment than the many IBC tanks, which makes a larger profit gap between the two sensitivity scenarios of respectively IBC and flexitanks.

5.2.3 Discussion of Sensitivity Analysis

In all three cases, the profitability of the cases are very sensitive to the heating, and the potential reduction in selling price to compensate for placing the heating and purchase of heating equipment at the plants. An attractive solution in the long run for the company is to develop a centralized heating facility, that more efficiently and synchronized can heat the biomass. If the company i.e. invest in their own centralised heating facility, the price could be negotiated the other way.

In chapter 4 it was stated that some producers were able to give the IBC for free. The cases are as well sensitive to the extensiveness of this agreement. Especially the Ukraine case where a yearly total of 10.800 IBC tanks is required. It is not considered realistic that the company would get that amount for free, and a considerable cost is added to the company for this purchase.

The cases are as well sensitive to the unclear price of Flexitanks. Both the quality and potential added costs can cause uncertainty to the price of the flexitanks. Paying a higher price to limit risks of leakage, product loss that also could add costs, is realistic. According to DHL flexitanks can be recycled (DHL n.d.[b]).

For all three cases the Incoterms as well constitutes uncertainty and potential of increased costs. It is not possible to state the exact change in the cost of the agreement, but it seems fair to assume it will be reduced if applying new equipment. The cases could as well be sensitive to conducting transportation that is not within the standard solution, and impact i.e. THC. Whether the level of Incoterm agreement is optimal is difficult to decide based solely on the cost analysis. The matter completely depends on the operators of the transportation and how experienced the handlers are with the new equipment. Finding a suitable Incoterm on each route require extensive mapping and contact with 3PL providers and their experience with the equipment, to negotiate a better price.

The analysis above and answering of Research Question 1, shows that there are several current solutions to transport the biomass, but with different logistical barriers and cost implications of each scenario, that should be weighted against each other. The discussion illustrates the many variables and uncertainties that can impact costs. The sensitivity analysis took a negative approach to the analysis to gain understanding to cost drivers and other aspects that can enable more informed decision making when it is still decision making under uncertainty. The results of the analysis and scenario mapping indicates that the scenarios are feasible but maybe not optimal.

5.3 Identification of logistics barriers and cost drivers

This section aims to answer Research Question 2 and Research Question 3. Based on chapter 2, 4, and the analysis above, it is the objective to identify the main barriers for both improving and developing the solutions further, and the main cost drivers. With an outset in that, some general requirements to a potential solution is clarified.

In the interest of the company it is important to find a solution that meets the requirements and that are designed to reduce costs and overcome logistics barriers. The analysis suggests that that the main logistic barriers are also cost drivers, and both are related to technical and practical barriers as well as they are interrelated. Figure 5.13 below illustrates barriers, cost drivers, and potential enablers for reducing these.

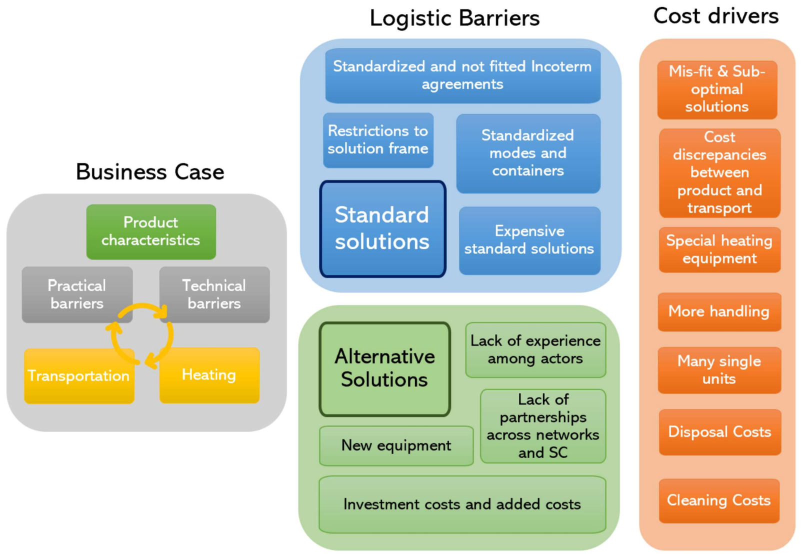

Figure 5.13: Logistics barriers, cost drivers, and potential enablers for reducing these.

The case specific cost drivers and barriers have been discussed extensively above, through the 3 steps of analysis. Here they will briefly be summarized. The main barriers are related to the biomass and the fact that its characteristics sets new and different requirements to the transport solutions. The standard solution is not fitted to handle this, which makes it sub-optimal and drives cost further due to sub-optimal attempts to solve the product specific challenges. The solution is expensive and it does not solve the problems, which is a barrier in itself as cost efficiency is important.

The two step analysis of the Alternative scenario considered by the company in some cases was more profitable, as incremental cost reductions were made. At the same time, the Alternative scenario was very sensitive to some decision parameters. There are potentially many added costs, hidden costs, and great uncertainties. Most importantly, the alternative scenario *dos not* solve the practical and technical problems. It is basically the same problems in a cheaper package.

The theory presented by Urbinati, Franzò, and Chiaroni 2021 discussed in chapter 2, can be relevant to consider in this context, to understand on which levels of the company's environment the company should look for solutions, as well as where the root cause problems are located in a CSC perspective. The company's current barriers and enablers are put in the context of the three different levels illustrating where solutions should be found and where barriers are rooted. This is illustrated in Figure 5.14.

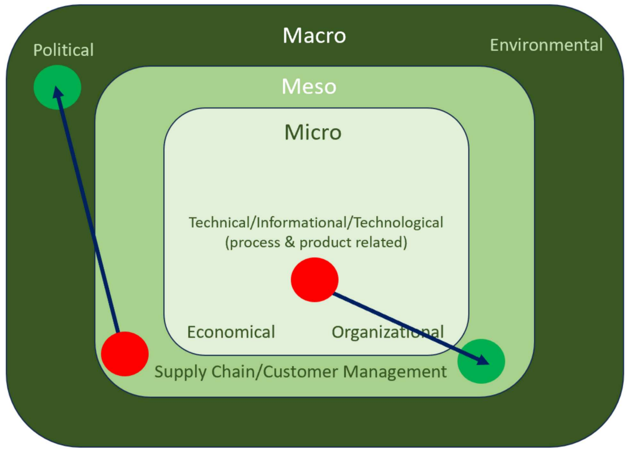

Figure 5.14: Enablers and barriers of CSC in the framework of CEBM presented by (Urbinati, Franzò, and Chiaroni 2021).

It is considered that policy on macro-level could improve the situation by putting requirements to organization of logistics. If it is a political decision, hopefully there will be allocated resources to enable it too. The technical and practical barriers regarding both the product and heating of the product is placed at micro-level and is considered both economical and organizational inhibited. The solutions is to be found at the meso-level through strategic partnerships. Many of the barriers are also placed at meso-level within the industry or supply chain. These are the mentioned barriers such as lack of experience among operators, lack of solutions that lies outside the standardization, and the general lack of innovation. These are considered to be placed at meso-level. The barrier of expensive standard solutions is not plotted in the figure but is considered to be a mix of macro- and meso-level induced barriers.

In the remaining of this section the focus will be on general barriers and cost drivers for the logistic sector as a whole, reflected by the findings in the case analysis. The analysis showed that it is possible to establish a solution now, but perhaps not an optimal solution neither in a practical nor economical sense, due to the limitations of the current logistics possibilities. Cost efficiency is in general challenged by new requirements from the circular offerings. Fitting the products into standardized settings are both costly and sub-optimal. The standardization that in general can characterize the logistics sector creates rigidity and limitations to innovation. Only incremental innovation is possible, as long as it fits in the standardized options. As a sole actor it is almost impossible to challenge this rigidity. Lower volumes and acting alone means both relatively more expensive solutions, as well as even less room for being innovative and find product fitted solutions. The case highlights that innovation is inhibited by lack of knowledge and experience, that can drive costs. This means that solutions are searched for within the actors own domain, and innovation or simply already existing solutions outside their respective domain is never realized. An observation for this case, that might be present in the sector in general, is the fact that actors search for the cheapest option, and not the best option. The possibilities to find the best option is limited by the factors mentioned above.

To facilitate a robust solution that fits the purpose, it is important to define a clear scope and framing requirements to the solutions clearly, and remove the focus slightly from merely cost reductions. Cost reductions most likely will be a positive consequence of better fit is solutions, when focusing on the actual requirements to the solution in a practical sense. The solution should solve the root cause of practical and technical problems, and not just find a cheaper version of the same problem. It is of course extremely challenging to re-invent fundamental structures of logistics and create something new. A requirement to the solution, is to be more driven towards root cause problem-solving than towards solutions that creates incremental cost reductions.

This section answered Research Question Q2 and Research Question 3. The cost drivers and barriers were mapped to enable recommendations. How to understand requirements to the overall solution was proposed.

5.4 Recommendations

This section proposes a recommendation, first through a general recommendation for the company regarding their cases in general matters and in the aspect of how to go from here. Second, more general recommendation for future focus within the sector and research. The specific case considerations is provided in the discussion of the recommendations later in this chapter. The section aims to collect the findings in Research Question 1-Research Question 3, to answer the overall research problem;

How can logistic and cost barriers for circular supply chains be overcome to enable viability and full potential of CEBMs?

The recommendation will be a general supply chain strategic framework as presented in theory, while also providing general recommendations in both an organizational and logistic sector perspective. The recommendation will be further discussed in section 5.5.

5.4.1 Organizational Supply Chain Strategy Recommendations

Based on the Supply Chain Strategy framework presented in chapter 2, (Chan et al. 2016) the following recommendations considering supply chain strategy are made. It is recommended that the company strives to have a priority of cost efficiency in the design of their overall supply chain strategy for the physical distribution of the biomasses from the three origins. As theory suggests, circular supply chain struggle to be viable due to high costs of standard transportation and furthermore challenges to adapt the standard solution into more innovative solutions. At the same time having more attention to problem-solving of the actual root cause problems inflicted by the 'new' product characteristics is highly recommended, to find not just a feasible solution but an optimal solution. Regarding the three logistics drivers in the supply chain strategic fit; transport, inventory, and facilities, it is recommended that decision making within these three drivers could enable a better fit both in strategic sense but also for the specific case matters. The following is recommended within each logistic driver.

Transport

For long distance across seas there is only one option, which is ship transportation. For land-transportation there are several options, where theory suggests that rail is the most efficient and cheapest for bulk biomass. This risk of rail is reduced flexibility, more consolidation, and perhaps more last mile transportation. Regarding transport, it is recommended that the company understands the product requirements and is mapping the possible networks extensively to make the optimal decision regarding transport. Regarding equipment it is as well recommended to search for a fit between requirements of the product and for transportation. Enabling larger volumes might open to new options for transportation.

Facilities

Facilities is in the specific case of the company a great barrier, as many of the practical problems could be solved with the right access to facilities. Looking outside their own domain of solutions and towards other actors either in the sector or other industries might clarify potential facilities that could solve problems. Larger volumes could also create a larger solution space.

Inventory

Inventory in general can create more flexibility in flows and also enable the production plants with a continuous flow. Volumes in general could open up options for alternative inventory keeping. Communication with plants is recommended to establish the solutions that matches their needs optimally.

5.4.2 Sectorial Recommendations

Cost reductions has a large focus as cost efficiency is necessary to enable CSCs. Cost efficiency is perhaps the most tangible, but perhaps not the most optimal way to start approaching the problem. Thinking outside the box in literal terms is challenging in a sector where everything is standardized and generalized. This challenges innovation and creates barriers in many logistics aspects, as innovation still needs to happen inside the pre-defined frame. The costs currently required to move outside this frame is becoming a barrier, and innovation is a cost driver, especially as a sole actor with less volume. Three general recommendation are proposed below.

Bundling

Bundling across actors to enable larger volumes will open up for alternative and more suitable options. The volumes can enable better economy and enable tailor-made solutions and challenge the rigidity in the sector. Volume enables better economy that can drive improvement in the solution space.

Innovation

Innovation is necessary to challenge and overcome the rigidity and conventionality of the sector, to in turn enable CLSCs. But changing fundamentals and deeply rooted structures of logistics is extremely challenging and can not be made by a sole actor. This aspect is strengthened by improved bundling between actors, and as well changed legislation in the logistics sector, that could force establishing radically different offerings. Fundamental change could enable not just a feasible, but optimal CSC solution for i.e. biomass transportation and handling. Letting the changed requirements of the circular offerings drive innovation and solutions, can create better fitted solutions. Sharing know-how across actors and industries can contribute to incrementally driving global change in the logistics sector towards changing radically.

Strategic Partnerships

To enable both volume and innovation, strategic partnerships are a great enabler. Strategic partnerships not just within one supply chain or a supply chain network, but across industries and actors could open doors to facilities that are potentially already existing, or create opportunities for creating some new. Industrial symbiosis is in theory as well suggested to drive radical innovation, when different actors establishes interdependence and are exploiting each others facilities. It is considered that cross network cooperation could reduce the logistic barriers and implications of costs. A specific example of this is suggested in the discussion of recommendations later in this chapter.

The figure below illustrates the dynamics that are enabled through partnerships and bundling to drive innovation.

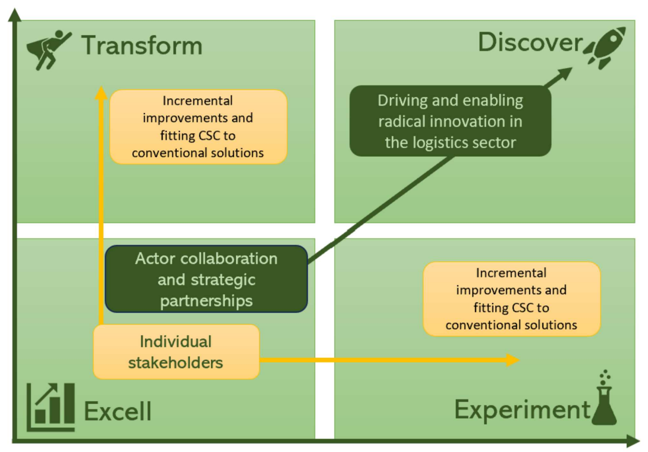

Figure 5.15: Possibilities for change for respectively an individual actor vs. cross network actor cooperation. Own figure.

Radical change is difficult as a sole actor, if the environment you operate in is not ready to offer radical and innovative solutions for product specific requirements. It is therefore recommended for the company to invest in strategic partnerships, that are might not within the field of the company, as new and radical opportunities could emerge.

It is recommended that a strategic focus on the aspects of creating fit in the product requirements and the supply chain would enable more cost efficient solutions, through a general focus on *better* solutions instead of merely *cheaper* solutions. A focus both on organizational level as well as sectorial level of *Bundling, Partnerships and Innovation*, are considered to reduce costs, enable better solutions for the specific cases, and as well enable more innovation for the sector in general. In turn this could enabling circular logistic solutions for circular offerings. The following section will dive a bit more into the specifics of recommendations for the case company.

5.5 Discussion of Recommendations

The discussion will be both towards the specific case of the company and in more general matters.

5.5.1 Discussion of recommended Supply Chain Strategy of the case company

It was recommended that the company designs a logistics solution in line with a cost efficient supply chain strategy, via well fitted choices regarding transportation, facilities, and inventory, where different attributes to the specific drivers enables to create the desired strategic fit to the supply chain.

As suggested in several sources in *Theory*, logistic costs of CEBM should be minimized in order for the CEBM to be fully functional and viable to enable the full potential of the business model. Based on the analysis it is clear that prioritizing cost efficiency in logistics is key to ensure viability. Cost efficiency is achieved through creating strategic fit of the core decision areas of the logistic aspects in the SC strategy regarding; transportation, inventory and facilities to enable supply chain cost efficiency. In the recommendations it was proposed that there is an overly focus on cost efficiency instead of more focus on suitability of solutions. Below the decision attributes of each logistic aspect in the supply chain framework; facilities, transport and inventory are discussed.

Facilities

Facilities are in the context understood as the physical possible enablers in aspects of equipment and storage facilities etc., that can contribute to a cost efficient supply chain strategy.

Means

Based on the analysis, applying flexitanks to transport the product is the most cost efficient solution, as it in all three cases contributed to a larger profit than using the IBC tanks. Environmental priorities also suggests that flexitanks is a better solution. The amount of material is less compared to IBC tanks. The cleaning of IBC tanks suggest large resource usage of water, money, and time. Recycling of the flexitanks seems in comparison as the better option. The fact that large 3PL providers such as DHL has experience with this type of equipment is also positive. This could mean that good transportation prices could be negotiated as there is experience and specific knowledge. Less units handling is also considered to reduce costs. If heating was decided to be made at the plants, and in case a heating tank was chosen, where larger volumes could be heated before being pumped, it could potentially open the door for applying other means for containing the product, where pumping directly from the unit is not necessary, but instead being loaded to a tank and then heated. An example of such an alternative mean is illustrated in Figure 5.16.

Figure 5.16: Collapsible 1000 L. container with thin plastic bag. (Cowab n.d.).

The boxes contains a thin plastic bag that is single use and is destroyed when lifted and loaded to the heating tank. The plastic bags with residue of the organic materials can be reused and the boxes collapsed and transported space efficiently after.

Equipment
Choices of equipment is closely related to means. Regarding handling activities at the plants, it is assumed that plants have the equipment to handle the units and load it to plants via pumping. Due to the characteristics of the product it could also be suggested that the bags should be lifted and then pumped.

A great cost driver is the heating, so facilities for doing this efficiently is crucial. No matter if the company established a centralised heating facility to ship from, or if strategic partnerships are made i.e. locations where surplus heat from production could be applied and further build on the cascading principles. These are both solutions that could be prioritized in longer term. The equipment needed is the flexitank heating pads or a heating tank where larger volumes could be heated and pumped directly to the tank. This seems both possible now and in the future. By time other heating facilities might occur, where simultaneously heating of many units is possible.

Transportation

Creating cost efficiency via transportation choices is more tricky as there are less options. For the Oman and Argentina case transportation by vessels is the only option, and the choice of equipment to contain the product does not influence the mode. Creating cost efficiency here is in general seen to be possible in three ways; 1) affect prices via either economics of scale, 2) affect prices via cheaper container options, and as standardized as possible, 3) via the Incoterm agreements or partnerships with 3PL, where clear mapping of the transport market options and operators should be done.

Impacting costs in the Ukraine case had more solution space. Changing to a cheaper road mode had the wanted effect, despite purchase of new equipment. Improving costs further would as well be through the three mentioned aspects above. As theory suggested railway is theoretically the cheapest way to transport biomass bulk by land, this should be looked into. Challenges can occur across borders due to the compatibility between railways and also legislation of this type of bulk can differ. The company already have agreements with DB. It is suggested that it could be investigated if railway is a better solution. There could be practical trade offs as well causing reduced flexibility and control of the product flow. As the Femern tunnel between Germany and Denmark as well will be finalized within a foreseeable future, this might open up for lowering costs via shorter routes for both road and rail. Further investigation of potential exploitation of reverse flows is also recommended, to reduce transportation costs in the Ukraine business case.

Inventory

As the lead times regarding transportation times are rather long, at least for the shipments from Argentina and Oman, being several weeks, the flexibility is extremely limited, especially if inventory nationally does not exists. The company does not have any inventory facilities so far and it is expected that the plants will store the product if inventory is needed. For Ukraine the transport is 5 days, which gives more transportation wise flexibility. For the plants it is optimal with a rather stable flow. As the shipments from Oman and Argentina are very large and not frequent, it simply is decisive that inventory can be kept at the plants in order to take in large volumes. The Ukraine delivery can be rather frequent with smaller continuous deliveries and just 5 days delivery time. The inventory not necessarily contributes directly to cost efficiency, but a centralized storing unit could provide some flexibility. For the Oman case there was a constraint of only being able to load the biomass to ISO tanks between April and mid-October. This means that they need to be able to ship 600-1200 tons during these 7 months. If the plants are not able to store great amount of products, a storage in Denmark to ship from when needed could be a solution.

5.5.2 Discussion of a potential Strategic Partnerships

As stressed in the recommendation, strategic partnerships outside the company's current supply chain is highly recommended. It is considered that this would benefit the company both short and long term, and in different levels of the root to the barriers.

Actor engagement and cross cooperation are crucial to enable a full functionally and viable supply chains of the biomass. As circular logistics should be designed to be cost efficient, supply chain networks and seeing opportunities across actors are crucial to fully exploit the opportunities that lies in already existing and established networks and facilities, i.e. regarding heating of the product. This eliminates large investment costs, and reduces both costs and risks as they are shared across the network between the partners. As the company is outsourcing many of the services within logistics to either the producers or 3PL and as well potentially will rely on the plants to be responsible for key activities such as storage and heating, actor engagement and relationships are key.

It is considered that it should be a priority to exploit already established solutions outside the company's normal domain. Creating a strategic partnership with the purpose of creating a viable heating solution could remove the practical barrier and some costs of heating facilities and equipment. Many productions are generating surplus heat from another production, and in line with the cascading principle that is already categorizing this business model, surplus heat as a resource could be used to solve a critical problem for the company. There are many large production industries, especially chemical and biochemical companies spread across Denmark, that could generate surplus heat to enable facilitating i.e. a sauna, as the company has already brainstormed.

Regarding strategic partnerships to overcome barriers collectively, a potential opportunity emerged during the conduction of the research. During the process of the thesis an interview with the CCO of the port in Kalundborg was conducted. The interview provided insights to a solution that could be possible within the current solution space and boundaries of logistics, but an opportunity lying outside the domain of the data provided by the company. It is considered that the Port of Kalundborg is a very interesting strategic partner for the company, and could easy current barriers of logistics long term via establishing the company as a part of an industrial symbiosis. The services and opportunities they could provide almost covers all of the company's practical and technical barriers.

The port of Kalundborg has a strategically good location for ships coming in and has shorter shipping time than to Copenhagen. Shipping times are similar to Aarhus. The centrally and strategically good location of the port is illustrated in Figure 5.17.

Figure 5.17: The ports central location in Denmark with easy access to the large shipping routes. Source: Port of Kalundborg.

The Port is a deep water port which enables big vessels to dock with up to 12 meters deep waters at the dock. The roads leading into the port have been expanded so large modular vehicles with can access the ports facilities too. In the future, the plan is to lead the railways to the port too, which could be relevant for the Ukraine case. This covers all transport modes that are relevant for the company to use. The overview and sea access is illustrated in Figure 5.18.

Figure 5.18: Overview of the port in sea-map and from air. Source: Port of Kalundborg

Furthermore, the container transport prices in the zone around Kalundborg is the cheapest in this part of Denmark, as illustrated in Figure 5.19.

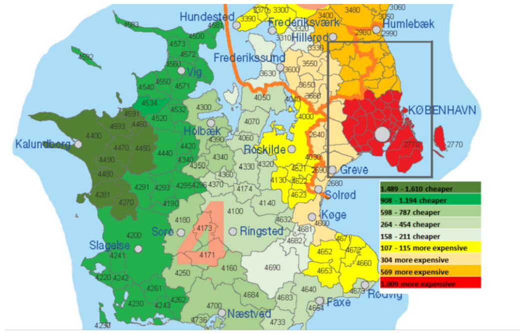

Figure 5.19: Container prices for road transport on the island of Sjælland in Denmark. Source: Port of Kalundborg.

The port has extensive access to local know-how. Around the port is located very large and global industrial production sites, mainly within medicine and biochemistry. The circular network between the production sites is already functioning between many of them and is called the 'Kalundborg Symbioses'. Becoming a part of this network could open up for the company to be a part of a system regarding access to surplus heat for either a large sauna or another heating option. The current Kalundborg Industrial Symbiosis is presented in Figure 5.20.

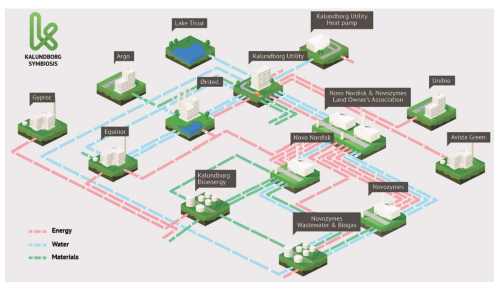

Figure 5.20: The industrial symbiosos - Kalundborg Symbioses. Source: Port of Kalundborg.

The port are handling a great variety of goods; Drybulk, single large unit bulk, liquid bulk, Ro/Ro, and heavy lifts. Furthermore the port are renting out silos for heating and storage of different volumes. There is 17 silos with in total 38.000 cubic meters of capacity. Clients can rent the silos in a 50-50 owned partnership. From here trucks can be loaded and shipped to the customers. The heating efficiency should according to the CCO be good enough for keeping the product at a state where it is possible to pump, as they already have experience with keeping fish oil liquid, which has similar characteristics.

Last but not least, there is a large biogas plant within a kilometer that the port is cooperating with already, that receives other biomasses from nearby productions. In fig. 2.12 in the Theory section the placement of the biogas plants that are included in the common biogas owner and biogas plant operator, Bigaden, and their locations in Denmark is illustrated. There are several plants close to Kalundborg. It is highly recommended that the company initiates contact with the port to map a potential cooperation.

5.5.3 Discussion of market risks and opportunities

Looking at the demand side, the dynamics and trends in the market indicates that the demand will increase within all industries that are capable of using biomasses (Kjärstad et al. 2023). This is both due to legislation, but also the markets in the Nordic countries where industries are consuming regional and national sources of biomasses at a high rate. Which is why the company seeks to leverage on this and fill this demand-gap by importing international sources of high quality biomass. On the demand side, literature suggested that it is likely that competition between different industries will occur, fighting over the same biomasses. This would impact prices and in general the assumed increase in demand really stresses why the supply chains of international trade of biomass is important(Kjärstad et al. 2023).

It was mentioned that the product has a considerable degree of supply certainty of the biomass, which is true in a static perspective. But external factors can always impact uncertainty and supply uncertainty. Looking into the future, with the theoretical insight in mind, supply certainty could be reduced. Emerging biogas producing companies and countries could impact the markets in the Nordics, and the products could instead be exported to regions closer, from where it is currently more relevant to export. As the development of biogas and other biofuels might develop rapid in other countries, this could shift market dynamics completely challenging supply chains and companies.

For the industries depending on the biomasses, there lies a huge uncertainty and risk in building business completely dependent on by-product and waste biomasses. Despite the fact that enabling global transportation of biomass is not just an important step, but a crucial step for the green transition, it is risky being dependent on a resource that potentially can become limited. On the bright side, biomasses will continue to be produced as waste and residues. This amplifies the need for establishing resilient, cost efficient, and suitable supply chains of biomasses. The market dynamics and high demand, can create huge challenges that can slow down the green transition. Responding to the demand can be challenged if feasible and viable CSC solutions are not in place to support the physical distribution of the biomasses in a global scale.

Chapter 6

Discussion

This chapter will discuss strengths and weaknesses of crucial aspects of the thesis in general terms. It will cover discussion of the general approach and the applied sources of data via a discussion of reliability and credibility of the research. In the end, the research will be put into a wider context considering contribution and as well impact on social and environmental aspects.

6.1 Strengths and weaknesses

To weigh the results of the research contribution and understand how and where the study could create value or purpose, it is crucial to understand the general strengths and weaknesses of especially the methodology, but as well the general quality of data and data analysis. Understanding this enables to demarcate the area of application and general interpretations and conclusion. The following sections aims to discuss these limitations and opportunities of the research.

6.1.1 Literature

The theoretical study provided insight via a both wide and in-depth literature study. The approach can be described as a funnel approach. First the topic of general sustainability was studied, leading to circular economy, waste management and cascading principles in biogas production. Lastly specific research regarding biomass production and logistics of biomass was conducted. A challenge was that not a lot of research had been done in the field of biomass logistics in circular economy context. The lack of research was also a motivation for the study, realizing that there is not extensive material and guidelines in the sectors and industry, in how to operate CSCs.

Parallel with research of the sustainability aspect, a literature study of supply chain strategy and strategic fit, lead to more specific literature study regarding circular supply chains. Here the discovery was a general lack of research within circular logistics, but a fast growth in publications in recent years. This as well was a catalyst of motivation that this topic in general terms is important and has been in the shadow of development of circular business models.

6.1.2 Methodology

The methods of collection of secondary data, and the qualitative data had a clear approach and scope. The focus was to simultaneously gather general insights to the topic via the literature review, while conducting unstructured interviews to gain insights to the company potential problematic business cases. The process of scoping the project was long and not always moving in one pre-decided direction. The gradual demarcation instead lead to insights in many aspects and perspectives to the overall problem complexity, which later was valuable, as the final scope of the business case turned out to be indeed complex.

Choices of methods depended on the opportunities of the research scope, and trade-offs had to be made as the time frame of the research was rather short. The methods chosen can affect results and conclusions, which is very important to have in mind to be able to evaluate strengths and weaknesses of the study.

As discussed in chapter 3, the research design was to a great extend exploratory and would be challenging to replicate in detail. The methods were with a problem solving approach, where a parallel collection of data through interviews was collected. Late in the process quantitative case data was provided. This data gathering methods might not be possible in other organizations, while also other types of data might be available instead.

Deciding on the method regarding how to approach the quantitative data was a process parallel to scoping the project with the company and in dialogue with the supervisor. Here the approach became to use the opportunities at hand, and it turned out to be slightly in another direction than perceived in the beginning. Access to data happened very late in the research process, and as the type of data was for a long time period unclear many methods where discussed. In the end when receiving the data, it became apparent that a cost estimation and analysis leading to scenario development and comparison was what made most sense. The hope was to do a more in-depth or advanced analysis, but the rather general and small amount of data made this idea to rest. The sensitivity analysis contributed well to understanding dynamics and cost impact of choices, that could assist to qualitative conclusions. As the conclusion to a great extent was based on the sensitivity analysis, choosing other parameters with other significance could have possibly impacted the results. As well, if another individual conducting the same study might have picked other parameters due to individual biases.

When that is said, the rather wide approach to the problem, extensive literature study and interviews with external experts, materials engineer, and commercial manager at the port provided other insights to the problem solving. Optimally, conducting interviews with biogas plants or transportation operators could have provided valuable insights to the problem as well.

6.1.3 Limitations & Assumptions

The uniqueness of the business case, and especially the fact that the business cases currently are still at a theoretical level at the company, set both limitations and opportunities for the study, that impacts as well the strengths, weaknesses and interpretations of the study. The exploratory approach to the study, is visible in the process of developing further on a given baseline and frame provided by the company. Exploring alternative solutions that could solve the current challenges for the company in a more free frame, gained insights to more general sectorial issues, than the specific case entry point to the study.

An extensive amount of assumptions had to be made in the scenario development to create room for analysis and interpretations. The assumptions were to a great extent as possible described and attempted to be backed up by industrial research to make reasonable estimations of assumptions, but each case will always be unique and with as well rather general data provided by the company it leaves a degree of weakness and limitations to the overall interpretation of results and recommendations.

The extensive discussion aspect in the analysis chapter aimed to compensate for these uncertainties. A discussion after each analysis step was an attempt to deeply describe how assumptions potentially impacted results, and as well how and why they were made. It was stressed throughout the thesis that the quantitative results individually were not interpreted as a direct statements of the economic outcome of the scenarios. But combined with the qualitative analysis, it could be applied for gaining insights to context, dynamics, cost drivers and barriers for the biomass, and guide decision making.

6.1.4 Reliability and credibility of the data

Credibility is related to how believable a research is (Bell, Bryman, and Harley 2019). The interviewed experts have provided data, and since it is in their priority to solve this case, it is considered valid. By afterwards listening to recorded interviews, and partly transcription of interviews, the data was double checked. If questions and doubt occurred, the company representatives were always fast to assist to correct and help understanding misinterpretations. If the company could not provide data that was considered important to the analysis or general understanding of the case, literature research assisted, via up-to-date research papers and industrial sites, which are assumed credible.

Ensuring reliability of the study, information was attempted to be confirmed by several academical articles and other sources that are considered reliable; academical articles, University books, International Freight Transport website, governmental documents and guidelines, industry reports, case company internal documents, and communication with industry experts.

However, in the case of information and case data provided by the company regarding products and prices of different services, this data has not been able to be compared against other reliable sources due to the uniqueness of the matter. This means that the reliability of the company is important to be able to decide on reliability of the result. The company is considered reliable within their field as they are world leading within circular waste management across sectors, and due to this they have been acquired by the largest UK-based waste collection group. As the business case is important, and it is of high priority for the company to find a viable solution that could imply profit gains, new market opportunities, and pushing the green transition in Denmark further, it is considered that it is in the company's best interest to provide reliable data.

6.1.5 General Validity

Validity concerns the logical and level of correspondence to the real world (Bell, Bryman, and Harley 2019). In general the reason and soundness of the study are considered good as the study was conducted in cooperation with an industrial actor with a real business case problem, even if it in many aspects is a problem with assuming no prior equals. The results showed that there are several factors within logistics that can cause barriers and drive costs, and at the same time many potential ways to overcome these on different levels. Overcoming the barriers are currently possible via incremental logistics changes, depending on the priorities and opportunities for the company in their supply chain. In the future it might be possible through radical innovation and fundamental change for the sector. The proposal of the Port in Kalundborg illustrated, that even with out radical change, for now it is still possible to overcome some practical barriers of the case.

The cost impact of the incremental logistic improvements could be very dependent on industrial partnerships and capabilities of SC actors to solve the practical barriers. Resources and ability to invest plays a crucial role of enabling the incremental improvements. Combined with the very explicit and apparent complexity of the business case and overall problem context, the study can be accepted as valid as assuming many companies and industries are facing maybe not similar cases but likewise unexplored business cases where uncertainty and decision making on uncertain ground is more the norm than the exception. Especially if dealing with progressive and innovative solutions within circularity. With focus primarily on the supply side and very limited on the demand side, interviews with one or several biogas plants could have added validity to the study through insights to the demand side of the problem. In general a larger focus on the demand side could have enabled interesting insights to the case.

The complex dimension of market dynamics created an extra layer of uncertainty and perspectives to the analysis and discussions. This was attempted to be considered through discussions throughout the research to give the reader a broad context understanding of the underlying problem context. The continuous and extensive discussion of each step in the analysis chapter was with the purpose to give the reader insight to all the uncertainties and potential sources of errors or misinterpretations as possible. Which if not give validation to the results, attend to give validity to the research method and approach.

6.2 Further Research

In chapter 5, section 5.5 is considered to be a general discussion of further improvement areas for the company to look into to enable a more cost efficient strategy and logistic solutions, and these could even be areas of future academic research.

For the general research, this thesis subject and overall problem have many potential dimensions, that even stretches outside Industrial Engineering, as process-, chemical- or materials engineers could contribute greatly to the case with different approaches. Staying within this field, including more actors in the research and mapping the current capabilities within specific logistic providers further could be an important aspect. As well involvement of the biogas plants will be essential for future research when developing internal processes for i.e. heating and handling of the products at the plant, and storage options.

The research is considered far from done and still has great potential for an internal costs analysis based on the company's supply network, and with new partnerships or choices, the cost analysis could be tweaked further. It is highly recommended that the company engage contact with the Port of Kalundborg to explore the potential cooperation and the facilities and services that could be offered.

Further research could apply environmental data to evaluate solutions not merely on cost efficiency but as well environmental impact. Considering this study's root in sustainability and circularity, this could be both very interesting adding this dimension but also of highest priority for understanding impact or contribution to the social and environmental bottom line.

6.3 Contribution to subject area

The study propose suggestions for incremental logistics changes to reduce costs, and found that change in equipment and cheaper modes could reduce costs. A negative approach to a sensitivity scenario suggests that solutions that deviates from the standard solution potentially are very cost sensitive to added costs and price compensations if key activities needs to be made by other actors.

The study contributes with insights to the great potential of various biomasses application in biogas production, which could enable other actors to see potential in their production waste and enter in circular B2B and B2E networks via their waste. Reducing resource waste and enabling better circular solutions for cascading and energy recovery, would push the green transition forward via better partnerships and end-to-end solutions. As discussed above, the uniqueness of the study makes it challenging to replicate directly. With this said, it is considered that the study gains insight to first of all potential logistics and cost barriers for biomass transportation. The study contributes with insights to the complexity of creating an economically viable logistic solutions, as many of the logistics barriers and cost drivers are dependent on company and context. The study contributes with a sensitivity analysis approach to guide decision making. The study highlights cross SC network and strategic partnerships as a facilitator for overcoming logistic and cost barriers of CSCs.

6.4 Environmental & Social Considerations

As mentioned in the discussion of future research of this topic, investigating environmental impact seems crucial if not an obligation. Speaking in general terms; this research investigates development and cost implications of a logistic solution for enabling circularity of a waste resource to production of green and renewable energy. Contributing to the green transition has positive impact on the environment and social well being. However, there are negative environmental implications that must be considered when developing a global logistic solution, despite the fact that it contributes to the green transition via cascading of biomass to biogas production.

Considering bulk transport, especially on road, it can always have a social impact when considering road safety, noise etc. The choices of equipment has as discussed environmental impact as well, where the materials used to the equipment and as well the degree of which it needs to be cleaned or recycled have environmental implications too. Transporting cheap bulk across Europe or across the globe, is not a positive contributor to the environment. Companies to an increasing degree are impacted by legislation regarding use of green transport, and the fact that the company priorities to partner up with 3PL that operates within guidelines of green transport is a good start. But having a sustainable solution at heart, and not merely an cost efficient logistic solution could provide an even stronger business case in the future for viability of the business case and improve the green transition further. It should be mentioned that the transportation of biomass is seen as a substitute for transportation of other fossil fuels etc., and has the purpose to phase out this, and hopefully contribute to less negative environmental impact.

Chapter 7

Conclusion

On a global scale, agriculture and various organic industrial productions generate extensive amounts of by-product biomasses. Many solutions that enable the green transition are dependent on biomasses to be cascaded to i.e. production of biogas. The rapid growth in biomass-consuming industries especially in the Nordic countries are causing the demand to increase. This requires global supply chains of biomass. Establishing innovative and cost efficient CSC solutions to enable the physical distribution is therefore becoming increasingly important due to the potential global market of different sources of biomass with unique characteristics and requirements to the logistics solutions.

Enabling the physical distribution of the biomass bulk is challenged by expensive standard solutions, standardized Incoterm agreements, lack of experience, and lack of innovative solutions. At the same time, innovation, not just by changing fuel types, but thinking innovation in large scale into conventional ways of organizing logistics is challenged due to the squared and standardized nature of logistics. The resource potential of circularity of especially applying the cascading principles of waste and by-product biomasses for energy recovery in terms of i.e. biogas production is not fully exploited due to logistic barriers. Waste and by-product biomasses fall outside the normal standard product, and therefore do not fit in the standardized transportation. Due to prices and demand, the business case of importing the energy dense residue biomass for biogas production is attractive. The characteristics of the product is meanwhile causing challenges to logistics in a practical and technical dimension, as the product solidifies during transport and needs heating. These specific product characteristics is a general challenge for enabling circular offerings. Finding both feasible and viable solutions are challenging. Barriers to find a solution is related to general barriers in the logistics sector and expensive standard solutions of standardized and conventional logistics are challenging establishment of a CSC.

The case was studied with an exploratory method and problem solving approach. Via interviews with the case company the nature of the problem was investigated and from case data different logistics scenarios were explored via a cost analysis. Three analysis steps in the cost analysis were conducted to analyse the company's current approaches to the solution of the problematic business case. Due to the nature of the so far rather unexplored business case and therefore limited access to specific economical and logistic data, the methods of problem solving approach was suitable. The data enabled to conduct a cost analysis of different logistic scenarios, where a sensitivity analysis enabled to discover cost impacts and dynamics under uncertainty. The purpose of the analysis was not to estimate exact costs of solutions, but to facilitate better decision making under uncertainty of unexplored business cases with limited data. As well the aim was to gain insights to general aspects in the logistics sector that challenges development and innovation of circular logistics. It was realized that even the alternative solutions were challenged by high costs and at the same time did not solve the root cause of problems. Based on both the cost analysis and the experts input, a recommendation was suggested. The quality of findings could have been further improved with an even deeper industrial analysis of external opportunities for an optimized logistics design. As well an environmental approach to the cost scenarios could have gained valuable insights to better decision making, not just in terms of costs, but for sustainability as well.

The study showed, that having a cost efficient supply chain strategy is necessary to enabling CSCs. At the same time, it was suggested that in general there is an extensive focus on finding cheaper solutions, and too little on finding better solutions that actually solve the practical problems with the new characteristics of circular offerings. Finding this, could have positive cost implications too. The cost efficiency for the cases was achieved only by incremental changes, by i.e. changing transport modes or equipment, but at the same time being exposed to great uncertainty. To overcoming the practical and cost wise barriers, bundling, innovation, and strategic partnerships was suggested as three aspects for the company to focus their attention, to enable a cost efficient CSC and viable business model in the long run. Bundling could enable volumes and more room for tailor-made solutions where the product characteristics is the main driver of a suitable solution. Strategic partnerships, i.e. with the port of Kalundborg, could enable exploiting already existing solutions outside the company's own domain, and being a part of an industrial symbiosis is considered to strengthen the company's option of finding not just feasible but optimal solutions. Creating radical innovation, both in small scale for the company's specific case, and in larger scale for the logistic sector is more challenging and less tangible. But both bundling and partnerships are considered to be enablers for more radical innovation. Innovation can be both in regards of means and transportation, where the products are in focus, and their specific requirements to the solutions are obeyed. To exemplify this, the practical challenges the company is facing, i.e. in regards to heating, decisions could be made both in short term to make the business case running now, or in longer term to make the business case more viable. In order to get the business case going in the short term the heating can be done by specifically designed equipment. However, in a long term it is considered more time and cost efficient to establish large-volume heating facilities and strategic partnerships to enable this is recommended. To illustrate that point, the Port of Kalundborg is an example of such partnership. The port can facilitate services that could reduce logistic barriers and potentially could create a feasible solution based on the company's requirements to the solution. It is considered that the main barriers for further improvement currently lies outside the domain of the company. Sectorial change via improved strategic partnerships and enabling radical change across all logistic actors end-to-end, is required to facilitate actual feasible and viable logistic solutions for physical distribution of cascading of biomass.

Overcoming practical and costs barriers would contribute to enabling circular logistics and CE supply chains. Having highly functional and cost efficient logistic solutions for circularity of physical distribution of waste and by-product resources, could boost the green transition and reduce resource waste. There is enormous potential of biomasses to be inducted in 'closing the loop' supply chains, as waste generation is extensive globally. It is suggested that overcoming logistics and cost barriers are not merely related to isolated and discrete challenges, but are challenged by an overall lack of non-standardized solutions, and general development of logistics in circular matters. Where an extensive focus has been on developing circular business models, the logistics that support it falls short, and innovation of logistics has been focused on renewable fuels for modes, and not innovation of the logistics itself. Enabling innovation in a standardized sector, makes innovation possible only if it still fits in the standardization solution. Through actor bundling and strategic partnerships, both practical challenges could be reduced and as well challenging the rigidity of the logistic sector could be possible. These aspects could enable more radical innovation of logistics, and challenge the squared conventional thinking in the sector, where thinking outside the box is limited by standardization. Thinking outside the box in literal terms is challenging in a sector where everything already are in boxes, and to do so, it requires more strategic cooperation and volumes to enable innovation.

Bibliography

Amin, Saman Hassanzadeh, Zhang Guoqing, and Miqdad Nidal Eldali (2020). "A review of closed-loop supply chain models". In: *Journal of Data, Information and Management* 2. DOI: 10.1007/s42488-020-00034-y. URL: https://doi.org/10.1007/s42488-020-00034-y.

"Barriers to the wider implementation of biogas as a source of energy: A state-of-the-art review" (2019). In: *Energy Strategy Reviews* 26, p. 100414. ISSN: 2211-467X. DOI: https://doi.org/10.1016/j.esr.2019.100414. URL: https://www.sciencedirect.com/science/article/pii/S2211467X19301075.

Bell, Emma, Alan Bryman, and Bill Harley (2019). *Business Research Methods, 5th ed.* ISBN: 978-0-19-880987-6.

Bhukya, Gopal et al. (2023). "Pre-Treated Crude Glycerol a Valuable Green Energy Source in the Era of Circular Bioeconomy—a Review". In: *Circular Economy and Sustainability*. DOI: 10.1007/s43615-023-00310-0. URL: https://doi.org/10.1007/s43615-023-00310-0.

Bigaden (n.d.). *Bigaden.* Online; accessed 24th of November 2023. URL: https://bigadan.dk/.

Biogas Express (2023). *How does biogas work as a circular economy?* Online; accessed 8th of Novemeber October 2023. URL: https://biogas-express.com/news/how-does-biogas-work-as-a-circular-economy/.

Bionenergy, IEA (2021). "Implementation of bioenergy in Sweden – 2021 update". In: *IEA Bioenergy, Country Reports* 10. URL: https://www.ieabioenergy.com/wp-content/uploads/2021/11/CountryReport2021_Sweden_final.pdf.

Carter, Craig and Dale Rogers (June 2008). "A Framework of Sustainable Supply Chain Management: Moving Toward New Theory". In: *International Journal of Physical Distribution Logistics Management* 38, pp. 360–387. DOI: 10.1108/09600030810882816.

Chan, Hing Kai et al. (2016). "A mixed-method approach to extracting the value of social media data". In: *Production and Operations Management* 25.3, pp. 568–583.

Chopra, Sunil and Peter Meindl (2013). *Supply Chain Management - Strategy, Planning, and Operation.* 5th. Pearson.

Comission, European (n.d.). *Biomass.* Online; accessed 17th of January 2024. URL: https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biomass_en.

Commission, European et al. (2016a). *Study on the energy saving potential of increasing resource efficiency – Final report.* Publications Office. DOI: doi/10.2779/172229.

— (2016b). *Study on the energy saving potential of increasing resource efficiency – Final report.* Publications Office. DOI: doi/10.2779/172229.

Cowab (n.d.). *Collapsible box.* Online; accessed 23rd January 2024. URL: https://www.cowab.se/sakerhet/kemikalieforvaring/ibc-behallare?msclkid=6538ac1d29d31a5ffb86c9b2c5e utm_source=bing&utm_medium=cpc&utm_campaign=p-cowab-se-search-other-

phrase&utm_term=ibc&utm_content=%2Fsakerhet%2Fkemikalieforvaring%2Fibc-behallare.

Creswell, John (Jan. 2009). "Research Design : Qualitative, Quantitative, and Mixed Methods Approaches / J.W. Creswell." In.

Crowe, Sarah et al. (2011). "The Case Study Approach". In: DOI: 10.1186/1471-2288-11-100.

Dafnomilis, I. et al. (2018). "Optimal equipment deployment for biomass terminal operations". In: *Transportation Research Part E: Logistics and Transportation Review* 115, pp. 147–163. ISSN: 1366-5545. DOI: https://doi.org/10.1016/j.tre.2018.05.001. URL: https://www.sciencedirect.com/science/article/pii/S1366554517311444.

Danmark, Biogas (n.d.). *Biogas Outlook - 2023. Production and use of biogas in Denmark 2022-2035.* Online; accessed 17th of January 2024. URL: https://www.biogas.dk/wp-content/uploads/2023/06/Biogas-Outlook-2023-English-20-June-2023.pdf.

DHL (n.d.[a]). *DHL Flexitank.* Online; accessed 16th of January 2024. URL: https://www.dhl.com/content/dam/dhl/global/dhl-global-forwarding/documents/pdf/dhl-glo-dgf-flexitanks-brochure-june19.pdf.

— (n.d.[b]). *DHL Flexitank.* Online; accessed 19th of January 2024. URL: http://www.neoflex-europe.com/service/disposal-of-empty-flexitanks-at-destinations/.

Ellen McArhtur Foundation (n.d.). *What is Circular Ecoconomy?* Online; accessed 1st of November 2023. URL: https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview.

Esfandyari, Morteza, Ali Hafizi, and Mehdi Piroozmand (2021). "5 - Production of biogas, bio-oil, and biocoal from biomass". In: ed. by Mohammad Reza Rahimpour et al., pp. 139–164. DOI: https://doi.org/10.1016/B978-0-12-821601-9.00005-4. URL: https://www.sciencedirect.com/science/article/pii/B9780128216019000054.

Feng, Lu et al. (2023). "Developing a biogas centralised circular bioeconomy using agricultural residues - Challenges and opportunities". In: *Science of The Total Environment* 868, p. 161656. ISSN: 0048-9697. DOI: https://doi.org/10.1016/j.scitotenv.2023.161656. URL: https://www.sciencedirect.com/science/article/pii/S0048969723002711.

Fennemann, Verena, Christian Hohaus, and Jan-Philip Kopka (2018). *Moving in circles: Logistics as key enabler for a circular economy.* DOI: 10.24406/IML-N-502288. URL: https://publica.fraunhofer.de/handle/publica/299141.

Fjeld, Dag et al. (2021). "A common Nordic-Baltic costing framework for road, rail and sea transport of roundwood". In: *NIBIO.* URL: https://hdl.handle.net/11250/2723839.

Flexitanks (n.d.). *Flexitanks.* Online; accessed 13th of December 2023. URL: https://flexitank.com/price/.

Foreverest (n.d.). *IBC.* Online; accessed 16th of January 2024. URL: https://foreverest.net/news-list/handling-guide-of-loading-20-1000l-ibc-tanks-in-20ft-container.

Freight, Sea (n.d.). *Sea Freight Costs.* Online; accessed 18th of January 2024. URL: https://moverdb.com/container-shipping/argentina/.

Gasum (2023). *Biogas is a truly renewable fuel taking circular economy to its extreme.* Online; accessed 8th of Novemeber October 2023. URL: https://www.gasum.com/en/insights/energy-of-the-future/2022/biogas-is-a-truly-renewable-fuel-taking-circular-economy-to-its-extreme/.

Genovese, Andrea et al. (2017). “Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications”. In: *Omega* 66. New Research Frontiers in Sustainability, pp. 344–357. ISSN: 0305-0483. DOI: https://doi.org/10.1016/j.omega.2015.05.015. URL: https://www.sciencedirect.com/science/article/pii/S0305048315001322.

Giovanni, Pietro De (2022). “Leveraging the circular economy with a closed-loop supply chain and a reverse omnichannel using blockchain technology and incentives”. In: *International Journal of Operations Production Management* 42. DOI: 10.1108/IJOPM-07-2021-0445. URL: https://doi.org/10.1108/IJOPM-07-2021-0445.

Group, Flexitank (n.d.). *Flexitank*. Online; accessed 16th of January 2024. URL: https://www.flexitankgroup.com/flexitank-products.htm.

Guba, Yvonna S. and Egon G. Guba (2013). “The constructivist credo: Left Coast Press”. In.

Guide Jr, V Daniel R and Luk N Van Wassenhove (2006). “Closed-loop supply chains: an introduction to the feature issue (part 1)”. In: *Production and Operations Management* 15.3, pp. 345–350.

Hamelinck, Carlo N., Roald A.A. Suurs, and André P.C. Faaij (2005). “International bioenergy transport costs and energy balance”. In: *Biomass and Bioenergy* 29.2, pp. 114–134. ISSN: 0961-9534. DOI: https://doi.org/10.1016/j.biombioe.2005.04.002. URL: https://www.sciencedirect.com/science/article/pii/S096195340500053X.

Hussain, Matloub and Mohsin Malik (2020). “Organizational enablers for circular economy in the context of sustainable supply chain management”. In: *Journal of Cleaner Production* 256, p. 120375. ISSN: 0959-6526. DOI: https://doi.org/10.1016/j.jclepro.2020.120375. URL: https://www.sciencedirect.com/science/article/pii/S0959652620304224.

Insights, Global Market (n.d.). *Flexitanks*. Online; accessed 13th of December 2023. URL: https://www.gminsights.com/industry-analysis/flexitanks-market.

Jensen, Jonas Pagh (2018). “Narrowing, Slowing and Closing the resource Loops: circular economy in the wind industry”. English. In: Ph.d.-serien for Det Tekniske Fakultet for IT og Design, Aalborg Universitet. PhD supervisor: Professor Arne Remmen, Aalborg University Assistant PhD supervisor: Professor Han Brezet, Aalborg University.

Kalmykova, Yuliya, Madumita Sadagopan, and Leonardo Rosado (2018). “Circular economy – From review of theories and practices to development of implementation tools”. In: *Resources, Conservation and Recycling* 135. Sustainable Resource Management and the Circular Economy, pp. 190–201. ISSN: 0921-3449. DOI: https://doi.org/10.1016/j.resconrec.2017.10.034. URL: https://www.sciencedirect.com/science/article/pii/S0921344917303701.

Kirchherr, Julian, Denise Reike, and Marko Hekkert (2017). “Conceptualizing the circular economy: An analysis of 114 definitions”. In: *Resources, Conservation and Recycling* 127, pp. 221–232. ISSN: 0921-3449. DOI: https://doi.org/10.1016/j.resconrec.2017.09.005. URL: https://www.sciencedirect.com/science/article/pii/S0921344917302835.

Kjärstad, Jan et al. (2023). “Infrastruktur för en koldioxidneutral industri – CCS, biomassa och elektrifiering”. In: *Chalmers Tekniska Högskola, avdelningen för Energiteknik, IVL Svenska Miljöinstitutet, Skogforsk*.

Koosila, Leena (2022). *Circular Logistics in The Nordics*. Studentlitteratur.

Korhonen, Jouni et al. (2018). “Circular economy as an essentially contested concept”. In: *Journal of Cleaner Production* 175, pp. 544–552. ISSN: 0959-6526. DOI: https:

//doi.org/10.1016/j.jclepro.2017.12.111. URL: https://www.sciencedirect.com/science/article/pii/S0959652617330706.

Kumar, Bhavesh et al. (2023). "Green finance in circular economy: a literature review". In: *Circular Economy and Sustainability*. DOI: 10.1007/s10668-023-03361-3. URL: https://doi.org/10.1007/s10668-023-03361-3.

Lamber, Douglas M., Martha C. Cooper, and Janus D. Pagh (1998). "Supply Chain Management: Implementation Issues and Research Opportunities". In: *The International Journal of Logistics Management* 9. DOI: 10.1108/09574099810805807. URL: https://doi.org/10.1108/09574099810805807.

Lin, Tao et al. (2016). "Biomass feedstock preprocessing and long-distance transportation logistics". In: *GCB Bioenergy* 8.1, pp. 160–170. DOI: https://doi.org/10.1111/gcbb.12241. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/gcbb.12241.

Luciano Batista Michael Bourlakis, Palie Smart and Roger Maull (2018). "In search of a circular supply chain archetype – a content-analysis-based literature review". In: *Production Planning & Control* 29.6, pp. 438–451. DOI: 10.1080/09537287.2017.1343502. URL: https://doi.org/10.1080/09537287.2017.1343502.

Lüdeke-Freund, Florian, Stefan Gold, and Nancy M. P. Bocken (2018). "A Review and Typology of Circular Economy Business Model Patterns". In: *Journal of Industrial Ecology* 23.1, pp. 36–61. DOI: https://doi.org/10.1111/jiec.12763. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/jiec.12763.

Montag, Laura (Jan. 2022). "Circular Economy and Supply Chains: Definitions, Conceptualizations, and Research Agenda of the Circular Supply Chain Framework". In: *Circular Economy and Sustainability* 3. DOI: 10.1007/s43615-022-00172-y. URL: https://doi.org/10.1007/s43615-022-00172-y.

Neha Mehta, Ahmed I. Osman amd et al. (2021). "Conversion of biomass to biofuels and life cycle assessment: a review". In: *Environmental Chemistry Letters*. URL: https://link.springer.com/article/10.1007/s10311-021-01273-0.

OECD (2022). *Circular Economy - waste and materials*. URL: https://www.oecd.org/environment/environment-at-a-glance/env-2019-2343-en.pdf.

— (2023). *Environment at a Glance Indicators*. DOI: https://doi.org/https://doi.org/10.1787/ac4b8b89-en. URL: https://www.oecd-ilibrary.org/content/publication/ac4b8b89-en.

PB Pressbooks (2020). *Types of Research*. Online; accessed 16th November 2023. URL: https://scientificinquiryinsocialwork.pressbooks.com/chapter/7-1-types-of-research/.

Salmenperä, Hanna et al. (2021). "Critical factors for enhancing the circular economy in waste management". In: *Journal of Cleaner Production* 280, p. 124339. ISSN: 0959-6526. DOI: https://doi.org/10.1016/j.jclepro.2020.124339. URL: https://www.sciencedirect.com/science/article/pii/S0959652620343845.

Sassanelli, Claudio et al. (2019). "Circular economy performance assessment methods: A systematic literature review". In: *Journal of Cleaner Production* 229, pp. 440–453. ISSN: 0959-6526. DOI: https://doi.org/10.1016/j.jclepro.2019.05.019. URL: https://www.sciencedirect.com/science/article/pii/S0959652619315355.

Saunders, Mark et al. (Mar. 2019). ""Research Methods for Business Students" Chapter 4: Understanding research philosophy and approaches to theory development". In: pp. 128–171.

Schnorf, Vivienne et al. (2021). "Biomass transport for energy: Cost, energy and CO2 performance of forest wood and manure transport chains in Switzerland". In: *Journal* *of Cleaner Production* 293, p. 125971. ISSN: 0959-6526. DOI: https://doi.org/10.1016/j.jclepro.2021.125971. URL: https://www.sciencedirect.com/science/article/pii/S0959652621001918.

Simchi-Levi, David and Philip Kaminsky abd Edith Simchi-Levi (Mar. 2011). "Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies". In: *Journal of Business Logistics* 22. DOI: 10.1002/j.2158-1592.2001.tb00165.x.

Statistik, Danmarks (n.d.). *Danmarks forbrug af biomasse til energi holder historisk højt niveau.* Online; accessed 17th of January 2024. URL: https://www.dst.dk/da/Statistik/nyheder-analyser-publ/bagtal/2023/2023-08-23-Danmarks-forbrug-af-biomasse.

Svanberg, Martin (2016). "Improving physical flows in biomass-to-energy supply chain by means of pre-treatment technology and coordination". In: *PhD paper, Chalmers University of Technology.*

UNECE (2022). *Waste Management towards a more Circular Economy.* URL: https://unece.org/sites/default/files/2022-02/WASTE_EN.pdf.

United Nations (2020). *Enablers And Barriers to Circular Economy.* Online; accessed 2nd of Novemeber October 2023. URL: https://circulareconomy.europa.eu/platform/sites/default/files/r2pi_-_enablers_and_barriers_to_a_circular_economy_1.pdf.

Urbinati, Andrea, Simone Franzò, and Davide Chiaroni (2021). "Enablers and Barriers for Circular Business Models: an empirical analysis in the Italian automotive industry". In: *Sustainable Production and Consumption* 27, pp. 551–566. ISSN: 2352-5509. DOI: https://doi.org/10.1016/j.spc.2021.01.022. URL: https://www.sciencedirect.com/science/article/pii/S2352550921000221.

Vanhuyse, Fedra (2023). "The Urban Circularity assessment framework (UCAF): A Framework for Planning, Monitorin, Evaluation, and Learning from CE transition in Cities". In: *Circular Economy and Sustainability.* DOI: https://doi.org/10.1007/s43615-023-00314-w.

Vural, Ceren Altuntas and Arni Halldorsson (2023). *CIRCLOG: Facilitating continuous resource flows through circular logistics services.* Online; accessed 7th October 2023. URL: https://research.chalmers.se/en/project/11251.

Walzberg, Julien et al. (2021). "Do We Need a New Sustainability Assessment Method for the Circular Economy? A Critical Literature Review". In: *Frontiers in Sustainability* 1. ISSN: 2673-4524. DOI: 10.3389/frsus.2020.620047. URL: https://www.frontiersin.org/articles/10.3389/frsus.2020.620047.

Wu, Zhaohui and Mark Pagell (2011). "Balancing priorities: Decision-making in sustainable supply chain management". In: *Journal of Operations Management* 29.6, pp. 577–590. ISSN: 0272-6963. DOI: https://doi.org/10.1016/j.jom.2010.10.001. URL: https://www.sciencedirect.com/science/article/pii/S0272696310000847.

Yadav, Vinay Surendra and Abhijit Majumdar (2023). "Mitigating the barriers of industrial symbiosis for waste management: An integrated decision-making framework for the textile and clothing industry". In: *Waste Management Research*, p. 0734242X231197367. DOI: 10.1177/0734242X231197367. URL: https://doi.org/10.1177/0734242X231197367.

Yin, Robert K. (1999). "Enhancing the quality of case studies in health services research". In.

Zhang, Abraham et al. (2023). "Circular supply chain management: a bibliometric analysis-based literature review". In: *The International Journal of Logistics Management* 34.3, pp. 345–350. DOI: 10.1108/IJLM-04-2022-0199.

Zhurka, Marinela et al. (2020). "Biogas Production from Sunflower Head and Stalk Residues: Effect of Alkaline Pretreatment". In: *Molecules* 25.1. ISSN: 1420-3049. DOI: 10.3390/molecules25010164. URL: https://www.mdpi.com/1420-3049/25/1/164.

Appendix A

Appendix

A.1 CE Definitions

Table 2. Coding framework (obtained via the iterative coding process).

Core principles		Aims	
4R framework [I]: Explicit reference to the 4R framework/all 4R dimensions (reduce, reuse, recycle, recover)?	**Reduce** [D]: Discussion around refusing, rethinking, redesigning (including prolonging the lifespan of products), minimization, reduction, prevention of resource use and/or preserving of natural capital?	**Sustainable development** [D]: Explicit reference to sustainability and/or sustainable development?	**Environmental quality** [D]: Discussion on how CE aims to maintain, protect and/or restore the environment and/or resource efficiency/enable the transition towards a low carbon economy?
	Reuse [D]: Discussion around reusing (excluding waste), closing the loop, cycling, repairing and/or refurbishing of resources?		**Economic prosperity** [D]: Discussion on how CE aims to maintain, protect, transform and/or strengthen the economy?
	Recycle [D]: Discussion around remanufacturing, recycling, closing the loop, cycling and/or reuse of waste?		**Social equity** [D]: Discussion on how CE aims to protect, transform, strengthen and/or develop the society, human well-being and/or jobs?
	Recover [I]: Discussion around incineration of materials with energy recovery?		**Future generations (time dimension)** [D]: Discussion of future generations and/or the long-term perspective of CE?
Waste hierarchy [D]: Indication of an order or ranking of the various Rs mentioned, e.g. via words such as "first", "alternatively" or "least desirable"?			
Systems perspective [D]: Explicit discussion around CE as a system?	**Micro-systems perspective** [I]: Discussion around product level changes, firms and/or consumers and their preferences?		
	Meso-systems perspective [I]: Discussion around CE at the regional level and/or eco-industrial parks?		
	Macro-systems perspective [I]: Discussion around CE at the global and/or national level and/or the overall industry structure?		
Enabler			
Business models [D]: Explicit mentioning of business models (including specific type of business model such as product-as-a-service)?			

A.2 Four dimension of CEBM

Table 1 Business model dimensions used in the analysis

Major dimensions	*Subcategories*
Value proposition	Products
	Services
Value delivery	Target customers
	Value delivery processes
Value creation	Partners and stakeholders
	Value creation processes
Value capture	Revenues
	Costs

Figure A.2: (Lüdeke-Freund, Gold, and Bocken 2018)

A.3 CSC Archetypes

Table 6 CSC archetypal characteristics

No	CSC archetypal characteristics	Descriptions	Author contribution
1	R-Imperatives	A CSC systematically implements a waste hierarchy and circular retention strategies. These can be distinguished according to three loops: • short loops: refuse, reduce, reuse, repair • medium long loops: refurbish, remanufacture, repurpose • long loops: recycle, recover, re-mine	Ghisellini, Cialani, Ulgiati [47], Genovese et al. [63], Kirchherr, Reike, Hekkert [10], Nasir et al. [64], Angelis, Howard, Miemczyk [17], Batista et al. [2], Mangla et al. [66], Mishra, Hopkinson, Tidridge [67], Reike, Vermeulen, Witjes [13], Yang et al. [69], Farooque et al. [3], Bauwens, Hekkert, Kirchherr [82], Hussain, Malik [15], Vegter, van Hillegersberg, Olthaar [71]
2	Restorative and Regenerative Cycles	Within a CSC, resources are recovered through different cycles and circular flows. A key differentiation is made between • restorative cycles for technical products (not bio-organic materials) and • regenerative cycles for biological products (bio-organic nature) Another differentiation can be made between • closed-loop flows (=reverse-directed recovery flows) and • open-loop flows (=cascading forward-directed flows)	Ellen MacArthur Foundation [83], Ellen MacArthur Foundation [8], Geissdoerfer et al. [9], Masi, Day, Godsell [16], Angelis, Howard, Miemczyk [17], Batista et al. [2], Geissdoerfer et al. [18], Howard, Hopkinson, Miemczyk [84], Mangla et al. [66], Farooque et al. [3], González-Sánchez et al. [7], Hussain, Malik [15], Jia et al. [70], Morseletto [85], Vegter, van Hillegersberg, Olthaar [72], Zhang et al. [86]
3	Sustainability Framework	CSCs have a close but sometimes contested relationship to sustainability and sustainable development. The CE can at least be understood as a tool for sustainable development. Supply chains adopting CE principles could contribute to all three dimensions of sustainability such as • economic wins (e.g., reduced raw material and energy costs) • environmental wins (e.g., reduced waste and emissions) • social wins (e.g., new employment opportunities)	D'Amato et al. [87], Geissdoerfer et al. [9], Masi, Day, Godsell [16], Murray, Skene, Haynes [11], Angelis, Howard, Miemczyk [17], Batista et al. [2], Geissdoerfer et al. [18], Korhonen et al. [52], Korhonen, Honkasalo, Seppälä [88], Vlajic, Mijailovic, Bogdanova [68], Farooque et al. [3], Schroeder, Anggraeni, Weber [89], Suárez-Eiroa et al. [54], Hussain, Malik [15], Vegter, van Hillegersberg, Olthaar [71], LENGYEL

Figure A.3: (Montag 2022)

Table 6 (continued)

No	CSC archetypal characteristics	Descriptions	Author contribution
4	Value Focus	In CSCs, value has the highest priority. All core supply chain activities aim at proposing, creating, delivering, and capturing value, following a value logic framework: • value proposition (e.g., long-lasting products, products as service) • value creation and delivery (e.g., implementation of R-processes, waste elimination, use of renewables) • value capture (e.g., reduced economic, environmental, and social costs)	Richardson [90], Ellen MacArthur Foundation [83], Ellen MacArthur Foundation [8], Genovese et al. [63], Masi, Day, Godsell [16], Murray, Skene, Haynes [11], Nasir et al. [64], Nußholz [91], Angelis, Howard, Miemczyk [17], Batista et al. [2], Geissdoerfer et al. [18], Manninen et al. [92], Mishra, Hopkinson, Tidridge [67], Vlajic, Mijailovic, Bogdanova [68], Yang et al. [69], Farooque et al. [3], Suárez-Eiroa et al. [54], Morseletto [93], Vegter, van Hillegersberg, Olthaar [71]
5	Holistic System-Thinking	To enable the transition toward a CSC, holistic systems-thinking that incorporates every stage of the supply chain — from production to consumption, from every input to every output — is necessary. Only if the complex links and various interconnections between all actors of the supply chain as well as all resulting consequences of every supply chain action are understood and considered can a fully CSC be realized	Ellen MacArthur Foundation [8], Angelis, Howard, Miemczyk [17], Batista et al. [2], Howard, Hopkinson, Miemczyk [84], Geissdoerfer et al. [18], Kalmykova, Sadagopan, Rosado [94], Leising, Quist, Bocken [65], Mishra, Hopkinson, Tidridge [67], Vlajic, Mijailovic, Bogdanova [68], Farooque et al. [3], Suárez-Eiroa et al. [54], González-Sánchez et al. [7], Hussain, Malik [15], Jia et al. [70], Vegter, van Hillegersberg, Olthaar [71]
6	Paradigm Shift	The transition from a linear supply chain to a CSC can be characterized as a major paradigm shift. The shift from linear to circular requires a holistic transformation of economic, environmental, and corporate activities at all stages of the supply chain. To fully adopt CE principles, a paradigmatic, systemic, and thus high level of change in production as well as in consumption is needed	Loiseau et al. [95], Masi, Day, Godsell [16], Geissdoerfer et al. [9], Geissdoerfer et al. [18], Govindan, Hasanagic [96], Korhonen et al. [52], Vlajic, Mijailovic, Bogdanova [68], Farooque et al. [3], Hofmann [57], Hussain, Malik [15]

Figure A.4: (Montag 2022)

A.4 All CEBM

	BM Dimensions	CEBM design options derived from reviewing 26 CEBMs (the number of CEBMs that mention the respective design option is indicated in parentheses)[a]										
Value proposition	Products	Repaired, refurbished, remanufactured, or recycled products (3)	Reusable or recyclable products (3)	Products based on recycled waste (3)	Long-lasting products (3)	Used products, components, materials, or waste as production inputs (5)	Reusable or recyclable production inputs (1)					n.s. (9)[b]
	Services	Facilitating collaboration (3)	Take-back management (4)	Customer education (3)	Waste handling, processing (3)	Product-/service-based functions (2)	Maintenance, repair, control (4)	Product-/service-based results (1)	Upgrading (2)	Auxiliary services (2)		n.s. (11)
Value delivery	Target customers	Quality-conscious customers (1)	Cost-conscious customers (1)	Green customers (2)	B2B customers (4)	B2C suppliers (1)	B2B suppliers (2)	C2C suppliers (1)				n.s. (17)
	Value delivery processes	Connecting suppliers and customers (5)	Providing access to a product's functionality (2)	Providing (product-based) services and results (2)	Providing used products, components, materials, or waste (4)	Taking back used products, components, materials, or waste (4)	Sharing products, components, materials, or waste (2)					n.s. (11)
Value creation	Partners and stakeholders	Suppliers (1)	Manufacturers (5)	Retailers (2)	Service providers (2)	Public institutions (2)	Collectors of products, components, materials, waste (2)	Others (e.g., researchers) (1)				n.s. (17)
	Value creation processes	Maintaining or repairing products, components (6)	Refurbishing or remanufacturin g products, components (5)	Recycling of products, components, materials, waste (3)	Upgrading or upcycling of products, components, materials, waste (3)	Reselling products, components, materials, waste (3)	Taking back or recapturing products, components, materials, waste (7)	Winning back base materials (4)	Using used products, components, materials, waste as input (8)	Matching over- and under-capacities (4)	Designing products, components, materials (4)	n.s. (1)
Value capture	Revenues	Additional product revenues (3)	Payments per unit of service (5)	Payments for functions or results (1)	Price premiums (6)							n.s. (12)
	Costs	Labor (1)	Repair, maintenance, control (3)	Waste handling, processing (7)	Manufacturing (1)	Resource inputs (13)	Transportation, logistics (1)	Supply risks (1)				n.s. (11)

Figure 3 Morphological box of CEBM design options. *Notes:* [a] CEBMs can be assigned to multiple options per business model dimension; totals per dimension do not always add up to 26. [b] The abbreviation "n.s." means "not specified" (the number of CEBMs described in appendix II in the supporting information on the Web that do not specify options for the respective business model dimension). BM = business model; CEBMs = circular economy business models.

Figure A.5: (Lüdeke-Freund, Gold, and Bocken 2018)

A.5 Barriers to CE Logistics

Barriers	
Business Models	• Business models focus on selling (non-durable) goods • Transition to new (service-oriented) business models require radical change of mindset
Technologies	• Recycling technologies are technically immature • Data exchange beyond circular supply chains is not yet possible (data security/sovereignty)
Cooperation	• Lock-in effects (existing relations between supplier and customer) and complexity of established value chain networks • Major efforts to integrate the actors along all levels of the value chain
Products	• Products/materials are not designed for recycling (especially mass products with short innovation cycles such as smartphones) • Products and materials are too complex
Knowledge	• The producers' lack of knowledge of their products' materials composition (especially those of components and modules externally purchased) effectively prevents design for recycling
Costs	• Costs for logistics and recycling are high (compared to energy recovery from waste) • Costs for new systems deter the producers from investing
Markets	• Demand for secondary raw materials still too low • Primary material is still cheaper than secondary material • Sustainability plays no/subordinate role in procurement processes

Figure A.6: (Fennemann, Hohaus, and Kopka 2018)

Legal requirements	• Until now, there is no comprehensive legal basis for the Circular Economy; Regulation focusses on separate waste and environmental laws with only few connection to product/business laws
Consumer behavior	• Products serve as status symbols • Common »bargain hunter mentality«

Figure A.7: (Fennemann, Hohaus, and Kopka 2018)

A.6 Drivers to CE Logistics

Barriers	
Business Models	• Business models focus on selling (non-durable) goods • Transition to new (service-oriented) business models require radical change of mindset
Technologies	• Recycling technologies are technically immature • Data exchange beyond circular supply chains is not yet possible (data security/sovereignty)
Cooperation	• Lock-in effects (existing relations between supplier and customer) and complexity of established value chain networks • Major efforts to integrate the actors along all levels of the value chain
Products	• Products/materials are not designed for recycling (especially mass products with short innovation cycles such as smartphones) • Products and materials are too complex
Knowledge	• The producers' lack of knowledge of their products' materials composition (especially those of components and modules externally purchased) effectively prevents design for recycling
Costs	• Costs for logistics and recycling are high (compared to energy recovery from waste) • Costs for new systems deter the producers from investing
Markets	• Demand for secondary raw materials still too low • Primary material is still cheaper than secondary material • Sustainability plays no/subordinate role in procurement processes

Figure A.8: (Fennemann, Hohaus, and Kopka 2018)

A.7 Drivers to CE Logistics

Technology/Trend	Use cases (examples)
Atomization of shipments	• Reverse logistics of valuable material such as in end-of-life electric and electronical equipment Reverse logistics of hazardous waste
Information logistics and data sovereignty	• Use of decentralized systems for the provision of information (even on highly individualized products) relevant for the processes in the circular value chain »material passport«) • Protection of transport documentation and respective data security
New manufacturing technologies	• Use of secondary raw material as a substitute to primary raw material • Integration of secondary raw material producers as raw material supplier in the supply chains
Autonomous systems in Industry 4.0	• Autonomous supply chains make use of raw materials and components from primary and secondary sources on equal terms • Transport planning within supply chain networks is done across actors and functions for an optimal use of transport capacities
Social Networked Industry	• Better human-machine-interaction to improve the work efficiency such as to avoid redundant paths in waste collection • Augmented reality-assisted disassembly of complex products helps raising recovery rates and reducing the risk of injury

Figure A.9: (Fennemann, Hohaus, and Kopka 2018)

A.8 CEBM Barriers and enablers

Table 1
Enablers, barriers, and contextual factors for the design of CBMs.

Category – micro perspective	**Enablers**	**Barriers**
Technical/informational/ technological (product & process-related)	Availability of technical solutions for Rs practices	Low returned products' quality
		High returned products' flow variability
		High products' complexity
		Weak IP regime
	Availability of technical solutions for reverse supply chain	High returned products' weight
		Low returned products' specific value
		Low returned products' quantity
Economic/financial	High price of input resources	High investments costs and the time needed for break-even
	High volatility of input resources' price	
Organizational	Management environmental awareness	
		Low management risk appetite
		Short-middle term management incentive scheme
		High organizational inertia
		High complexity of the organizational hierarchy
Category – meso perspective	**Enablers**	**Barriers**
Supply chain/customer management	Partners availability for reverse supply chain	High numerosity or high geographical dispersion of customers and/or supply chain partners
	Geographical proximity of supply chain partners/customers	High required customization
		High speed of change of market requests
Category - macro perspective	**Contextual factors**	
Political	Presence of laws & regulations	
	Presence of economic incentives	
Environmental	Resources scarcity	

Figure A.10: (Urbinati, Franzò, and Chiaroni 2021)

A.9 Biogas LCA

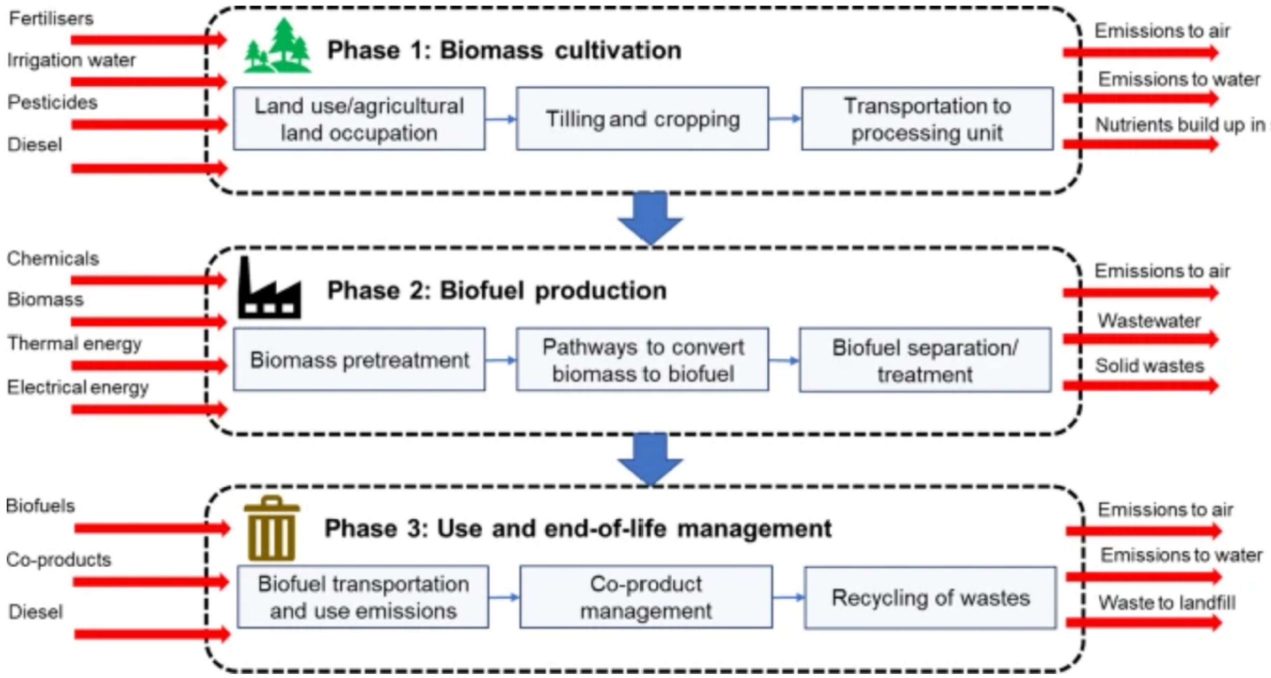

Figure A.11: (Neha Mehta et al. 2021)

A.10 Options and Key Variables

Table 1
Operation types, with possible options and key model variables

Operation type	Options	Key variables	
Biomass production	• Forestry residues • Energy crops • Felling • Industrial rest stream • Chipping • Baling	• Harvesting window[a] • Production costs (location dependent)	
Pre-treatment	• Storage • Chipping • Drying • Pelletising	• Equipment capacity • Capital and O&M • Energy consumption (power, fuel, heat)	• Load factor[b] • Dry matter loss • Moisture loss
Transport	• Truck • Train • Ship	• Transport distance • Speed • Capacity • Product weight • Product volume	• Capital and O&M • Fuel consumption • Load factor • Transfer time and costs
Energy conversion	• Power • Methanol • Pyrolysis oil	• Conversion efficiency • Capital and O&M • Load factor	

[a]Section of the year in which the biomass comes available, e.g. October–March. A window could also apply to apparatus that is only available during part of the year.
[b]Or: operation time, part of the time that a facility or transport means is available within its operation window.

Figure A.12: (Hamelinck, Suurs, and Faaij 2005)

A.11 Interview 1 - The company

The company er unik i deres forretningsmodel. I opkøbs processen viste det sig at ingen firmaer globalt laver det samme. Der er flere niche firmaer som fokusere på nicher indnefor hver sektor. Reconomy som har opkøbt firmaet består af en række firmaer hvor et af dem står for database systemer og resten står for indsamling. Men ikke omdistribuering mellem industrielle aktører.

Firmaet arbejder med 6 sektorer. Biogas, bio brændsel , alternative fuel, textiles, agro, farligt affald. Det er endepunktet i produktionen der afgør sektoren. Firmaet arbejder kun med industrielle produkter og det er endeproduktet der afgør sektoren.

I de fleste af sektorerene arbejder firmaet ud fra transport korridorer. Firmaet har en stor aftale med Deutcher Bahn. Dette er en god aftale med betyder også bl.a. at de har en række låste korridorer, med mindre felsibilitet. Nogle af deres produkt strømme kan de bevæge frit, man mange af deres produkt kategorier kræver det der kaldes notifikationer. Notifikationer er en beskrivelse af de tilladelser eller alternativer af veje for vejtransport som firmaet har for at transportere produktet. At transportere produkter fra andre kontinenter med skib er nyt.

Man har brug for certificeringer for at køre affald. Der måles på kuldioxid udledning på alle transport metoder og ruter. De bliver målt på bæredygtig transport da de transporterer affald og der generelt er en stigende interesse i grøn transport og da det i stigende grad bliver krav fra firmaer og nok på sigt bliver lovgivning.

The company står overfor mange udfordringer. Supply chain forstyrrelser under covid perioden påvirkede selvfølgleig også dem. Globale projekter blev sat på pause. Men også separat fra covid påvirkes projekter og potentielle projekter når logistik løsningerne ikke kan gå op eller tilpasses til de unikke produkt specifikationer. The company har igennem en længere periode prøve at vinde en konkurrencemæssig fordel for uudnyttet biomasse som er bi-produkt i diverse produktioner og distribuere det til biogas anlæg. Desværre er der mange ting der ikke kan lade sig gøre pga. utilstrækkelige logistik løsninger. Nogle gange er produkterne for billige til at det kan betale sig at flytte rundt. Som alle andre firmaer der er afhængige af en robuste supply chains skal undersøger de muligheder for at styrke og forbedre leveringskæder. Samtidigt har de en stigende fokus på at skabe logisitk løsninger der er specielt tilpassede til de cirkulære løsninger for produkter og affald de tilbyder. Nogle måder de har gjort dette på er at skabe general robusthed og styrke i kæderne, indføre backhalls hvor de udnytter tom retur transport for deres produkter og på den måde sænker omkostninger og øger resource udnyttelsen. De er blevet medejere af transport ruter som gør at de har større indflydelse, fleksibilitet og kontrol over leveringskæderne.

Ift. specifikke forbedringer af transport ser de på muligheder for alternative brændstoffer for deres vej transport, de gennemfører store og lnagsigtede aftaler med kunder og operatører og udvider på den måde deres business scope og som sagt øger deres netværks kontrol som har å stor værdi i disse tider. Generelt vil man have langt større kontrol over transportkæden for også i sidste ende at kunne påvirke omkostningsdifferencen og gøre det billigere at transportere produkter og kunne udvide scopet i hvilke produkter og affald der transporteres. Der skal først laves en evaluering af det potentielle produkts værdi nu og hvad man estimere af værdi det kan få i et nyt produktionssammenhænge. Derefter kan man estimere villigheden til at betale for transporten. Hvis produktet altså har en høj potentiel værdi senere i værdikæden vil villigheden til at betale være større. Lige nu er det 30-40% af projekterne der ikke kan lade sig gøre fordi transporten er for dyr eller for utilpasset, eller begge dele. Alt i business casen can lade sig gøre men logistikken og det praktiske ikke. Det er fx. her man ser på hvordan backhalls kan udnyttes i returflowet. Her er man nødt til at se på tværs af industrier for at kunne flytte restprodukter og affald mellem industrier. Der er mange brikker der skal falde på plads før det lader sig gøre. Linket skal kunne skabes kemisk og produktionsmæssigt skal det være muligt at implementere de potentialle restprodukt i produktion. Dernæst skal det kunne lade sig gøre lovgivningsmæssigt, og til slut skal det være økonomisk og logistisk ansvarligt. Det er her problmet ofte opstår da økonomi og logisitk ofte er afhængige eller påvirker hinanden.

Firmaet oplever stigende vigtighed af gode og robuste logistik løsninger samt logistik løsninger der er behovstilpassede og på nogle punkter er det en udfrodring at generalisere logistik løsningerne fordi produkterne kan have så store variationer og produkt karakterisitkker der kan stille specifikke krav. De estimere at der i 2024 skal flyttes 3000 tons produkt og affald pr dag. Dette betyder stigende vigtighed af logistik der også kan håndtere store voluminer og i konsistent flow. Mange kunder og potentielle kunder har stor interesse og vil gerne udvide og skabe kontakt, men selvfølgelig kun så længe der er en forretningspotentiale og at økonomien er forsvarlig. Det er svært at være idealist uden at der også er penge i det og at det kan udgøre en forretning. Lovgivningen skal også følge med, men der bliver også i stigende grad skubbet til denne som muliggør flere og flere løsninger. Samtidigt udvikler teknologien sig også som gør at mange løsninger kan forbedres og optimeres, og samtidigt give større kontrol over fx retur flow af produkter. Dette er fx. i form af implementering af Blockchain teknologi. Em ulempe ved dette er dog at de kræver ekstreme mængder af energi og serverplads hvilket kan være en negativ effekt miljømæssigt, men give mange forretningsmæssige fordele da det også bidrager til større kontrol i supply chainen. Som led i dette udvikles der også på produktdatabaser hvor bl.a. Vana, som er et dansk firma, udvikler store produkt data paser for alle slags produkter hvor indhold og kompositioner bliver kortlagt. Dette er et kæmpe skridt fremad for at øge cirkularitet i Danmark, da man på den måde kan sikre sig og har langt større garanti og overblik over produkter og hvordan de kan eller ikke kan indgå i nye forretningssammenhæng. Dette kan også medføre at sammenligning af potentielle returprodukter bliver langt bedre og at man kan tage bedre beslutninger ift. inpout i produkter.

Ift logistikken specifikt er den daglige operations fokus at få flyttet produkter fra A til B så effkeitvt som muligt. På et dagligt basis arbejdes der derfor med TFS tilladelser, notifikationer, lovgivning og der er i mange af deres transporter på ingen måde plads til at freestyle. De er bundet af korridorer for mange produkter so giver dem en lille håndfuld alternativer at transportere specifikke produkter på specifikke produkter. Det giver dem nogen fleksibilitet og sikkerhed mod det uvisse men sætter også store begrænsninger. Notifikationerne er for at kunne have en tilladt plan A, B, C og D for at kunne imødekomme overraskelser effektivt. Nogle gange sker det uventede alligevel for plan D, hvilket hurtigt kan koste mange tusinde euros. Det betyder at der på tværs af projekter hurtigt kan forsvinde mange penge blot på at kunne få tilladelse til at flytte produkter på en nye rute. Dette gælder oftest farligt affald eller andre produkter og affald med større risiko. De kan altså få lagt flere notikationer ind på ruter men det koster.

Firmaet overvejer muligheder for at indføre hubs og have større lager holdning for deres generelle produkter med store voluminer. De har nogle eksterne lagre rundt omkring men ellers er det ikke noget de har eksperimenteret meget med.

En anden begrænsing med transporten er at de ikke kan skifte fra jernbane til lastbil undervejs på ruten. Jernbaner er en effektiv og billig måde at transportere store voluminer men har også mange begrænsninger fx på tværs af grænser. Togtransport er også det mest miljørigtige og mange store industrier får point for grøn transport, men nogle gange er der også begrænsinger på hvilke produkter som kan tillades at flytte på togbane. Fx. kan farlige produkter udelukkes at transporteres på andet end lastbil. Generelt skaber farligt affald store restriktioner både for transport og lagring.

For firmaet er udvikling af logistik løsninger nu på lige fod af vigtigheden for udvikling af deres produkter og forretningsforbindelser. De arbejder konsekvent med at finde omkostningsoptimale logistik løsninger hvor de bl.a. prøver at få så meget produkt på jernbane som muligt. En anden ting de prøver at optimere er mængden af emballage og generelt ressourcer hvor der hurtigt kan opstå et stort spild. I tekstil industrien opleves stigende mængde af returprodukter som medfører et enormt transport spild. Dette har bl.a. medført at fri fragt i stigende grad bliver erstattet af en omkostning for at øge barrieren for at tøj sendes retur.

The company oplever også at det stigende EPR fokus skaber nye rammer og muligheder for udviklingen af cirkulære forretningsmodeller. Firmaer skal i stigende grad rapportere på produktspecifikationer og produkt komposition, i ex. embellage og produkter generelt. Dette hængder sammen med Vanas forretning som nævnt tidligere. Lovgivning hvor man er med til at betale for samlet mængde man forbruger påvirker i stigende grad. Alle europæiske lande skal indføre EPR systemer hvor lovgivningen nationalt dikterer hvor omfattende det skal være. Der er meget data og meget data er tilgængeligt men håndteringen af al dataen og systematiseringen og tilgængeligheden af det varierer meget fra land til land. Men generelt vil man i alle lande i stigende grad kunne muliggøre sammenligningen af produkter for at øge muligheden for cirkularitet. I The company arbejder man også på at implementere EPR sytemer. Dette i samarbejde med det omtale firma Vana, som skal stå for udviklingen, udbredelse og implementering af EPR systemer i Danmark. Her spiller big data en vigtig rolle.

Effektive og højkvalitetsløsninger ift både EPR og data indsmaling samt effkeitve logistik og transport løsninger kræver et ekstremt stærkt samarbejde på tværs af netværk. Dette er nødvendigt for effketivitet og kvaliteti flere henseender. Mes stigende fokus på CO2 udledning af transport hvor udledningen måles fordelt på tons der transporteres. For at sænke dette vil man gerne udnytte retursystemer i højere grad. Dette betyder at transport omkostninger reduceres og resourcer udnyttes bedre. En vigtig mulgørelse af dette betyder at man skal forstå ikke blot sin egen supply chain, men hele sit netværk og også se på tværs af netværk horisontalt for at kunne optimere fx. transport flows. Man skal undersøge og udvikle yderligere på muligheder for jernbane transport, da både monetære og miljø mæssige omkostninger er meget lavere og transporten på alle måder mere effektivt. Voluminerne er større og billigere, omlastning er ikke mulig og udledningen er det kvarte af hvad den ville være på lastbil. Muligørelsen af bedre jernbanetransport er også afhængig af internationale jernbane netværk og togvogns kompatibiliteten på tværs af lande grænser. Last mile og first mile foregår i størstedelen af tilfælde på lastbil, så der er trods alt en grad af omlastningen. Firstog last mile håndteres oftest af The companys egne løsninger og operatører. De prøver at optimere så first og last mile er så lille som muligt og altså minimere afstanden der transporteres på lastbil. I Sverige fx er der en stor begrænsing som har stoppet eller pauset og udfordret mange af deres netværk.

Ideelt havde The company i Norden implementeret flere hub løsninger rundt omkring for de produkter og voluminer hvor det ville være en fordel at have. At have hubs ville skabe mindre afhængighed, mere fleksibilitet, og især for store voluminer med stort flow havde det være en stor fordel. Som tidligere skrevet ville hubs give en langt større kontrol i proces og logistik og de ville være mere modstandsdygtige overfor disruptioner. Det ville forbedre kunde og service level og forbedre økonomien da der ville være mere flexibilitet og sikkerhed i leveringen. Men muligheden for lagring er dog begrænset til produkttyper hvor det kunne tillades. Formålet er altså at optimere og stabilisere netværket. Miljøgodkendelserne A12 og A13 er virtuelle hubs.

Ift priser og omkostninger. Noget handles negativt. Dvs. at differencen mellem indkøb og udgift er negativt. Prisen er baseret både på værdien af produktet lige nu men også værdien af det produktet kan være med til at skabe, dvs. værdi potentialet senere i værdikæden. Det er krævende at finde balancer og potentialer i markedet der kan skabe værdi. Det er The companys ansvar at komme ud til kunder og undersøge og dokumentere potentialet og værdien der potentielt kan skabes. Det er deres ansvar at finde løsninger og kunder der er villige til at købe produktet.

The company har igennem de sidste 17-18 år formået at skabe et ekstremt stærkt navn inden for cirkularitet både nationalt og internationalt. Dette har medført at de gradvis med succes har kunnet ekspandere deres forretning og udvikle forretningsmodellen. Firmaer er positive når The company kontakter dem. Opkøbet fra Reconomy var et sort klap på skulderen og en anerkendelse af at de er ekstremt dygtige i det de gør, også på et globalt plan.

A.12 Interview 2 - The company

Most of the interview was about textiles which ended up not being relevant for the thesis.

Biogas er et kompliceret sektor pga a produkt variationen. I mange af deres andre sektorer er produktet mere strømlinet, ensartet, og variation i produkter sætter ikke som sådan nogle krav til logistik eller håndtering. Biogas er en bred sektor i den forstand at man kan have fast og flydende i forskellige typer. Og det er biogassen der giver dem de største udfordringer for logistikken. Der er utrolig mange variable ift. substrater til biogas. Den absolut største udfordring er den type substrat som har høje smeltepunkter og derfor kræver opvarmning enten under transport eller lige inden produktion. I denne process kommer der en masse andre faktorer i: ekstra omkostninger, mere energi udledning, og compliance, fx. Transportere man sspecifikke substrater skal man følge en række spcifikke regler. Specielt på tværs af grænser er der mange compliance regler. Er produktet defineret som farligt affald, træder yderligere regler i kraft og der stilles ekstra krav. Man har da langt mere begrænsede muligheder for transport. Er affaldet defineret som farligt affald eller gå i forrådnelse, kræver transporten notifikationer, som giver et begrænset omfang af muligheder og ruter at vælge imellem.

A.13 Interview 3 - The company

Først gennemgåes hvilke substrater der arbejdes med. Substraterne har en direkte effekt på hvilke logisitk løsninger der er muligt at arbejde med. Og substraterne til biogas har stor variation og logistik løsning skal derfor tilpasses substratet specifikt.

Et biogasanlæg kan tage mange forskellige typer af substrater. Men soecielt en type af substrat giver dem en stor udfordring, og det er den type der har højt smeltepunkt og derfor vil blive fast under transport. At løse transport og logistik håndteringsproblemet af dette ville give dem en konkurrencemæssig fordel.

Oftest henter de danske anlæg substrater fra et nærliggende landbrud. Dette er oftest gylle og det får de i meget store mængder. Derudover henter de mange andre typer af substrater fra landbruget. Korn, halm rester, råddent affaldt. De kan også hente organiske rester fra produktionsprocesser. Anlæggene kan omsætte stort set alt der er organisk og det åbner op for et meget stort felt og potentiale af produkter. Produktionen af biogas producerer derudover noget restprodukt som kan bruges som en organisk gødning tilbage i landbruget.

Selve biogas produktionen fungere i princippet ligesom en ko mave. En række organsiej ting kommer ind, kulkhydrater fedt osv, i organiskje materialer. Det varmes op til ca 50-60 grader, fjerner ilt. Resultatet er gas; methan og kuldioxid. Det afgassede biomnasse kan anvendes som gødning tilbage i landbruget. Landmændende er ofte medejere af anlægget. De sælgewr masse tjener på det, producerer gas, tjener på dette og får igen gødning til at bibeholde deres landbrug. Disse basale substrater kommer fra lokale kilder.

Andre produkter har dog langt større biogas potentiale end disse landbrugs produkter. Dette er oftest produkter med meget højt fedt indhold hvor potentialet til at producere gas er langt højere. Det kan være organsiek syre med højt fedt indhold. Nogle produkter er svære at transportere og de som er defineret som farlige, og kræver derfor ekstra compliance. Disse masser er enten faste eller flydende. Eksempler kan være nogle produkter fra Afrika, dette er nogle faste biomasser. Det biomasse der giver de størte udfordringer men som også har noget af det største potentiale, er de biomasser der størkner ved rumtemperatur. Der er fx. potentiale fra en produktion i Ukraine. Der er en masse restprodukter fra en olie-produktion. Under transporten stivner de og skal derfor varmes op inden produktionen af biogas. Denne type af biomasse skaber store udfordringer praktisk og logistisk og er endnu ikke blevet løst på en måde som skaber en konkurrence dygtig business case.

Der er flere måder at transportere biomasser. For faste masser kan de transporteres i tankbiler. Flydende masser kan transporteres i palletanke (IBC tanke). De er nemme at stable og kan let passes i en P-trailer. Desuden kan det også transporteres i opvarmede tanke men dette er meget dyrt. Det økonomiske aspect er vigtigt at tage højde for da det variere meget. Tankbilæerne er mega dyre og teknologien og kvaliteten er sjældent god og produktet størkner oftest alligevel hvis tank bilen ikke er god nok. Der kan sættet olie i varmerørene eller udstødmningsrør kan føres i varmetankenen og holde produktet varm. Røgen kan da cirkuleres. På denne måde kan de lykkedes at holde produktet flydende under hele transporten. Desværre er der få tankbiler der fungerer rigtig godt og de som gør er meget dyre. Da produktet er billigt begrænser det mulighederne meget. Denne type af opvarmede tankbiler kan kun svare sig hvis de er en del af et returflow da dette betyder at prisen bliver mindre. Der skal derfor fastsættes et returflow for at det giver mening at anvende sig af dette alternativ. En tanktransport vil altid være dyrere end fx en p-trailer hvor IBC tankene kan transporteres. Opfykdte P-trailere er den bedst økonomiske løsning. Problemet her er da at produktet vil størkne. Produktet pumpes ind i tanken mens det er varmt, og det størkner under transporten. Når det lander i Danmark har man et rigtig stort energi potentiale men man kan ikke få produktet ud p en ordentligt økonmisk forsvarlig måde.

Indtilvidere løser firmaet problemet med opvarmning på følgende måde. De Ukrainske transportere har ikke gode nok opvarmede tankbiler og selvom der fx. fra Ukraine loves at produktet skal holdes varmt gør det det ikke. Kvaliteten af tankenen er ikke god nok og produktet størkner under den 6 dages lange transport fra Ukraine til Danmark. I pilot forsøget med trnaporten fra Uktraine har man forsøgt at tilsætte damp i tankbilerne åpå stationer undervejs. Det fungerede ikke. Det er også testet at man skyder damp ind i tanken ved ankomst. Det var effektivt men tager lang tid. Det er ikke en standard ydelse og vil derfor koste ekstra tid og penge. Denne løsning er da både dyr for transport og i opvarmning.

Derfor udvikledes der pilotforsøg med transport af produktet på P-trailere. Produktet fyldes på IBC tanke og lastes på P-trailr. På denne måde kan de lagres og det er ikke noget problem, men opvarmningsproblemet er der stadi gog dette skal ske umiddelbart før det fyldes på anlæggene. Der er set eksempler på opvarmningsstaioner, hvor IBC tankene sættes i et opvarmet rum på 45-50 grader, og derefter smelter produktet og indholdet kan tappes til anlægges. IBC tankene er genbruglige og skal derfor rengøres efter brug. Dette betyder en ekstra omkostning og tidskrævende proces. En udfordring ved flexitanke er at materialet på tankene ikke er mega stærkt og at der derfor kan være produktspild. Dette gør også at nogle transportøre ikke vil have med dem at gøre. Da flexitankene er enganstanke gør det dog at aflastningen hvis produktet er flydende kan tanken blot destrueres og tømmes. Herefter opstår problemet med at skilde sig af med det igen.

Den tredje løsning de har testet er en løsning med en flexitanke. Det er en stor ballon agtig tanke der kan pumpes produkt i. Her opstår samme problem for opvarmningen. Hvordan skal det ske og hvor skal det ske. Med flexitanke kan man holde det varmt under transport men The company har ikke testet det endnu. De puttes in i et gitter hvor damp anvnedes til at holde det varmt under transporten. Der skal altså tilkøbes et varmenet og det skal være i en container. Flexitankene lægges oven på ledningerne. Men det er ikke rigtig godt afprøvet og testet.Opvamrning kan altså ske under transporten men The company tvivler på at denne type opvamrning er tilstrækkelig, men de ved det ikke. Den anden mulighed er at varme op efter transporten. Til dette har de ikke nogen løsning endnu. En anden udfordring for transporten er at når den ankommer til Danmark skal produktet pumpes ud. I tankene kan der være mange kg tilbage som ikke kan fåes ud. Transportmåden kan gøre at de kan få billige substrater ind men de har ikke på anlægget løsninger endnu på at få alt materialet ud og der er et stort spild. Pga. disse udfordringer er der mange business cases som forkastes pga. for mange praktiske udfordringer og øgede omkostninger. Restproduktet i flexitanken gør også at det er svært at skille sig af med de store tanke, da flexitankene er tilæ engangs brug

Firmaet har set at de kan varmes op i store tanke og derefter kan pumpes til anlægget. Eksemplet er i en biodiesel produktion. Opvarmningen sker separat fra anlægget. Dette kan gøres for både IBC og Flexi.

Der er også set eksempler på at materialet kan fyldes i store 40ft containere hvor der kan installeres luft varmekilder inden i containeren. Det kan også væres i et helt lager hvor varmepumperne kan indstilles og holde varme og fugtighed stabilt. Dette er et eksempel fra en polsk import af træ hvor man ønsker at holde træet fri fra fugt. I princippet kunne det samme gøres for IBC tanker men de eksterne aktører er usikre på om det kan lade sig gøre, og forbeholdet er også om disse IBC kan passe godt i en container. Hvis man kunne stable IBC oven på hinanden i containeren. Et problem er da at der skal være en effektiv og stabil varmekilde. Men anlægget skal kunne se en business case i produktet før de er villige til at investere i varmekilder i et eksternt opvarmningsrum.

Det er derfor frustrerende for firmaet at have et utrolig godt produkt men ingen passende transport og logistik løsninger. IBC tankene bruges globalt, og kan være relativt dyre hvis de er nye. En fordel ved IBC tankene er at de kan bruges som lager, de kan transporteres på P-trailere, og der sker ikke noget med produkterne ved at det står længe. Nye IBC tanke koster 3000 DKR. og kan bruges igen. Brugte IBC tanke er billigere. IBC tankene har derfor relativt stort værdi hvilket betyder at rengøring af tankene er nødvenig for at beholde værdien. Men mange vil ikke have dem beskidte og det kræver igen arbejdskraft og resourcer at gøre dem rent. Da arbejdskraft er dyrt i Danmark kan det ikke svare sig. En udfordring er da - hvor skal de gøres rent og hvordan? I Litauen har de både en sauna til tankene men også en stor vaskehal hvor tankene kan gøres rent. Det er dog endnu et logistisk problem hvis beskidte IBC tanke igen skal sendes rundt i Europa. De skal derfor kunne rengøres i Danmark og indgå i et returflow.

Skal produkterne transporteres på skib pumper man produkterne på isotanke. Det smarte ved dette er at de passer i containere og nemt kan omloades til latbiler fx. Der købes store mængder glycerin fra biodiesel produktion i Uruguay. Dette sejles til Århus, fra skibet losses det til lastbil hvor der køres til Kolding hvor der er en varmestation og varmes op. Herfra varmes det op i ca. 24 timer og loades til tanken. Denne løsning er meget dyr men den fungerer. Hvis prisen på glycerin er høj nok kan der tjenes penge på det. Men prisen på glycerin varierer meget. Men hvis der var en løsning hvor det kunne transporteres i IBC eller flexitanke eller lignende, kunne der transporteres langt større voluminer. Også praktiske omstændigheder gør at ikke alle anlæg er klar til at tage i mod det på isotanke. Nogle vil genre tage imod IBC tanke hvor det kan lagres nemt og længe. Men der skal være resourcer til opvarmning klar. Nogle har eksperimenteret med blot at destruere IBC tankene når produktet er størknet, men dette er også et stort resource spild og tab af værdi i og med at værdien for IBC tankene mistes.

Man har også set på løsninger hvor substratet kan holdes i bevægelse undervejs for at det ikke størkner, men temperaturen er fortsat en langt vigtigere parameter. Man har også testet at

Firmaet koldkur anvender tanke som er kejle formede. De har 3-4 kamre hvor der i bunden er trakter, på denne måde er det lettere at drive tykke produkter ud af tanken. Med disse behøves der ikke tilsættes pumper som fx. med varme tankbiler. Firmaet har testet at anvende dette på kortere distancer og løsningen er meget dyr og kan derfor ikke svare sig på lange distancer.

Motivationen for at løse problemet er stor, da The company ser på forretningsideer globalt. Lokal transport er nemmere og mere effektivt og nogle gange kan det føres direkte til anlægget.

Problemet kan da opstilles at der er vej transport mulig og søfart. Tog er også en mulighed men er ikke testet endnu. På skibe skal det være beholder der passes i container. Her kan der enten anvendes ISO tanke eller flexitanke, og måske også mulighedes for IBC tanke der stables. På vejtransport har man de samme muligheder, hvor det kan lastes på P-trailere. Opvarmningen skal ske enten undervejs konstant eller tæt på anlægget. Løsningen for ISOtankene er lige nu på varmestationen i Kolding, den fungerer men er dyr. Damp tilføjes. ISO tankene er en relativt kendt løsning men de vil gerne afprøve de andre metoder da det kunne sænke prisen.

Business casen forelsås at være transport fra Ukraine til Danmark, hvor produktet er restprodukt fra olieproduktion. Det kan også være transport fra Uruguay, men hvor løsningen skal være en anden end ISO tanke da det er for dyrt.

Priserne for biomasse er højest i hhv Danmark, Sverige og Tyskland i den rækkefølge, da det er sat efter prisen på biogas. Men prisen variere en del.

Forretningmæssigt skal opvarmningen ske så tæt som muligt på anlægget. Man har testet at varme det op i Tyskland da prisen for opvarmningen var betydeligt lavere. Det blev gjort i Flensborg. Derefter testede man i Polen, da priserne der er endnu billigere. Men i begge tilfælde fungerer det ikke. Produktet skal derfor ske så tæt på unload stedet, dvs. anlægget som muligt. Det kan være der er potentiale for at varme det op nordligt i Tyskland, og derefter transporteres til biogas anlæg lige over grænsen.

A.14 Interview 4 - The company

Flexitanks er at foretrække fordi deres producenter er vant til at bruge dem. Firmaet vil dog helst ikke bruge dem da det ikke har erfaring med at håndtere det. Da Firmaet selv har ansvar for deres logisitk afdeling, og på trods af det kan logistik afdelingen ikke løse det på en tilfredsstillende måde. Med flexitanke er der overordent 3 problemer. 1) hvordam varmes det op? heating delene er ikke effektive nok. Der er også mulighed for en anden mulighed for flexitanke. Men uanset hvad er der stor risiko for at opvarmning under transporten ikke fungerer. Det betyder bagefter at opvarmningen da skal ske på en centralt center eller ude hos biogas anlæggene. Anlægene er ikke så glade for at modtage noget der ikke er standard. Derefter skal der skilles af med flexitankene som potentielt kan indeholde meget restprodukt. Transport firmaerne vil ikke være en del af at løse problemet efter levering. Problematikken er ofte, at hvis man kan fylde en last så er det det billigste. Dvs. et projekt initieres kun hvis man kan transportere en stor volumen. Kan man udnytte sig af returbiler er det optimlat prismæssigt og miljømæssigt.

Der er et stort koordineringsproblem ift. at tilrettelægge ruterne optimalt. Dette er fx i sammenhæng med om man kan levere til en havn hvor der findes opvarmningsfaciliteter og jhvor til produktet så skal efter dette, om distancen er kort nok til at det giver mening at levere dertil. Her opstår også muligheden for tog-transport, da man da skal vælge anlæg der er tæt på togbanen. Dette kan påvirke prisen. Man kan måske transportere størstedelen på tog, men derefter kræver det omlastninger og dette påvirker prisen. Hvis varme da også skal indgå i ligningen bliver det endnu dyrere og mere tidskrævende. For CO2 udslip er tog også at foretrække. Kan en transport løæsning ICT certificeres, og det kan det hvis bare det er affald, derfor kan incitamentet for at få det på jernbane i et udslip sammenhæng måske ikke være høj nok. Det kan være værd at fokusere på om man kan vælge modtagere og leverandører ligger tæt på jernbaner. Om man transportere det med tog, lastbil, eller skib, påvirker det ikke miljøcertifikaterne man kan få. Transport prisen er det der kan ødelægge hele projektet og kombineret med det praktiske i at det er svært at pumpe, opvarmne at det størkner, at der er stort rest tilbage i nogle løsninger osv. En potentiel udfordring for flexitank er at materialet ikke er neutralt for miljøetog kune beskyttes af et tyndt lag plastik. Det er måske en fordel ved at det størkner.

Det er vigtigt at der i diksussionen skal diskuteres komplexiteten i lokationen af anlæg, havne, anlæg og togbaner imellem fx. Variationen i anlæg er også en stor variationsfaktor om de er villige og kapable til at tage i mod det. Der er en række kriterier til anlæggene som er nødt til at møde for at de kan modtage denne type materiale. Der er pumper, evt. opvarmning, evt en større biomasse det kan blandes i. Det kræver relative store og kontinuerlige voluminer da anlæggene også tilpasser sig den specifikke masse og det tager tid. Der kan opstille kravsanalyse for anlæggene, både resourcer og faciliteter men evt. også lokation og produktspecifikke krav. Firmaet har dog tiltro til at der findes anlæg som er villige til at tage i mod det. Der bygges flere og flere anlæg og alle produkter på det danske markede for biomasse bliver støvsuget op. Det er vigtigt at fokusere på voluminer, da dette er en væsentlig faktor for at der er en business case. Fedt er et attraktivt produkt fordi energi potentialet er højt, men det kræver større tilvending for anlæggene at tilpasse sig. Derfor skal mængderne og kontinuiteten være god og stabil.

Variationen i produktet er en afgørende faktor i både håndtering og opvarmning. Nogle havne har varmefasciliteter til at varme produktet op. Her er der da ekstra omkostninger på hvor ekstra håndtering og opvarmningstiden. Derudover er der variation i hvor lang tid det vil tage at varme produktet op og der det vil også være en variation der kan skabe usikkerhed.

Lovgivning er en faktor der ikke antages at der ser ind på. Der er forskellig lovgivning og compliance på tværs af lande hvilket kan komplicerer transporten. Lovgivning er også noget man på forskellige måder kan komme rundt om. Udfordringer skal diskuteres men måske ikke dykkes ned i da det er for omfattande og komplekst.

Om et anlæg er villige til at modtage produktet afhænger udelukkende af anlægget. Nogle tager imod 120.000T og andre tager 1mio tons. Hvis det er fedtholdige substrater tager det tid for anlægget at tilpasse sig denne type masse. Derfor er det fordeklagtigt at kunne facilitetere et kontinuerligt flow, hvor et stort anlæg måske kunne modtage to læse pr uge og små 1 lidt sjælnere. Det kan da være mere interne faktorer fra anlægget som påvirker den mængde de skal have eller er villige til at tage imod. Dernæst er der i leverandør enden hvor mange tons de om året er mulige at producere. Alle biomasserne betegnes som produkter og omfattes derfor ikke af affals lovgivining. Firmet har ikke business cases og ikke case data men mere generel data, da firmaet simpelthen ikke har logistik løsninger lige nu til at retfærdiggøre business casen.

Som diskuteret tidligere. Opvarmede trucks er den eneste metode der lige nu er testet. Trabsport på P-trailere med eneten IBC eller flexi er kun på et teoretisk plan. Foruden selve deb praktiske logistik løsning er der parametrene omkring opvarmning, håndtering og det at skille sig af med resourcene der opbevares i eller rengøring og genbrug af beholderne. Da nogle af resourcerne har positiv værdi vil man altså bruge dem igen. Tankene har forskellige klasser og specifikationer for hvad de må bruges til. I lande hvor arbejdskraft er billig, vasker man gerne palle tankene så det kan bruges igen og så har de en specifik levetid, fx. 3 år. Nogle steder i Danmark vasker man også. Nogle af aktører er ikke så tilfredse med at skulle købe palletanke der har været brugt til i deres øjne, affald. Da der er meget lidt der testet, er der åbne arme for forslag på løsninger. Fx rent praktisk hvordan får vi produktet ud, hvilke materialer kræver det og hvordan gennemføres det. Dette er parametre der skal løses af firmaet før der kan være et business case. Nogle biogas anlæg har allerede faciliteter og udstry til fx at vende i luften. Der kan også være et teoretisk case med transport fra Spanien eller Portugal. Også i dette tilfælde dræber det at anvende opvarmede tank biler business casen på stedet. Manuelt arbejde er sjældent populært hos modtager. Og også små enheder er ikke populært. Håndteringen skal optimeres og skal kunne gøres i stor skala, billigt og effektivt. Der kan komme mange ekstra omkostninger oveni hvos der er yderligere håndtering af produkter. Import og eksport netværkenen er vigtige at undersøge for at udforske muligheder for backhawls og tomme returbiler, der kan udnyttes, da returbiler er det absolut billigste. Kunne man centralisere databaser med information om returbiler. Det er vigtigt for firmaet at kende materiale flows for at kunne vide mulighederne for returflows. Der er nogle ruter hvor der bare ikke er returbiler fordi der er mere import end eksport i den ene vej. I nogle projketer er det billigste nogle gange at sende indenom Danmark, omlaste og sende videre. Fx et produkt fra Norge til Danmark og derefter til Polen.

Firmaet har ikke lager specifikt, men det har lagerpladser forskellige steder som er produktspecifikke og også afhænger af om der er noget der afsendes derfra. Produkttypen og valget af transport kommer med mange variationer og komplikationer. Derer sjældent en one-size fits all. En transport løsning isoleret kan være billigst, men hvis stepsene af håndtering eller materialer kommer oveni kan det skabe et tipping point, og derfor nødvendigt at se helheden samt kompleksiteten i løsningerne for at kunne tage gode nok beslutninger. Hvordan produktet opfører sig undervejs, sætter krav og følges af en række restriktioner på mulighederne.

Markedet for transport af biomasse der er flydende i Danmark fungerer rigtig godt. Så længe det er noget der kan pumpes er der mangemuligheder og kan lade sig gøre i stor skala. I den faste del af skalaen er der andre muligheder. Kan man finde biler der kører fx. kalk eller korn, kan den faste biomasse transporteres i dette på fx. returbiler mellem sjælland og jylland. I et case var det billigere at transportere på tværs af landet i returbil i stedet for internt i Jylland på nye biler. Massefylden er en væsentlig faktor. Halm fx. ubearbejdet fylder meget, vejer lidt, og har en stort biomasse potenitale hvis der er behandlet og komprimeret. Hvis ikke det er det er prisen for høj og potentialet for lavt. Vægten pr kubikmeter er også en væsentlig faktor for om transporten kan lade sig gøre. Behandlingen af produktet må også overvejes om man gøre før eller efter, og hvis man vælger at behandle produktet inden, må man kortlægge krav til transporten, hvordan det opfører sig og hvordan det ændre håndteringen af produktet igennem hele processen. Jo mere manuelt arbejde er i udgangspunkt udelukket, men hvis de kan se potentialet i det og minimere omkostningerne er der større mulighed. Specielt store anlæg skal det ske så effketivt som muligt. De vil kun modtage store og letmedgørlige voluminer. Men hvis potentialet og mængderne er der, er det ikke udelukket at de vil kunne investere i udstry til at kunne håndtere det, det vil måske påvirke købsprisen, ved afskrivning af udstry fx. Dette skal altså overvejes i produkt prisen. En generel risikovurdering er nødvemndig for at analysere om anlæggene er villige til at tage imod. Disse risiko kunne fx være omkring for mange led i transportkæden.

Ift. produkt kvalitet og konsinuitet er det vigtigt at sikre sig. I kontrakterne fastlægges hvad produktet indeholder og evt. grænseværdier for indhold. Dette er vigtigt da det har betydning for produktion og da restprioduktet for biogas produktionen ofte anvendes som gødning, og skal ud i naturen er der derfor klare grænser. Dette er da beskrevet i kontrakten. Fx. sæberester, svovl og chlor er der krav på forid det påvirker biogas og restprodukt kvaliteten. I udgangspunkt vil man have så rene produkter som muligt for at have så meget energi holdig masse som muligt. Leverandør lover, firmaet stoler og laver da stikprøver nu og da, men i udgangspunktet stoler man på leverandøren. Man måler kune på indgangen i anlægget, så man sikre sig at der ikke fortyndes osv. eller at anlægget anvendes som affaldshåndterings anlæg. Oftest kender firmaet restproduktet bedre end afsenderen selv, da det har betydning for firmaet hvad der er i og hvad de lover mod anlæggene. Jo renere produktet er jo mere kan det svare sig at transportere. Ift produktet, kan man evt. tilsætte vand eller andet, da det kunne påvirke smeltepunktet, men det ville også påvirke prisen, men gøre håndteringen nemmere.

De mindre anlæg er oftere mere kreative til at finde løsninger. Fx spyd til at tømme flexitanke effektivt. Nogle af disse løsninger har foirmaet solgt videre og løsningerne kan opskaleres. Det er derfor vigtigt at hjave stort samarbjde og god kommunikation med anlægggene for at finde gode løsninger der passer deres skala og ressourcer. De mindre anlæg er mere opfindsomme, men de store anlæg er måske mere villige til at investere i det udstyr det kræver. I udgangspunkt er manuelt arbejde ikke ønskværdigt.

A.15 Analysis Assumptions

The cost data provided by the company in chapter 4, are simplified, and for the cost estimations it should be considered that extra costs might occur that are not quantified nor addressed in this analysis. The reader should have this in mind when interpreting the results. For the analysis of the logistics intervention of the standard solution, none of the suggested solution have been tested yet, and as well it should be understood that handling etc. could add costs that are so far unknown.

As the case data has a large focus on the supply and logistics side, and not much focus on the demand side, it is assumed, as stated in the project demarcation, that the focus is on the supply and logistics aspects, and not on the demand side. The thesis is conducted under under the assumption that it will be possible to sell all the imported biomass to plants in Denmark. This assumption is based on the study of the markets and dynamics on the market of biomass and biomass import in Denmark (Danmark n.d.), (Statistik n.d.). 30% of the total use of biomass was imported in 2022 and that the import share is predicted to increase and as well in 2022. Denmark imported 2,7 million tons alone in wooden pellets. This makes the assumption that importing in total 13.200 tons a year of good quality biomass will be able to sell if a reasonable logistics and handling solution is found and the plants are capable of handling it.

For the logistics interventions proposed by the company, it it assumed that the company in each business case will continue with the current Incoterm agreement, being respectively an FOB for the Argentina case, CIF for Oman, and FCA for the Ukraine. This is elaborated in the analysis. In the sensitivity analysis price changes is considered. In the discussion changing the levels of agreements is considered.

It is assumed that in the need for keeping inventory, or if the full volumes of biomass can not be loaded directly to the production plants at arrival in Denmark, the plants will be willing to store it at the plants. Hence, inventory costs is considered eliminated as the company currently operates from the assumption that in the need of inventory, it is kept for free at the consuming plant. The company does not have storing facilities.

Regarding shipping from Oman and Argentina, the company considers a maximum of approximately 20 containers pr shipment should be possible to charge on each ship. They expect a frequency of 1-2 shipments pr month, which is also what is considered optimal regarding the plants requirement for continuous flow and a rather stable and known schedule for delivery to plan production flow.

For the company, even a slight profit in the business case is attractive as they often can optimize on purchase price, selling price, and hopefully transportation and other logistic aspects too.

The potential costs of equipment needed for loading and unloading is considered a cost placed at the plants. During the interviews it become clear that often the smaller plants are creative and willing to find both practical and cheap solutions to solve the practical issues. As the costs are considered to be placed at the plants the increased handling costs, man hour costs, or investments in equipment, is in the analysis considered as placed at the plants. Unloading from the units are considered to be either by pumping or tilting, and it is assumed that larger plants would already have equipment for these activities and is not considered a barrier for the plants to be willing to take the product. Further equipment is also considered to be placed at the plants as an investment cost, but this will be highlighted in the analysis when relevant.

Often transport solutions would have a cost function that gains economy of scale as volumes are increasing. In this case, based on the given data, the only assumption that can be drawn is that the cost function is linear, meaning more volume doesn't mean cheaper price. It is though considered that with attractive volumes and a good solutions, the company has potential of negotiating good logistics deals with an increasing volume. But a linear cost function is the only thing that can be assumed based on the data provided.

A.16 Costs calculations Business cases

	Aggregation	*Pr ton*	*Pr shipment*	*Standard*	*Alternative*	*Sensitivity*
Tons		1	20	10.000	10.000	10.000
Sales price DK	Pr ton	360	€ 7.200,00	€ 3.600.000,00	€ 3.600.000,00	€ 3.060.000,00
Tank truck	Pr shipment	168		-€ 1.680.000,00		
Curtain Side Truck	Pr shipment	€ 2.600,00	-€ 2.600,00		-€ 1.404.000,00	-€ 1.404.000,00
IBC	Pr piece	€ 30,00			-€ 279.000,00	-€ 324.000,00
Flexi	Pr piece	€ 250,00	-€ 250,00		-€ 135.000,00	-€ 162.000,00
FCA	Pr ton	€ 130,00	-€ 2.600,00	-€ 1.300.000,00	-€ 1.404.000,00	-€ 1.474.200,00
Heating	shipment & hour	€ 60,00		-€ 435.840,00		
Customs	Pr shipment	€ 10,00	-€ 10,00	-€ 4.540,00	-€ 5.400,00	-€ 5.400,00
Cleaning	Pr piece	€ 5,00			-€ 54.000,00	-€ 54.000,00
Flexitank disposal	Pr piece				-€ 2.500,00	-€ 2.500,00
Profit Standard	Standard			€ 179.620,00		
Profit IBC	IBC		€ 1.990,00		€ 453.600,00	-€ 201.600,00
Profit Flexitank	FLEXI		€ 1.740,00		€ 649.100,00	€ 11.900,00
0,92 tons pr IBC	20 tons pr container					
500	lastbiler	m i alt 10.000 IBC		454 trucks	500 trucks	500 trucks
20 t pr flexi						
500 trucks						

Figure A.13: Ukraine Case Calculations

	Aggregation	*Pr ton*	*Pr shipment*	*Standard*	*Alternative*	*Sensitivity*
Tons	tons	1t	20 t	1200	1200	1200
Sales price DK		€ 510,00	€ 10.200,00	€ 612.000,00	€ 612.000,00	€ 520.200,00
IBC	Pr piece	€ 30,00	-€ 600,00		-€ 36.000,00	-€ 36.000,00
Flexitank	Pr piece	€ 200,00	-€ 200,00		-€ 12.000,00	-€ 18.000,00
FOB	Pr ton	€ 210,00	-€ 4.200,00	-€ 252.000,00	-€ 252.000,00	-€ 264.600,00
Container Transport	Pr unit		-€ 2.000,00		-€ 120.000,00	-€ 120.000,00
ISO tank transport	Pr unit	€ 6.000,00	-€ 6.000,00	-€ 276.000,00		
Heating	Shipment and hour	€ 60,00		-€ 49.680,00		
Customs	Pr shipmend	€ 5,00	-€ 5,00	-€ 230,00	-€ 300,00	-€ 300,00
Cleaning IBC	Pr piece				-€ 6.000,00	-€ 6.000,00
Flexitank disposal	Pr piece				-€ 300,00	-€ 300,00
Tankhire after 10 days	Pr day	€ 46,00				
Profit Standard	**Standard**			**€ 34.090,00**		
Profit IBC	**IBC**				**€ 197.700,00**	**€ 93.300,00**
Profit Flexitank	**FLEXI**				**€ 227.400,00**	**€ 117.000,00**
IBC	1200 IBC in			46 containers	60 containers	60 containers
60	container med 20 IBC pr år		shipments pr year			
Flexi	60	Flexitanks in	60 containers			
		~3	shipments pr year			

Figure A.14: Argentina Case Calculations

	Aggregation	*Pr ton*	*Pr shipment*	*Standard*	*Alternative*	*Sensitivity*
Tons	tons	1t	20 t	2000	2000	2000
Sales price DK	Pr ton	€ 500,00	€ 10.000,00	€ 1.000.000,00	€ 1.000.000,00	€ 850.000,00
IBC	Pr piece	€ 30,00			-€ 42.000,00	-€ 60.000,00
Flexi	Pr piece	€ 200,00	-€ 200,00		-€ 20.000,00	-€ 30.000,00
CIF	Pr ton	€ 360,00	-€ 7.200,00	-€ 720.000,00	-€ 720.000,00	-€ 576.000,00
Heating	shipment & hour	€ 60,00		-€ 99.600,00		
THC	Pr shipment	€ 268,00	-€ 268,00	-€ 22.244,00	-€ 26.800,00	-€ 29.480,00
Cleaning IBC	Pr piece	€ 5,00			-€ 10.000,00	-€ 10.000,00
Flexitank disposal	Pr piece	€ 5,00			-€ 500,00	-€ 500,00
Last mile	Pr ton	€ 41,00	-€ 820,00	-€ 82.000,00	-€ 82.000,00	-€ 82.000,00
Customs	Pr shipment	€ 5,00	-€ 5,00	-€ 415,00	-€ 500,00	-€ 500,00
Profit Standard	**Standard**			**€ 75.741,00**		
Profit IBC	**IBC**		**€ 1.707,00**		**€ 118.700,00**	**€ 92.020,00**
Profit Flexitank	**FLEXI**		**€ 1.507,00**		**€ 150.200,00**	**€ 131.520,00**
2000 IBC	100	containers	årligt		600 for free	no IBC for free
	5	gange pr år april - nov		83 containers	100 containers	100 containers
20t pr flexi	100 container					
100	flexi	5	times pr year			

Figure A.15: Oman Cost Calculations

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF SERVICE MANAGEMENT & LOGISTICS
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY