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Sustainable Intermodal Supply of Biofuels

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Göteborg, on a cold and windy March day 2015.

Sustainable Intermodal Supply of Biofuels

Abstract

Sweden shows significant consumption of forest fuels in its heating plants (HPs) and combined heat and power plants (CHPs) that places great demands on the logistics systems supplying these plants with fuel. The aim of this study is to help in the development of sustainable supply chains involving the intermodal bulk flow of wood as a fuel for Sweden's HPs and CHPs. The study has involved an investigation of the definitions used for wood biofuels and their raw materials in the literature. After generally used distribution networks are identified and analysed, the study describes the various logistical challenges in the wood biofuel industry. Information and data have been obtained from a literature review and survey, followed by a case study.

Key challenges identified in the literature review are seasonal variations, storage, the chipping process, the low density of wood biofuels, the absence of standard terms, sources of supply, and dependency on policies. The survey reveals the situation of wood biofuel supply chains in Sweden. The key fuel used by the country's power plants is woodchips, which has underscored their importance in keeping heat and electricity resources sustainable. The industry is oriented toward a local market that mostly uses trucks with direct transport of wood from the forest, the preferred site for chipping. Road transport is rated quite favourably, with reliability as the most important factor. At the same time, storage is used to overcome fluctuations in demand and is an essential part of the supply chain, as most CHPs have storage facilities. On this point, challenges include determining the size and location of storage facilities and identifying alternative possibilities for transport that might improve the transport chain and reduce environmental impacts, while at once maintaining flexibility. The case study explores the sustainability of the various chains. The assessment of these chains considers costs and CO_2 calculations. Frequent use and keeping transport distances short play important roles in keeping costs down. Large costs are associated with the terminal and chipping processes. All-road systems for wood biofuels often involve terminal costs which is their common characteristic with intermodal chains making the intermodal system potentially applicable due to low added costs.

Keywords: Wood biofuel, transport, logistics, survey, logistical challenges, market, sustainability.

Sammanfattning

Sverige använder mycket skogsbränsle i fjärrvärmeverk. Detta ställer stora krav på logistiksystemet som försörjer verken med bränsle. Denna studie syftar till bidra till utvecklingen av hållbara försörjningskällor med ett fokus intermodala flöden inom Sverige för fjärrvärmeverk. Studien inbegriper en litteraturgenomgång av definitioner för biobränslen och dess råmaterial. De vanligast förekommande distributionsnätverken identifieras och analyseras. Studien beskriver de olika logistiska utmaningarna i biobränsleindustrin. Data samlas in genom en litteraturgenomgång och en enkät, följt av en fallstudie.

Viktiga identifierade utmaningar genom litteratursstudien är säsongsvariationer, lagringen, flisningen, biobränsles låga densitet, avsaknaden av standardtermer, råvarukällor and beroendet av politiska beslut. Enkäten visar situationen för försörjningskedjorna för biobränsle i Sverige. Det huvudsakliga bränslet som används är träflis. Industrin har ett lokalt fokus och använder mest lastbilstransporter direkt från skogen. Lastbilstransporter rankas som det tydligt mest föredragna transportslaget, med tillförlitligheten som den viktigaste faktorn. Lagring används för att hantera variationer i efterfrågan och är en väsentlig del i försörjningskedjan, där de flesta verk har lagringsmöjligheter. Den mest föredragna platsen för flisningen är i skogen. I utmaningarna ingår att fastställa storleken och platsen för lagringen samt att identifiera alternativa transportmöjligheter som kan förbättra transportkedjan och leda till lägre miljömässig påverkan, samtidigt som flexibiliteten i kedjan behålls. Fallstudien undersöker hållbarheten i ett antal, existerande eller möjliga, försörjningskedjor som kan användas för att försörja verk i Sverige. Utvärderingen av kedjorna baseras på kostnad och CO_2 utsläpp. Ett högt utnyttjande av resurserna och att hålla transportavstånden korta är viktigt för att hålla kostnaderna nere. Stora kostnader kan kopplas till terminaler och flisningen. Flera aktiviteter förekommer både i ett vägsystem och i ett intermodalt system vilket gynnar en övergång till ett intermodalt system. Lagernivåerna spelar en viktig roll vid beställningen av biobränsle.

Nyckelord: Biobränsle, transport, logistik, enkät, logistiska utmaningar, marknad, hållbarhet.

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List of Appended Papers

Paper 1
Awais, F., 2013, Wood biofuels logistical challenges in Sweden. Presented at the NOFOMA conference 2013, Gothenburg, Sweden.
Paper 2
Awais, F. Flodén, J., 2013, Logistic requirements and characteristics of the Swedish wood biofuel industry. Submitted to the *Scandinavian Journal of Forest Research*.
Paper 3
Flodén, J., Awais, F., 2014. Meeting the challenges for intermodal transportation of biofuel.

List of Abbreviations

DH: District heating

HP: Heating plant

CHP: Combined heating plants

FAO: Food and agricultural organisation

GHG: Greenhouse gases

MW: Megawatt

MWh: Megawatt hour

GWh: Gigawatt hour

TWh: Terawatt hour

1. Introduction

This section provides an overview of the definitions of wood biofuels and different supply chains, along with a discussion of the problems.

1.1. Background

The extent of economic and civil growth has always been associated with the consumption of natural energy resources (Mikkilä et al., 2009). At present, the growing need for energy resources poses numerous problems for the world, while the presence of oil and gas resources within only a handful of countries raises concerns of steady availability and the constant threat of their depletion. The use of fossil fuels has also been a chief contributor to environmental problems such as air pollution and Green House Gas emissions. Possible solutions to these problems call for the development of renewable, environmentally friendly energy resources, among which the use of biomass presents an interesting alternative. Some of the many reasons for adopting biomass as an energy source include its worldwide availability, use in power generation, and the CO_2-neutral basis of its biofuels (Hamelinck et al., 2005).

Wood, an old and environmentally sustainable biofuel still used for energy purposes, is the focus of this study. Timilsina and Shrestha (2011) report that interest in biofuels as an alternative to fossil fuels emerged during the oil crisis in the 1970s. The subsequent price drops and incentives in the oil industry later stagnated the trend of biofuel production in many countries. Yet, with anticipated energy shortages in the coming years, along with increased oil prices and climate deterioration, interest in biofuels has been renewed. Its resurgence was further supported by the expansion in output and consumption of biofuels, along with advancements in the technologies available.

The decreased production cost of biofuels is a major motivator to use such means of energy instead of expensive oil sources. However, in nearly every case, biofuels still require subsidies to compete with oil products (e.g., gasoline and diesel). Climate preservation also dictates the use of biofuels against fossil fuels, given the former’s lesser effects on the climate via reduced CO_2 emissions. Concerns such as rising oil prices and resource shortages call for further investigation of biofuels’ increased production and decreased production costs.

According to the Swedish District Heating Association, the district-heating (DH) sector has shown a steady reduction in the use of the fossil fuels since the 1980s. Currently, most of the energy supplied to Swedish heating plants (HPs) is renewable. These circumstances derive mostly from an elevated carbon tax among the industry’s recent measures to reduce the use of fossil fuels, which has indeed led to major reductions in carbon emissions (Trad, 2010).

Sweden uses biofuels in large quantities for the purposes of DH, combined heat, and electricity production. The use of forest fuels or woodchips as biofuel has increased over the previous decade and could continue to be a significant part of future fuel used. In 2010, Sweden consumed 8.4 million m^3 of forest chips for the purpose of energy generation. Logging residues form the most common raw material for the production of woodchips in Sweden (Routa et al., 2012). Obviously, this consumption has been possible due to the development of infrastructure necessary for the production of energy from biofuels. During the late 1970s, nearly 90% of the DH in Sweden was supported by oil, which later changed due to the oil crisis of the time. Numerous new HPs were built, while old plants were converted to accommodate biomass. Commonly used fuels at HPs and combined heating plants (CHPs) are wood residues (e.g., from sawmills and forests), recovered wood, and refined wood fuels (e.g., wood pellets). During the 1990s, the support scheme for CHPs resulted in the construction of several large plants around Sweden. By 2000, nearly every town and city in Sweden had an HP or CHP using local biofuels. At present, Sweden has nearly 500 HPs around the country (Andersson, 2012). Table 1 shows that the consumption of fossil fuels (e.g., coal) has decreased over time in the DH sector while the use of biofuels (e.g., wood biofuels) has risen.

The increasing demand for energy has sharpened the focus on the logistics of supplying plants with fuel, since logistics is considered to pose key challenges for the increased use of biofuels (Gold and Seuring, 2011, Svanberg and Halldórsson, 2013, Rentizelas et al., 2009). The increased demand and production of wood biofuel calls for a closer examination of the logistics activities involved in transporting these goods to energy plants.

The wood biofuel supply chain starts with the trees in the forest and ends with individual consumers. Along the way, it involves several processes: harvesting, sorting, transporting to terminals, along with sawmills, pulp mills, paper mills, and HPs, and the conversion of wood into products such as wood pellets, pulp, paper, and lumber (Carlsson and Rönnqvist, 2004). Sweden makes great use of these forest fuels in CHPs and HPs, which require different amounts of different wood biofuels. The DH sector uses nearly half of all biofuels consumed in Sweden and major developments in the DH sector during the past three decades. The DH sector serves almost half of Sweden's population, including both commercial and residential buildings. Of late, HPs have been combined with the production of electricity, thus giving rise to CHPs. The high environmental tax on the use of fossil fuels in Sweden is a major reason for the DH sector's shift from oil to biofuels. In fact, biofuels have replaced oil as a source of fuel in most places, which has resulted in the tremendous demand for biofuels by

HPs. Another contributing factor is Sweden's endowment and enrichment of forests, which are major sources of wood used as biofuel (Olsson, 2006).

The growing demand for bioenergy requires the long-distance transport of wood. This necessity highlights the importance of rail in the transport of both biofuels and traditional forest products (Tahvanainen and Anttila, 2011). Long-distance transport involving intermodal modes can reduce costs and involve the transport of large volumes to meet demand. The transport of wood biofuels presents interesting scenarios of intermodal transportation from the source to the destination, while the consumers (i.e., HPs and CHPs) look for efficient supply chains within Sweden.

Sustainability is at the heart of using biofuels. The use of biofuels in the DH sector is a sustainable activity that greatly reduces emissions. It can be argued that the supply of wood biofuels causes the most emissions in the whole process of their use, since the supply of wood biofuels relies heavily on processes that use fossil fuels and assumes variable costs, making it the least sustainable part of the whole chain. The great dependency on road transportation in wood biofuel supply chains negatively affects the whole process given the high costs associated with long-distance transport. In response, a focus on the sustainability of wood biofuels would greatly contribute to improving the sustainability of the total process. Sustainability in wood biofuel supply chains can be seen as a step toward progress in an otherwise highly sustainable process. As such, this thesis aims to help in the development of sustainable supply chains involving the intermodal bulk flow of wood fuel among Sweden's HPs and CHPs

Table 1: Energy produced by district heating plants in Sweden from different fuels (excluding electricity) 2006–2011, GWh. Source: Swedish District Heating Association (2011)

Fuel	**2011**	**2010**	**2009**	**2008**	**2007**	**2006**
Industrial waste heat	3,852.3	4,121.5	3,589.8	3,842.2	3,739.9	3,785.1
Solar				n/a	n/a	8.1
Waste	9,581.4	10,191.1	9,477.7	7,719.7	7,285.6	7,458.8
Waste gas	718.7	740.4	574.4	870.1	844.3	828.9
Recycled woodchips	2,445.1	2,906.5	3,165.5	2,338.8	1,453.7	1,321.0
Logging residues, stem woodchips, sawdust, etc.	14,284.4	18,765.1	16,716.7	13,642.0	11,823.1	14,182.6
Pellets, wood briquettes, etc.	3,470.6	4,579.8	4,012.0	4,023.0	3,479.2	3,882.9
Landfill and sewage gas	115.5	173.4	128.6	129.1	26.1	245.9
Tall oil pitch	710.8	983.7	862.5	737.9	667.7	743.7
Bio oil	960.0	2,256.4	2,072.7	1,309.3	1,641.7	1,713.7
Other biofuel				3,288.1	3,498.6	788.9
Other fuel				840.0	783.4	995.0
Peat and peat briquettes	1,726.9	2,674.3	2,608.0	2,549.3	2,583.7	2,166.6
Purchased hot water (unspecified fuel)	140.4	17.3	47.5	183.0	600.5	652.4
Electricity for heat pumps	1,264.6	1,427.8	1,436.6	1,564.6	1,643.1	1,553.9
Heat output from heat	3,921.3	4,574.5	4,659.7	4,768.2	5,164.4	5,064.2
Electricity for electric boilers	144.7	139.4	211.1	221.3	339.3	235.9
Support electricity	1,758.4	1,792.1	1,458.8	1,382.1	1,612.0	1,156.1
Natural gas	2 ,11.1	3,306.0	2,451.9	1,675.8	2,049.1	1,721.6
Heating oil	2,068.9	4,558.1	3,836.7	1,269.8	1,686.4	2,701.9
Coal	1,347.6	1,606.1	1,443.7	1,449.4	1,803.0	1,947.4
Other fossil fuel	171.8	325.1	498.1	229.0	323.9	265.4
Flue gas condensation	3,899.0					
Total fuel / energy for heat	53,428.9	63,710.6	57,815.5	52,468.1	51,405.6	51,865.9
Total heat supply	48,079.5	61,171.9	50,825.1	47,758.6	47,432.4	46,735.9
Efficiency	97%	96%	88%	91%	92%	90%

1.2. Discussion of the Problem

This study investigates the supply chain of wood used for energy from a holistic perspective. The discussion of the problem therefore uses general terms to address the need of biofuels and logistical aspects of the wood biofuel industry.

Climate preservation is at the heart of the concept of forest fuels. With growing demand for forest fuels, improving supply networks is a logical possible next step for the DH sector. Rauch and Gronalt (2010) explain that, logistically, wood is heavy to transport and provides less energy than fossil fuels, which suggests an economic dilemma in the transport of forest fuels. Since the transport of wood fuels from widespread sources to widespread destinations involves far higher costs than fossil fuels, cost-effective solutions should be sought. Several factors can be evaluated for ways to make wood transport more cost-effective, including the mode of transport, physical condition (e.g., chipped, unchipped, baled) of the wood, and moisture content, among others. The main cost drivers in developing a supply chain of wood fuels are chipping and storage, while present and future energy costs are forecast to remain high or increase.

Continually increased demand and consumption, along with dynamic aspects of supply chains, of wood biofuels present an opportunity to study the phenomenon in detail. With its substantial consumption and large number of HPs and CHPs using biofuels, Sweden is an ideal place for studying the supply chains of wood biomass. CHPs and HPs require fuels in large quantities and facilitate the study of different aspects of intermodal transport. Large CHPs and HPs with significant consumption can withstand costs related to intermodal transport options, including the combination of rail and road transport, by increasing resource use. As such, CHP operations in Sweden present an opportunity to study the situation of the wood biofuel industry and define the logistical problems and sustainability of the wood biofuel supply chain.

Aside from the necessity of both biofuels and improving the wood biofuel supply system in the today's energy-deprived world, presented research has aspired flesh out the study of logistics and transport management. In this sense, wood biofuel supply systems present opportunities to study key concepts in intermodal transport, including sustainable transport, storage, terminal, and capacity management, among many others. In the current study, focus was kept on sustainable intermodal transport.

Priemus et al. (1999) describe freight transportation in Europe, which has increased compared with passenger transport. Intermodal transportation can be used to reduce traffic on the road, which will prevent current and possible congestion problems. Freight transportation most affects the environment when it uses trucks. Greener approaches to freight transportation include the use of pipelines, ships, and trains. To increase the use of environmentally friendly modes, terminals with advanced transhipment techniques should be developed in the right places. At the same time, advanced terminals and networks posing reduced costs and environmental impacts can be achieved by better configurations of mode combination, terminals, and freight flow. Wiegmans et al. (1999) highlight the importance of handling operations at a terminal, which are thought to constitute an expensive part of the supply chain. In this sense, the objective should be reduced operations. Modifying handling operations is acceptable only if given a significant increase in the performance of the terminal, a reduction of costs, or a combination of both. Jourquin et al. (1999) further reinforces this point by stating that improvements and innovations introduced by the use intermodal transport should be both feasible and economical in order to pose benefits.

The supply chain of wood biofuels can benefit from intermodality since it involves the use of storage and transhipment terminals. Multiple sourcing points can bring goods to terminal points, from which they can be transported in huge volumes to single destination points (e.g., power plants). Such a setup can be ideal for implementing intermodal solutions. With the growing demand for wood biofuels and the increase in overall freight transportation, shifting loads to different modes is a possible solution. Regardless, intermodal solutions involving trains and trucks need to be both feasible and economical. Wood biofuel supply chains in Sweden provide excellent grounds for studying both existing and potential intermodal solutions for products that contribute to the sustainability of society.

1.3. Purpose

The purpose of this study is to investigate wood biofuel supply chains in Sweden and to facilitate the use of intermodal freight transport for supplying district heating plants.

The study examines the various logistical activities and problems involved in the supply chains of raw materials for HPs and CHPs in Sweden. These activities and problems are analysed in a context of sustainability to suggest sustainable transport chains for the supply of wood biofuels. More specifically, this thesis investigates the transportation of wood biofuels in multimodal transport systems, which currently dominate wood biofuel supply chains. In this sense, the thesis examines the potential of implementing intermodal transport systems within current chains. The benefits of using road and rail transport have been investigated in wood biofuel chains, as such taking advantage of the benefits of different modes is a top goal of intermodal transport. The survey has largely focussed on current and possible intermodal activities of wood biofuel chains, while the case study lastly investigates the potential of intermodal activities in wood biofuel supply chains.

This thesis' focus on the combination of road and rail transportation is highly motivated by the present infrastructure in Sweden for rail–road intermodal transport. Rail and road transport are the most commonly used modes for transporting biofuels in Sweden, whereas ships are used only for imports. Section 2 highlights the Swedish rail–road intermodal system and briefly introduces how biofuels are currently transported in intermodal settings.

1.4. Research Questions

To fulfil the purpose of this study, the research questions developed will be set as guiding beacons to identify and develop a sustainable supply chain for the wood biofuels.

RQ 1: What are the different actors and practices involved in wood biofuel supply systems for heating plants?

RQ 2: What are the main preferences, requirements, and logistical challenges in the wood biofuel supply system for heating plants?

RQ 3: How can sustainable intermodal transport options be designed for a wood biofuel supply system for heating plants?

1.5. Delimitations

Despite various biofuels, this study is particularly concerned with wood to be used as biofuel. The raw material to be discussed for the selected product is wood biomass available from both wood processing plants and forests. Other applications of wood such as for furniture or other purposes are not the focus of this study, thus those applications' various aspects and supply chains are excluded. The different modes of transportation discussed in the study are road and rail. The study is limited to Sweden's HPs and CHPs that involve national supply chains. As one of the largest consumers of wood biofuels and showing increased usage, Sweden provides an ideal situation for studying supply chains.

1.6. Importance of the Study

The study is important from multiple points of view. Identifying logistical problems in wood biofuel chains provides potential starting points for improvement. The survey of CHPs highlights the current market situation along with attitudes toward different modes and logistics activities. The calculation of costs and CO_2 emissions for a wood supply chain based on a case study highlight the economics and various options for sustainable logistics practices. The study is most important from a logistics point of view, though provides insights into market trends and attitudes currently present among wood biofuel consumers.

2. Frame of Reference

This section provides an overview of the background knowledge used in conducting the study.

2.1. Definitions of Biofuels

The category of biofuels involves a diverse range of products and substances used to generate energy. Wood from trees is one of the most widely used solid biofuels and can be transformed into products such as wood pellets and torrefied wood (Bradley et al., 2009b). Compared to fossil fuels, however, wood is heavy and yields less energy (Rauch and Gronalt, 2010).

The Food and Agricultural Organization (FAO) of the United Nations has developed common terms for biofuels, thereby providing a structured way to classify the various biofuels available. The purpose of developing bioenergy terminology was to standardise definitions of various terms related to bioenergy for international usage. Differences in definitions due to local alterations have posed several problems that frustrated the comparison and report of different regions. In response, Thraen et al. (2004) have focused on unifying and organising terms and definitions of wood and other biofuels used in forest and energy statistics, bioenergy balances, and commercial trading operations.

Woodchips used as fuels consist of a mixture of hard and soft woods reduced to a size of roughly 5–8 cm and heterogeneous in shape. Woodchips are classified according to moisture content, bulk density, net calorific value, energy density, and particle size.

The UN FAO uses *woodchips* to refer to any chipped biomass mechanically reduced to a defined particle size. Mechanically processing of woodchips involves the use of sharp tools. The chipped biomass is usually rectangular in shape, 5–50 mm in length, and of a generally low thickness compared to its other dimensions.

Figure 1: Different types of woodchips (photo: Flodén).

Woodchips come in many varieties. Cutter chips, either with or without bark, are woodchips produced as a by-product of the wood processing industry. Forest chips are chips of various forest woods in three subcategories: green chips, stem woodchips, and whole-tree woodchips. While green chips are made of fresh logging and thinning by-products, including branches and treetops, stem woodchips are made of trunk wood (i.e., the tree trunk without branches) and can be with or without bark. Lastly, whole-tree chips are made up of all tree parts, including trunks, bark, branches, needles, and leaves. Among other by-products related to woodchips are logging residues, which are wood biomass produced when merchandisable timber is harvested in forests. Logging residues derive from treetops and branches cut while fresh or after seasoning.

2.2. Biofuel Supply Chains

Supply chains for forest fuels either deliver products directly to power plants or use terminals as buffers. Determining terminal locations and the various costs involved, along with the demand of wood fuels, presents complex scenarios for the industry in developing cost-effective, CO_2-neutral energy (Rauch and Gronalt, 2010). The biofuel supply chain starts with natural forests and the wood processing industry (e.g., sawmills, the paper and pulp industry), which are the main sources of raw materials necessary for the production of woodchips. Figure 2 describes the general flow of wood products involving the interaction of important actors in the wood industry.

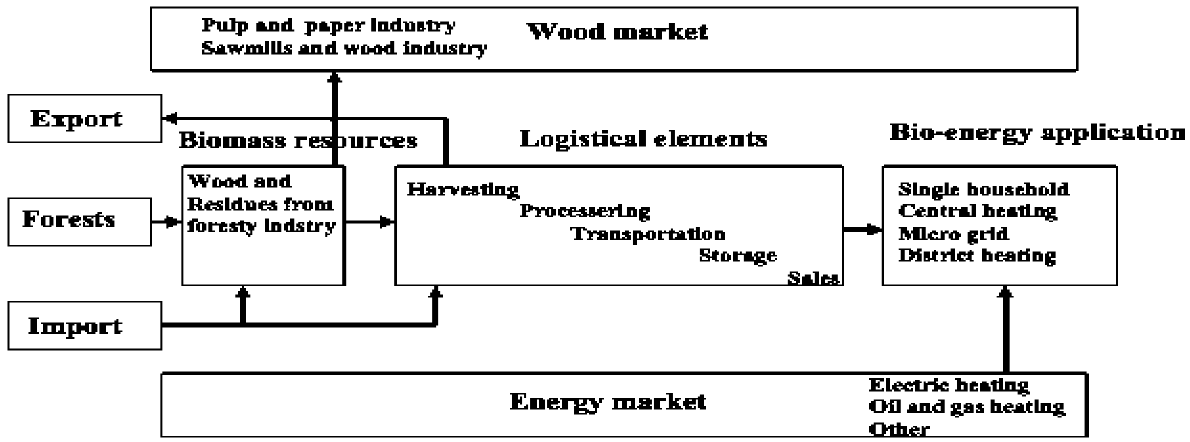

Figure 2: The biofuel supply chain (Energidata AS et al., 2005).

The primary operations of a normal biomass chain are harvesting and collection, storage, transport, and pre-treatment. Gold and Seuring (2011) reveal in their literature review that the overall design of biomass chains is the area most focused upon, followed by harvesting and collection. Topics with less scientific focus are biomass storage and pre-treatment techniques.

Most of the literature focuses on the overall layouts of biomass supply chains, not their components. The area first focused upon in the biomass supply chain is supply chain architecture, which involves optimisation solutions for the location of storage and the chipping process. Biofuel chains are complex and involve different actors and market segments. Though energy plants that use biofuels are smaller than those using fossil fuels, their logistics is more complex, since they require more deliveries due to wood's low energy content (Gold and Seuring, 2011).

2.3. Industry Actors

Important industry actors in wood biofuel supply chains are discussed in this section, along with their current statuses in Sweden.

2.3.1. The forest sector

The use of forest resources has generally always contributed significantly to the Swedish economy, and Sweden's forestland is considered to be an economic resource. In support, for more than a century Swedish regulations have ensured the long-term productivity of forests. In 2000, Swedish exports from forests represented 13% of total exports, which demonstrates the sector's economic importance to the country. In 1993, changes to Swedish regulations regarding forestland gave both associated economic and environmental factors equal importance (Ericsson et al., 2004).

The Swedish National Board of Forestry (2001) has determined that nearly half of Swedish forestland is owned by private, non-industrial owners, that companies own the other half, and that the Swedish state owns a very small share of forestland. However, the government has greater influence in the forest industry than private interests, since one third of the forestland is owned by companies managed by a government-owned company. The remaining percentage of the land is owned by other public organisations such as municipalities and other combined entities. Recent figures from the Swedish Forest Agency regarding ownership show the following breakdown:

- 50% individual ownership;
- 25% privately owned company ownership;
- 14% state-owned companies ownership;
- 6% other private ownership;
- 3% state ownership; and
- 2% other public ownership (Eriksson, 2011).

An estimated 344,000 private forest owners in Sweden belong to one of three forest owners' associations in the country. Forest owners' associations provide assistance to forest owners with managing various forest operations (e.g. harvesting, sales) and inform their members of the importance of harvesting logging residues. Meanwhile, the three largest forest companies in Sweden are Stora Enso, SCA, and Södra. In general, the presence of organised forest owners in the Swedish forest sector indicates the strong influence of these actors on the sector. Other organisations that influence the sector are manufacturers of forest harvesting equipment and transport companies. Transport companies have played a particularly valuable role in the development of wood biofuels, for they could provide the existing transport infrastructure for wood biomass (Ericsson et al., 2004).

2.3.2. Wood processing industry

The wood processing industry, including the pulp and paper industry, wields significant control over the flows of wood biomass, for they both are major consumers of wood and produce a large share of the raw materials for wood biofuels. The relationship between the forest and energy industry is also historically significant. Wood processing companies are often large buyers of electricity and own facilities that generate electricity with steam-powered turbines usually present at sawmills. In turn, sawmills are often involved in providing waste heat and electricity to neighbouring communities in addition to wood biofuels. Some pulp and sawmills have integrated into their operations the production of refined wood biofuels such as wood pellets.

Swedish wood processing companies have also been involved in research and development programs for the industry, which has induced the coordinated harvesting of timber and logging residues for use as biofuel (Ericsson et al., 2004). Woodchips are also used as a raw material for the production of pulp and paper, though the quality requirements for chips to be used as pulp are higher than they are for energy use, making woodchips for pulp more expensive. A certain competition among the industries for raw materials exists, since power plants can easily burn high-quality pulp chips if the price is right.

2.3.3. District heating

Like most northern European countries, building the DH sector in Sweden started with municipality initiatives and were later managed by municipalities as well. Later, control was shifted to municipally owned companies, some of which were later sold to large international utilities. These large companies now provide 42% of the energy produced by the DH sector. The Swedish population has generally accepted the DH system, which has supported its development (Ericsson, 2009).

DH systems have been widely accepted in Sweden due to the country's cold climate and thus seasonal high demand for heat energy among the general population. The main drivers behind the success of DH systems are high fuel efficiency, low emissions, and fuel flexibility compared to the single household heating system. Local authorities play a vital role in the physical planning and selection of heating systems in Sweden. Decisions regarding the development of infrastructure, including place of construction and type of both heating system and roads, are made by local authorities. In this regard, political decisions and the fixed costs of establishing a DH system are crucial (Ericsson et al., 2004). HPs require large investments, though their benefits have promoted their construction since the 1950s. The first 10 HPs in Sweden involved oil-powered CHPs. Later, with the development of the nuclear energy sector and lower electricity prices, the DH sector became less attractive. Yet, with the help of a Swedish scheme for tradable renewable electricity certificates introduced in 2003, investments in the DH sector have returned. In 2007, the DH sector provided 7.5 TWh of energy, 42% of which was produced from biomass (Ericsson, 2009).

Generating electricity is highly integrated into DH systems, which has given rise to CHPs. In Sweden, however, the potential of CHPs has not yet been fulfilled. A factor considered to hinder the developments of CHPs in Sweden is the dominance of nuclear energy in the electricity sector, which limits the economic growth of CHPs. The increased generation of nuclear electricity resulted in surplus electricity in the 1990s in Sweden, and nuclear power has been largely dominant ever since (Ericsson et al., 2004).

2.4. Sustainability

Sustainability suggest that our economic systems should be managed in ways that allow societies to live off of the dividends of current resources so that future generations will be able to live as well, if not better. The most common definition of *sustainability* comes from the Brundtland Commission, which defines *sustainable development* as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (World Commission on Environment and Development, 1987). This definition highlights the concept of the needs of both present and future generations and how they should be aligned with nature’s ability to provide resources. Anand and Sen (2000) provide a more general discussion about sustainability and our responsibility toward future generations. Many other definitions of *sustainability* have been suggested in logistics research (e.g., Janic, (2006); Seuring and Müller, (2008); Carter and Easton (2011)).

Sustainable development can further be divided into three areas: environmental sustainability, economic sustainability, and social sustainability (Carter and Rogers, 2008). While environmental sustainability concerns emissions and the use of natural resources, economic sustainability concerns the long-term profitability and survival of the system. Lastly, social sustainability concerns society and social responsibility, including aspects such as health and safety, employment, social equity, and human rights. Together, the three areas highlight the holistic view of sustainability, since all areas must be sustainable for the entire system to be sustainable. As Petter Stordalen has phrased it, ‘There is no business on a dead planet’.[1] Sustainability also involves inter-community aspects, since a high level of sustainability in one area cannot outweigh unsustainability in another area. For example, it is not considered sustainable for a company to be green and have a very low environmental impact while taking economic losses and ultimately going bankrupt.

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[1] http://www.stordalenfoundation.no/EN/

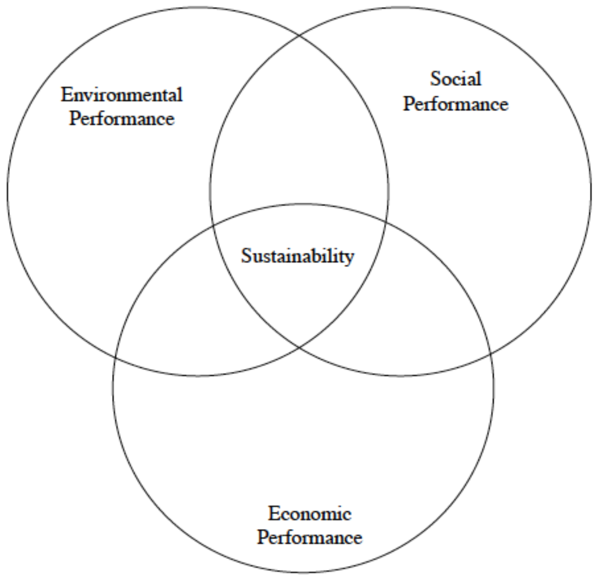

Figure 3: The relationship among the three pillars of sustainability (Carter and Rogers, 2008).

Figure 3 illustrates the balance among environmental, social, and economic performance that sustainability seeks in any process.

2.4.1. *Environmental sustainability*

Environmental sustainability refers to the maintenance of natural capital, which Goodland (1995) defines in terms of output and input rules. Whereas the output rule is related to waste emissions, which should be kept within the assimilative limits of an environment, the input rule relates to the use of renewables and non-renewables along with operational principles. Sutton (2004 pp. 11) describes environmental sustainability as 'the ability to maintain things or qualities that are valued in the physical environment'. Here, the physical environment is the natural and biological environment around us.

By some contrast, Park (2007) describes environmental sustainability as 'the long-term maintenance of ecosystems and other environmental systems for the benefit of future generations'. From this definition, it is clear that environment sustainability results in the maintenance of natural resources in the state in which they exist, as well as benefits future generations, which is consistent with the Brundtland Report.

By still greater contrast, Ekins (2011pp. 637) defines the term as the 'maintenance of important environmental functions, and hence the maintenance of the capacity of the capital stock to provide those functions'. This definition associates the maintenance of capital with the maintenance of vital environmental functions, which helps to explain environmental sustainability in economic terms.

To achieve environmental sustainability, logistics is paramount, given the emissions produced by various processes in the supply chain. The environmental sustainability of a supply chain, which is often referred to as the greening of the supply chain, involves environmental issues associated with decisions in transport, storage, inventory control, warehousing, packaging, and facility location. The aim of green supply chain management is to reduce the carbon footprint of all activities involved in the chain (Min and Kim, 2012). Wiedmann and Minx (2008 pp. 4) define *carbon footprint* as 'a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product'. CO_2 released from vehicles is the most significant representative of air pollution, and its measurement provides meaningful information for developing environment-related policies (Lumbreras et al., 2013). Companies willing to improve environmental sustainability prefer that their suppliers reduce their environmental liability as much as possible (Sarkis, 1995).

***Assessing environmental sustainability*.** The definitions presented here all prioritise the maintenance of the environment in terms of processes and the state. Maintaining the environment requires monitoring the environment. Ekins (2011) discusses how environmental sustainability can be expressed in terms of capital, yet concludes that the valuation of environmental functions is extremely complex, given their non-marginal nature and/or high costs that arise from the loss of environmental functions. Defining safe minimum standards for the valuation of environmental functions has been proposed to reduce such complexity, and various challenges involved in developing these standards have been data generation and understanding ecosystems. In past decades, these challenges were met with developments in climate science and GHG accounting protocols. The OECD (2001) has outlined a strategy for achieving environmental sustainability, which involves five general objectives:

- Maintaining the integrity of ecosystems via the efficient management of natural resources;
- Decoupling environmental pressures from economic growth;
- Improving decision-making processes by advancing the measurement process;
- Enhancing quality of life; and
- Achieving global environmental interdependence involving the improvement of governance and cooperation.

After certain indicators have been established for indicating sustainability, they should be measured both quantitatively and qualitatively. A chief difficulty in this regard is the selection of appropriate indicators, not data collection. The different indicators may refer to different objectives or values depending upon the national or international policies (Moldan et al., 2012). Since environmental sustainability can be dictated by objectives, a prominent example in this regard is the European Council's objective of reducing GHG emissions by 20%, making renewable sources 20% of all energy sources, and increasing energy efficiency by 20%—all by 2020 (EC, 2007). Such an understanding of environmental sustainability precipitates the development of measures to develop standards for monitoring the achievement of environmental objectives.

In supply chains, environmental sustainability can be estimated by calculating the external costs related to the chain. Button (1993) states that external costs occur when the welfare of one group is affected by the activities of another without any compensation. External effects can be either negative or positive, though most related to transportation are negative (e.g., noise, visual intrusion, risk of accident, emissions, congestion). External costs are also closely related to social costs and their valuation. External costs associated with freight transportation can be measured in different ways, though are always associated with the measurement of emissions (Mckinnon et al., 2012). The payment of external costs should not be considered a sustainable activity, since it involves paying for an activity that can be avoided, meaning that the continuation of the practice would weaken economic sustainability. Such a practice would also undermine environmental sustainability, whose underlying principle is to conserve the environment for future generations and not to simply pay extra to be allowed to damage it.

2.4.2. Economic sustainability

Barbier (1987) has outlined four criteria for sustainable economic development, which are as follows:

1. Economic growth cannot be separated from the society, since economic changes are associated with social, cultural, and ecological changes;
2. Any quantitative aspect of sustainable economic development is associated with the increase in materials for the present and future generations that live in poverty, which can substantially support physical and social well-being in efforts against poverty;
3. Any qualitative aspect is multidimensional and requires ensuring long-term ecological, social, and cultural potential in support of economic activity and structure; and

4. Quantitative and qualitative aspects are not easily measureable.

The abovementioned criteria associate sustainable economic development with the increase of material standards for the poor. This material increase can be measured in terms of increased food, real income, educational services, healthcare, sanitation, and water supply, among other aspects. In sum, the objective of sustainable economic development is to reduce poverty by providing long-lasting livelihood while minimising resource depletion and environmental, cultural, and social damage (Barbier, 1987). Aspects of sustainable economic development can be associated with companies as well, which aid economic development by providing jobs, income, and other benefits to people in the society.

While differentiating the three pillars of sustainability, Goodland (1995) has defined *economic sustainability* as the maintenance of capital that keeps economic capital stable. Economic sustainability can also be seen in terms of a firm's social responsibility. Carroll (1979) states that principal social responsibility of a firm is to fulfil its economic responsibilities, which include making the organisation to act as a business in society and to produce goods to be sold at a profit. All other business roles should be based on this fundamental assumption. Moldan et al. (2012) stress that the economic crises have highlighted the need for economic sustainability; these crises urge countries to keep focus on the maintenance or restoration of economic capital. Nevertheless, striking a balance between economic growth and sustainability has been a challenge for modern societies.

Carter and Rogers (2008) state that the economic responsibility of firms seems to be lacking in literature addressing logistics and purchasing social responsibility, which makes it difficult to define sustainable logistical practices. They argue that being environmentally and socially sustainable may or may not be profitable at times. Earlier, Bowen et al. (2001) describe that green (i.e., environmentally sustainable) supply chain management practices would be adopted by organisations if particular financial or operational gains were involved. These financial gains can be regarded to contribute to the economic balance that organisations seek along with environmentally friendly activities. Rao and Holt (2005) have concluded that making supply chains greener has the same potential in terms of economic performance and competitiveness as that of non-green supply chains. They argue that if organisations implement green supply chains, then they will not only save costs but also be able to enhance sales, market share, and new market opportunities, thereby prompting enhanced economic performance.

Green activities can be referred to as economically sustainable activities involving the intersection of environmental, societal, social, and economic bottom lines. Carter and Rogers (2008) provide the following examples based upon their literature review:

- Cost savings due to reductions in waste and packaging;
- Reduced health and safety costs;
- Reduced labour costs due to increased motivation with improved working conditions;
- Proactively shaped future regulations by continuously focusing on changing environmental and social concerns;
- Reduced lead times and costs result in better product quality; and
- Improved reputation.

From all of the above, it is clear that sustainable supply chain management involves the long-term economic performance of supply chains, not only their environmental and social sustainability.

Assessing economic sustainability. In the current study, economic sustainability is viewed according to Goodland (1995), who assumes it to be the maintenance of capital. Carroll (1979) view that any company's first responsibility—to make profit—also fits well in supply chains in which costs should not outweigh profits. The examples of green activities given by Carter and Rogers (2008) said to be environmentally and economically sustainable involve mostly cost-saving activities. Therefore, to evaluate the economic performance of a process, its costs need to be identified. Long-term economic performance can be measured in terms of costs incurred by the various activities in a supply chain. In all, the estimation of costs and measurement of economic performance of a process contribute to the measurement of economic sustainability.

Savitz and Weber (2006) definition of *sustainability* that refers to good corporate citizenship as a principle of smart management further reinforces Carroll (1979) ideal of making profit by reducing costs. To have smart management and economic sustainability in supply chains, a logical starting point is the estimation of the chain's costs. Economic sustainability can be expressed in monetary terms easily divided into costs and revenue. The estimation of costs can help to define the economic performance of a firm or supply chain.

Flodén (2007) explains that identifying the various costs in a supply chain can be complex. Identifying incomplete costs or revenues of a supply chain can lead to an incorrect representation of economic sustainability. Calculations of costs involve a great variety of estimations since different factors and actors influence costs differently. While estimating costs, determining the cost variables can be more helpful than the actual costs, since determining cost variables and what they depend upon allows the calculation of actual costs in different scenarios. The cost variables for a supply chain system have to relate to operational transport activities.

The price and cost of transportation are two different concepts since the price charged for transportation can be influenced by a wide variety of factors. Like any industrial costs, transport costs can be divided into the two general categories of fixed and variable costs. These fixed and variable costs also depend upon the period in which they are studied. For example, the rent of a terminal area can be regarded as a fixed cost; however, if closing the terminal is an option, then rent can be regarded as a variable cost. Similarly, a predefined train schedule can be regarded as a fixed cost; however, if variability is possible in the schedule, then it should be deemed a variable cost. As such, fixed costs can be variable costs considered to be fixed for a specific period.

Fixed costs can be further divided into other categories, including shared costs, which are shared by different actors or transport modes within a supply chain. Numerous studies show that variable costs can also be divided into two major categories: time and distance transported. Examples of common time dependent costs are financial costs, salary costs, vehicle taxes, and insurance, while common examples of distance-dependent costs are tires, fuels, maintenance, kilometre taxes, and rail infrastructure fees. It should be kept in mind that some of these costs can be fixed depending upon the time frame (Flodén (2007).

2.4.3. Social sustainability

Social sustainability is an overlapping concept that involves topics such as social capital, social cohesion, social inclusion, and social exclusion. Invariably, social sustainability is considered in light of the goals of social development, which can be highly diverse (Hopwood et al., 2005, Littig and Grießler, 2005). Similar to that of sustainability itself, the definition of social sustainability cannot be fixed, since it is a dynamic concept that changes over time. Changes may be caused by external influences; for example, changes in the local authority service can affect social cohesion and the interaction of societies (Dempsey et al., 2011). Labuschagne et al. (2005) have identified criteria for social sustainability for industries that encompass general themes of internal human resources, external population and stakeholder participation, and macro social performance. The criteria have been developed based upon various frameworks of sustainability such as the Global Reporting Initiative, the UN Commission on Sustainable Development Framework, the Sustainability Metrics of the Institution of

Chemical Engineers, and Wuppertal Sustainability Indicators. The general themes given by Labuschagne et al. (2005) are:

- Internal human resources, which focuses on the social responsibility of the company toward its employees;
- External population, which is related to the external effects of the company on the community in which it operates;
- Stakeholder participation, which is related to treating its stakeholders in an ethically and socially responsible manner.
- Macro social performance, which involves the impact of a company on a regional or national level (Labuschagne et al., 2005).

Hutchins and Sutherland (2008) describe how corporate social responsibility (CSR) is important to the social pillar of sustainability. Many definitions of *CSR* refer to ethical behaviour related to the environment, society, and the economy. The goals of social sustainability and CSR tend to cater to basic needs by reducing poverty, increasing human health, and protecting ecosystems, yet also include higher-level needs, as well such as education and gender equity. Companies can meet their social sustainability and CSR goals by fulfilling the basic needs of the society in which they exist and extending their efforts to meet higher-level needs such as safety, quality of life, and equity.

Hutchins and Sutherland (2008) have also proposed four indicators of social sustainability in the various actors of the supply chain that need evaluation: labour equity, health care, safety, and philanthropy. These indicators form portions of the criteria suggested by Labuschagne et al. (2005), which can be used to promote the social sustainability of the whole company.

Lammgård (2007) argues that information about attitudes, preferences, and needs of the companies toward environmental or intermodal road–rail transport solutions will help to not only segment the industry but also to define the demands and needs of freight transportation. Such findings can be used to clarify the acceptability of sustainable practices in supply chains by identifying the attitudes, preferences, demands, and needs of the different actors. The attitudes and preferences will also highlight the conditions in which sustainable activities can be applicable.

Assessing social sustainability. Though the above discussion provides the general themes and indicators of social sustainability, in supply chains these indicators are highly dependent on the nature and context of the business. Since most sustainability research related to transport focuses on environmental aspects, social aspects of sustainability in supply chains are seldom studied (Gold and Seuring, 2011). In response, the social cost perspective includes a great variety of actors not limited to governments and public sectors, but involving each individual in the society. The valuation of external social effects is often made in light of investments in infrastructure and political decisions and involves a kind of monetary estimation of the external social effects caused by transport activities. However, in reality the determination of such costs is difficult; for example, the destruction of a natural habitat due to infrastructural construction cannot be valued in monetary terms.

Zhou et al. (2000) describe how social sustainability can be ensured by meeting the needs of the product's population. This approach holds that fulfilling the demands of the population with a certain product promotes social sustainability in continuous process industries. This type of measure can relate to supply chain activities instead of actors, as identified by Hutchins and Sutherland (2008).

In the current study, Lammgård (2007) view of defining the demands and needs of freight transportation by investigating the attitudes and preferences of the industry has been applied. This approach indicates the acceptability of sustainable practices involved in supply chains within the context of wood biofuels. The attitudes and preferences of the power plants demonstrate the acceptability of sustainable intermodal activities in wood biofuel supply chains. The reason for focusing on the attitudes and demands of the actors involved in the DH supply chains is that traditional indicators have little importance for these actors.

The primary contributions of the DH industry are in terms of environmental sustainability, not social sustainability. It is difficult to pinpoint the labour equity, health care, and educational benefits of actors in wood biofuel supply chains, for the industry caters to the environment instead of issuing social benefits. Nevertheless, safety and employment stability can be highly relevant to actors in wood biofuel supply chains since these companies work in rural areas that have provided jobs and safety to their employees. Another theme that indicates the social sustainability of actors considers their macro social performance in supply chains.

2.4.4. Applying sustainability

Barbier (1987) describes how sustainable development involves a trade-off among environmental, economic, and social aspects of a system and claims that it is not possible to optimise all three functions all of the time. Any economic process that depends upon conditions such as the even use of resources and services may conflict with the maximisation of productivity and preservation of genetic diversity of the ecological and resource system. Thus, depending upon the objectives, decisions should be made regarding what trade-offs should be given priority, and the process of selecting relevant trade-offs should be adaptable to different scenarios. Individual preferences regarding economic, environmental, and social aspects may change over time and have different degrees of importance in different situations. Variations of economic, environmental, and social goals may also occur depending upon the region, since different regions have different preferences.

The dynamic aspects of sustainability based upon time, personal preferences, region, and several other conditions make decisions concerning trade-offs possible based upon objectives. In other cases, certain aspects may have more significance than others. Supply chain management poses implications for three aspects of sustainability, depending upon the type of supply chain. For example, an urban supply chain might focus on social and environmental factors rather than economic factors, while a freight distribution supply chain might not be able to induce many social impacts. In fact, social impacts may become less prominent in industrial regions where the majority of business activity occurs among companies focusing on costs. As above-mentioned, making supply chains green may or may not imply cost-effectiveness. However, with advancements in environmental sustainability, significant economic gains can be achieved by making supply chains green. Reducing packaging and introducing intermodal transportation are just a few examples.

2.5. Sustainable Transport

A sustainable transport system (STS) should uphold the three aspects of sustainability discussed at length in the previous section. In general, an STS should increase economic growth and social equity without damaging the environment. The European Commission (2004) has outlined STSs as follows:

- An STS allows access and the development of people, organisations, and societies while meeting the safety needs and not deteriorating the health of humans or the ecosystem;
- An STS should promote social equity for the current and future generations;
- An STS is affordable and functions properly with the chosen mode selection to support a competitive economy while balancing regional development; and
- An STS reduces the emissions by restricting the use of non-renewable fuels to the extent at which the planet can absorb them back, as well as minimises emissions and noise impacts, ideally by using renewable resources.

However, the above definition does not fully align with the concept of sustainability, which holds that non-renewable fuels should never be used in an STS and that the choice of mode should be limited to the best modes and exclude all others (Behrends et al., 2008).

2.6. Intermodal Transport

Generally, intermodal transportation involves promoting the benefits of different modes of transportation in a single organised transport chain. Road transportation offers the flexibility and ease of reaching different destinations, while rail and sea transport enable large volumes of goods to be transported over long distances at low costs. A combination of these different modes can help to reduce costs for transporting goods. For example, distribution and collection networks are usually over roads, while longer hauls are normally performed via rail or sea transport. Terminals are used to shift from one mode to another. To make the system efficient, goods are carried in standardised load carriers called intermodal transport units (e.g., containers, swap bodies, semitrailers (Flodén 2007, Bektas and Crainic, 2007).

2.6.1. Definitions

The concept of intermodal transport can be narrowed with standardised terms, for the combination of multiple modes has been defined in different terms. The most commonly used terms are multimodal transport, combined transport, intermodal transport, and co-modality (Reis et al., 2013). An early definition of multimodal transport provided by the United Nations (1980) states that international multi mode transport involves utilisation of at least two different modes. In an international construct the goods are taken from one country and delivered to a destination in another country by the use of at least two modes operated by a transport operator.

More recently, the United Nations (2001) defined multimodal, intermodal, and combined transport. While multimodal transport is ‘the carriage of goods by two or more modes of transport’, intermodal transport is ‘the movement of goods in one and the same loading unit or road vehicle, which uses successively two or more modes of transport without handling the goods themselves in changing modes’. Lastly, combined transport is ‘intermodal transport where the major part of the European journey is by rail, inland waterways, or sea, and any initial and/or final legs carried out by road are as short as possible.’

2.7. Chain Components

Jensen (1990) explains that the key feature of intermodal transport is the combination of cost and service benefits of different modes to improve the overall efficiency of the transport network. Reis et al. (2013) describe intermodal freight transport as the integration of transport agents. Theoretically, the performance of all transport agents can be optimised, though the maximum performance that can be achieved in the real world will always be lower than the theoretical performance.

Nozick and Morlok (1997) explain that rail transport in intermodal chains begins and ends at terminals. Goods are transported to terminals by road at both the origin and destination. Goods in intermodal chains are either carried in load units (e.g., containers, trailers). A shipper loads an empty load unit, which is taken to the origin terminal and transported to the destination terminal by rail, accompanied with the necessary routing information. At the destination terminal, the train is unloaded and the goods are taken to the consignee by road. Due to uneven flows between the origin and destination terminals, normally positioning the empty and filled load units is required and should be considered in the system. Figure 4 illustrates intermodal chains developed by Flodén (2007).

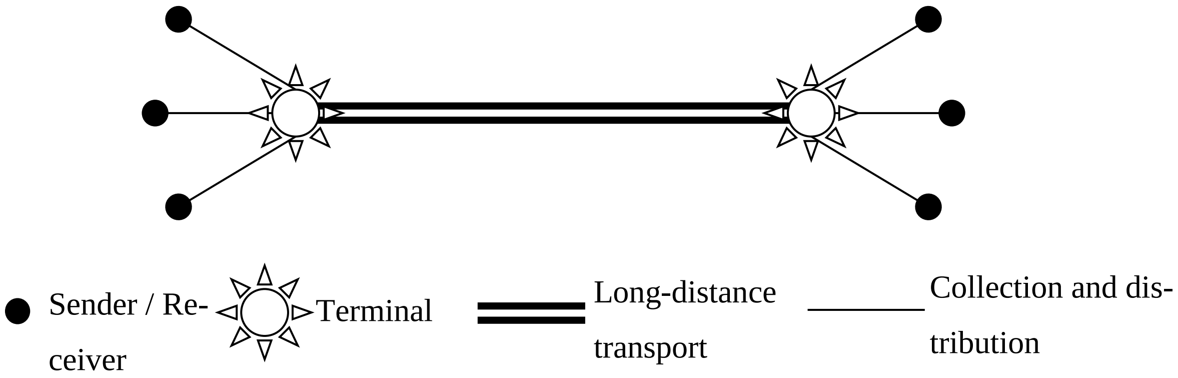

Figure 4: A typical intermodal supply chain.

2.7.1. Terminals

Intermodal terminals can be privately or publically owned and include rail yards and air, sea, and river ports. The key roles of intermodal terminals include providing space and equipment to exchange loads between different modes. Other roles of the terminal may include storage and the consolidation and/or sorting of vehicles and goods. Thus, terminals perform a critical role in the intermodal supply chain, and delays in terminal operations can reduce the efficiency of the whole chain. Operations at different intermodal terminals (e.g., land terminals, seaports, airports) might differ, though their purposes remain the same. Equipment present at the terminals can differ as well; seaports are often equipped with quay cranes and forklifts, among other equipment (Bektas and Crainic, 2007).

Several factors are involved in the success of an intermodal terminal's operation. The high use of terminals does not necessarily mean that the overall system is efficient. Intermodal terminals require the fast transhipment of goods between different modes, yet have trouble with competing for large flows over medium distances, suggesting the number of terminals should be kept to a minimum. For short distances, costs depend upon road transport, which often involves travelling long distances or in opposite directions to reach terminals. Intermodal terminals thus need to be integrated well into the overall supply chain (Jensen, 1990).

The ownership of intermodal terminals is decisive in most transport systems. Forwarders often keep the consolidation of goods to themselves, while the movement of goods between terminals is contracted out (Bergqvist et al., 2010).

A large flow of goods requires trailers with heavy containers and swap bodies, which in turn require large terminals that are expensive to operate. Such conditions require few large terminals with substantial distance among them for the system to be efficient given high transhipment and maintenance costs (Nelldal et al., 2005).

2.7.2. Load units

In outlining the various components of intermodal chains, Bektas and Crainic (2007) describe the importance of load units and terminals. Intermodal chains rely heavily on containerisation for its many benefits, including safety and handling. The standard structure of containers used also facilitates the exchange between modes, thereby reducing handling costs. Terminal equipment and operating procedures are often improved to save on costs associated with handling the containers. Some load units used in intermodal chains are discussed in what follows.

Lorry and trailer combinations. These units include conventional freight-carrying vehicles that tow separate load trailers to form what is known in Europe as a *road train*. Depending on weight restrictions, vehicles can have any combination of four-, five-, or six- axle configurations. Trailer axles often include a steerable front with a single or double bogie fitted at the rear. The rear can be separated from the vehicle and stand on its own wheels alone with landing legs. An alternative to such a design includes two or three closely spaced axles, which are non-steerable and located centrally along the length of the trailer. Trailer combinations are generally designed to carry 6 meters ISO containers or a 7.15- or 7.45-m swap body. The skeletal frame of the vehicles includes twist locks for fastening containers or swap bodies (Lowe, 2006).

Containers. Freight containers are usually built according to standard dimensions set by the International Standards Organization (ISO), hence the term *ISO container*. These containers are equipped with twist locks and can be lifted from the top by special container cranes, straddle carriers, or stackers. ISO containers have fork pockets underneath so that they can be carried by heavy-duty forklifts. Standard ISO containers are 6, 9, 12, and 13.7 metres long, 2.4 meters wide, and either 2.6 or 2.9 meters high. They are built to be strong and can usually be stacked eight or nine units high. In Europe, 6 and 12 meters ISO containers are the most commonly used since these measurements fall within the legal dimensions of road transport on the continent. Bigger and/or specialised containers are also used for special purposes (Lowe, 2006).

Swap bodies. Swap bodies are lifting units with strong material for lifting on and off of road and rail vehicles. Both 7.15- and 7.45-m long swap bodies have fold-down legs that enable them to stand alone. Lifting pockets appear underneath all swap bodies for lifting purposes. Swap bodies are not as strong as ISO containers given their lighter construction; however, savings on tare weight and increased payload potential are attractive (Lowe, 2006).

2.7.3. Transportation

Every mode of transport can be used in an intermodal transport system. The different modes of transport are road, rail, inland shipping, short sea shipping, deep sea shipping, air, and pipeline. In this study, rail and road are discussed since biofuels are currently transported largely via these modes.

Rail freight. Rail transport of large volumes over long distances results in lower costs and emissions. In an intermodal setting, rail transport uses intermodal rail wagons that can carry ISO containers, standard swap bodies, or whole vehicle combinations. ISO containers are usually carried on skeletal flat wagons with low loading heights to carry 2.9 meters tall ISO containers fitted along with twist locks at 6- and 12-meters centres. Whole vehicles are carried on special pocket wagons that keep them securely fastened. The vehicles are kept low so that they can pass through bridges and tunnels (Lowe, 2006).

Road haulage. Transporting goods generally starts with a road transport carrying the goods loaded in an ISO container or swap body. The initial choice of vehicle may depend upon the shipper or the road haulier responsible for the movement of goods. Road hauliers may transport goods all of the way themselves or may transfer loads to a rail or ship for the long haul, after which a local road haulier becomes responsible for delivering the goods to the destination. The shipper can arrange such an arrangement as well. Other actors can be involved in the intermodal supply chain, including freight forwarders, which do not own any vehicles but contract necessary actors in the chain. These actors act on the behalf of the shippers. Freight forwarders exist to make the transport of goods simple and easy for the shipper (Lowe, 2006).

2.7.4. *Chain characteristics*

Flodén (2007) elaborates that costs in an intermodal transport system incurred at a terminal must be kept lower than the usual road transport costs. This guideline implies that a practical intermodal transport system should try to minimise the use of terminals and maximise the long-haul transport system. The balance of costs of terminals and long hauls shows that intermodal transport may not be competitive for short distances. A certain distance, which is highly case sensitive between the sender and receiver of goods, is said to be a minimum requirement for any intermodal transport system. However, this requirement can be altered with better management and advances in the technology or equipment, according to different studies.

Bergqvist and Flodén (2010) describe how intermodal transport systems have substantial potential to reduce CO_2 emissions given increased road–rail transport. However, certain challenges such as technical developments, attitudinal changes among actors and the need of differentiated business models still exist. Strong competition and low value transport customers make it difficult to invest in methods to reduce emissions. In this regard, operating principles are needed to develop standardised market requirements.

Lowe (2006) summarises some benefits of intermodal transport with single load units:

- Low transit costs while covering longer distances;
- Fast delivery times;
- Reduced traffic congestion;
- Less environmental pollution (e.g., noise, emissions, vibrations); and
- Reduced energy consumption when long hauls are made via rail or sea.

Konings (1996) identifies shortcomings of intermodal transport systems that require attention. For instance, intermodal transport chains often face certain disadvantages compared to other chains, including cost competition with direct road transport in the absence of terminal costs. However, this shortcoming is often balanced by the added advantages of handling. For short distances, these costs are higher, which thus limits the minimum distance in the system, and due to the added costs, it is necessary to save costs in the total cost of the system. Achieving reliability and reduced transit times is also troublesome for intermodal transport, especially at points where loads are exchanged between modes, which to reduce makes standardised load units for different modes seem vital. Furthermore, huge amounts of goods moved via intermodal transport will pressure not only handling terminals but also pre- and post-haulage performed by trucks. A greater number of loads means the increased use of trucks to collect and distribute goods at both ends of the intermodal chain. In response, researchers have sought solutions that promote cost-effectiveness and quality (Konings, 1996).

The shortcomings of the intermodal chain are also shared in wood biofuel supply chains as well, in which road transport dominates alongside issues with handling operations. Current policies and the increased demand of biofuels will involve international trade and long-distance transport of goods in large quantities. Transport costs can be determined by vehicle costs, availability, and biofuel characteristics in the case of bulk carriers (Lamersa et al., 2012). Transport is a vital part of biomass supply chains and can substantially add to costs depending upon the geographic locations of the supply and consumption points, as well as transport options (Miao et al., 2012). Though residential areas usually use domestic biofuel resources, much industry growth is anticipated in the power plant sector, which generates both heat and electricity (Hoefnagels et al., 2014). Transport in wood biofuel supply chains consumes the most fossil fuels. Studies have shown that using a combination of rail and road can allow the transport of large volumes with less energy use over longer distances (Lindholm and Berg, 2005).

2.8. Swedish Railroad Intermodal Transport System

In 1996, the deregulation of rail freight transport in Sweden led to open competition. The Swedish National Rail Administration (Banverket) had owned the railway infrastructure in the country, though such ownership was divided among the railway companies to cultivate competition among railway organisations (Lammgård, 2007). The three major forwarders Schenker, DHL, and DSV and the railway company Green Cargo are principal actors in the Swedish industrial transport system. In the past, the hauling company Bilspedition and a subsidiary company of the state-owned railway company called ASG dominated the road haulage sector. Furthermore, Swedish state railway company SJ had a monopoly in rail transport (Flodén, 2007).

In the early 2000s, the whole Swedish intermodal network structure was simplified and almost completely dismantled, resulting in all trains operating between just two terminals (Almotairi et al., 2011). The activities of the Swedish Road Administration and Banverket were merged into the Swedish Transport Administration (Trafikverket) on 1 April 2010. The railway network administered by Trafikverket consists of 11,900 km of track, 3,700 km of which consist of multiple or double tracks. The Swedish road network has 98,400 km of state roads; municipal roads consist of 46,500 km, while private roads receiving state subsidies comprise 75,900 km. Around 19,700 km of roads, or 20% of the country’s total road length, are gravel, and approximately 66% of gravel roads appear in Sweden's forest counties (Trafikverket, 2010a).

2.9. Wood Biofuel Supply Chain Actors

2.9.1. Terminals

Terminals used in wood biofuel supply chains can provide different services, including moisture content measurement, weighing, chipping, and storage. Chipping at a terminal can be performed only if away from residential areas due to the noise and dust produced during the process (Wolfsmayr and Rauch, 2013). Terminals are specifically used by HPs to accommodate seasonal fluctuations and capable of storing chipped and non-chipped wood biomass along with by-products from sawmills (Rauch and Gronalt, 2010, Wolfsmayr and Rauch, 2013). The reduction of terminal costs depends upon the entire wood biofuel supply chain, since the involvement of terminals often results in additional costs due to storage and other operations. However, chipping and transport costs can be reduced with high scales of input (Rauch and Gronalt, 2003).

Terminals tend to have either permanent or mobile chipping equipment on site. They often have a specified storage capacity for different type of wood biomass. For example, chipped wood biomass must be stored on a hard surface and protected from rain, meaning that different costs are incurred for storing different types of wood biofuels. Another reason is that storage period reduces the energy value of the wood biofuels; as such, their separation needs to be maintained. Terminals near harbours do not provide the possibility of chipping and thus are used only for imported wood biofuels. Often, terminals at plants have limited storage capacity, which requires wood biomass to be chipped upon arrival. Terminals are also said to provide good service in terms of using different modes of transport (Gunnarsson et al., 2004).

Required storage time of wood biofuels at terminals depends upon customer demand and contracts. To manage seasonal fluctuations, power plants require terminals to have buffer stocks to bridge the gap between the supply and demand of wood biofuels. A terminal needs to develop substantial stocks before supplying to a new power plant in order to deliver the desired service. This process requires estimating the input stocks that a plant requires to operate, along with the safety stocks that the plant and terminal can secure. With the knowledge of monthly stock needed for a plant, the respective storage capacity and investment can be calculated. Calculated costs should also take into account the maintenance costs of the stocks (Gronalt and Rauch, 2007). Transhipment operations at terminals add fixed and variable costs to wood biofuel supply chains (Mahmudi and Flynn, 2006).

Stockyardsterminalen is a prominent example of a terminal that handles wood biofuels in Sweden. The terminal has rail access and consists of 50,000 m^2 of storage. The company Stockyardsterminalen AB was founded in February 2008 and is owned equally by the municipality of Sävsjö and Sävsjö Transport AB (Stockarydsterminalen, 2009).

Wolfsmayr and Rauch (2013) describe the general type of terminals used in wood biofuel supply chains, as follows.

Industrial terminals are often located near forest-based industrial plants equipped with a stationary chipper for pulp wood, which can also accommodate forest fuels (Rauch and Gronalt, 2010).

Train terminals are often used to store large amounts of wood, which need to be transported for further use over long distances involving multimodal transhipment.

Simple terminals are present in forest areas whose sole purpose is to provide storage.

2.9.2. Transport actors

Internal competition in truck transport due to its wide use keep transport costs competitive. Wood biofuels from forests can be carried to plants in three forms: point-of-origin form, as part of another product, or in reduced particle size. Point-of-origin form involves carrying fuels in their harvested form and is rarely used due to low bulk density and high unit weight transport costs, unless compression techniques are used to increase payloads. This form also increases loading and unloading costs at facilities due to the heterogeneous nature of wood biomass. This form is only suitable for short transport distances between the point of origin and consumption. The form in which wood biofuels are carried along with other products is a commonly used method. Bark on round wood used as wood biofuel is a common example. The tree section method used in Scandinavia is a more specific form that involves leaving branches attached to the trunk. At a pulp mill, both the trunk and branches are taken where branches and bark are separated for energy purposes while the trunk is used for pulp production. However, if the point of consumption is not present at the pulp mill, transport costs double. The extra costs derive from the loading and unloading costs of the wood residues at the pulp mill and their transport to the power plant (Hankin et al., 1995).

Green Cargo is of special importance in wood biofuel supply chains, as its 2012 company report claims. It satisfies the vast list of Swedish freight transport needs, including fuel chips and pulp woodchips. Green Cargo operations involve rail-based freight transportation complemented by road transport, and the combination of rail and road transport solutions is a key part of its operations. By 2012, Green Cargo had 2,323 employees and provided its services to various industries such as the steel, chemical, automotive, engineering, forestry, and retail industries, including customers such as Volvo, Stora Enso, IKEA, and ICA. It is owned by the Swedish state and administered by the Ministry of Finance (Green Cargo, 2012).

Biofuels in Sweden are increasingly becoming a part of the intermodal transport system. Some major train terminals that handle wood biofuels are Norrland, Jämtland, Hälsingland, Medelpad, Ångermanland, Härjedalen, Dalarna, Småland, Halland, and southeastern Norway, as well as in ports such as Hargshamn in Uppland. Biofuels from these terminals are carried to populated areas such as Mälardalen, Nykvarn, Örebro, Eskilstuna, Uppsala, Karlstad, and Gävle, and potential destinations include Göteborg, Malmö/Lund, Västerås, and Skellefteå.

Trains are estimated to transport approximately 1,400 GWh of biofuel (including peat) per year, though this is a rough estimate since different units of volume are used. The quantity equals approximately 500–750 full trains, though the size depends upon the type and moisture content of the biofuels. Statistics from Swedish wood fuel producers show that more than 40,000 GWh of wood biofuels were sold in the market in 2011. Green Cargo is the most dominating company in the biofuel train transport, followed by Hector Rail; other forwarders involved in biofuel transportation are TÅGAB, CFL Cargo Sverige (formerly MidCargo), RushRail, and Inlandståget AB (Hersle and Berglund, 2012).

Rotary containers (volume = 46 m^3) are primarily used for the train transport of wood biofuels, for which each train carries 60–70 containers (i.e., 2–3 containers on a single carriage). The containers require a special forklift to be unloaded, and generally, 6-meter containers are rarely used in train transport. Most train cycles comprise 24 h, and the common frequency of train deliveries ranges from one to four trains per week, though some routes have higher frequencies (e.g., 14 trains per week).

3. Methodology

This section provides an overview of the methodology, along with the data collection tools used for the study.

This thesis is inspired by soft system methodology as it moves from the state of identifying problems to describing a system, in this case the wood biofuel supply chain. Checkland (1999) states that system thinking is based upon the concept of viewing the world as a system. It is described as:

"The existence at certain levels of complexity of properties which are emergent at that level, and which cannot be reduced in explanation to lower levels, is an illustration of an alternative paradigm – that of 'systems'. The systems paradigm is concerned with wholes and their properties."

Identification of the system and problems were followed by the calculation of costs and CO_2 emissions in a current wood biofuel supply chain. This helped in identifying the sustainable options that can be utilized in a wood biofuel supply chain based upon a case study. The inspiration from soft system methodology helped the study move from different phases of identification of the system to definitions and problems. The study is then concluded with a description of intermodal options that can be applied in wood biofuel supply chains while addressing the various problems in the system.

3.1. Research Theme

The wood biofuel supply chain is considered a system involving logistical activities such as harvesting, storage, transport, and pre-treatment activities. The following table provides the research design of the study:

Table 2: Research design.

Identification and problem description	Paper 1 Paper 2	Literature review
Description of preferences and constraints in wood biofuel chains	Paper 2	Survey Study
Improving sustainability in wood supply chains	Paper 3	Case Study

The first paper describes the wood biofuel literature and thus helped in laying out the problem situation for the wood biofuel supply chains and the logistical challenges found in the literature. The second paper focussed on testing the specific problems, along with a description of the activities involved in a wood biofuel supply chain. The third paper helped in the improvement of sustainable chains for wood biofuel power plants. Figure 5 describes the distribution of the topics in each of the three papers developed.

3.2. Data collection methods

This section describes the various data collection tools that were used during the study. The different sets of tools helped in developing diverse results as different tools result in different insights. The data collection tools used are as follows:

3.2.1. Literature review

The supply chains of wood biofuels are unique in various aspects and require a thorough understanding of the various processes involved in the method of delivery to the energy plants. The literature review carried out as the first part of this thesis helped in understanding not only the concept of wood biofuels but also the wood biofuel supply chain. Blumberg et al. (2005) describe the various purposes of a scientific literature review, which include developing the context of a problem or a topic with reference to previous studies along with several other purposes.

In this thesis the literature review had the purpose of establishing the context of the problem and the topic of wood biofuel supply chains. The first paper described the various definitions used for the wood biofuels in the industry and literature. The literature review also provided an overview of the whole supply chain of wood biofuels, along with the already identified problems. The literature review provided the necessary standpoint of understanding the logistics of wood biofuels along with the existing problems. The literature review study utilised the literature, which was present digitally from journal databases along with research reports from other institutions in Sweden. Usage of online resources gave the benefits of saving time in the literature review process and helped refine the search results to find the most relevant material for the topic at hand.

The literature review focused on the transportation of wood biofuels on different modes. An effort to provide comprehensive results with a focus on domestic wood biofuel transportation was made. The topic of biofuels includes different types of biofuels, along with issues not only in the field of logistics but also other technical fields. Therefore, defining keywords and selecting specific databases was not an easy task, along with the special focus on the domestic wood biofuel transportation. However, keywords used to search the material studied were “biofuels”, “wood biofuels”, “intermodal transport of biofuels”, “wood biofuel supply chains”, “wood fuels transportation”, “wood biofuels transportation”, “biofuel supply chains", and "issues in biofuel supply chains". The databases used were "Science Direct", "Emerald Insight", and "Google Scholar". Since the databases showed different results along with studies related to other geographical locations, a lot of valuable insights were provided by the other research reports from various institutions and organisations, such as the Swedish University of Agricultural Sciences, The Swedish Energy Agency, and Statistics Sweden.

3.2.2. Survey study

A survey is a great tool for obtaining primary data and learning opinions and attitudes (Blumberg et al., 2005). Some researchers consider designing a questionnaire more of an art rather than a science. Such researchers believe that there is no best way to design a question; however, different phrasing and formats provide different results, and all of these results are equally valuable in understanding the respondents (Krosnick, 1999).

A web-based survey was distributed via e-mail during the summer of 2013 to a complete sample of managers at all 76 existing biofuel-using CHPs in Sweden. Selection of CHPs was made due to the fact that they utilize large quantities of biofuels. Such characteristics make them ideal for a study of intermodal transport of wood biofuels. Online surveys have several advantages, as Blumberg et al. (2005) points out, which includes ease in the development and analysis phase. Online surveys are also cost efficient in comparison to other methods, such as surveys delivered via post, and it allows for branched surveys more adapted to the respondent's situation. In addition to the various benefits of web-based surveys, there are some drawbacks associated as well. The most prominent would be the ease with which the respondents can decide not to answer the survey with just the click of the button. This drawback is common to all survey studies; however, web-based surveys are easier to get rid of in comparison to other methods of data collection.

A pre testing was performed for the survey with a few respondents, which provided vital insights to improving the various questions in the survey. The survey was divided into two parts. The first included questions about the equipment and practices at the power plants. These questions covered the general topics of storage, transportation, chipping, and overall supply chain design. The second part investigated the perception of the power plants towards current and desired practices regarding the transport of wood biomass, which involved ranking the different practices or issues on a scale. The survey is provided in appendix. The survey comprised of closed questions with the option of open comments. Scale questions were used in order to determine the attitudes of the respondents towards different supply chain activities, issues, and practices.

Approaching the total population helped perform a census study. Blumberg et al. (2005) describe a census study as:

- "feasible when population is small,
- necessary when the elements are quite different from each other."

A total of seventy-six CHPs exist in Sweden; they have a small population and are easily approachable, especially via email. The second condition for a census study - for the respondents to be quite different - is not quite possible for CHPs, as they have common characteristics, such as storage terminals. Minor differences between the plants can be observed, such as some plants utilize storage terminals away from the plants while others use on-site storage. Similarly, sourcing wood biofuels is different for different plants, as some receive their stocks from the forests while others receive by-products from sawmills. However, due to the small population it is ideal to contact the whole population to get comprehensive results. Such conditions make a census study a suitable approach for studying the supply chains of wood biofuels.

In the current study, respondents who were reluctant to answer were approached through telephone and urged to answer. The total response rate was 42% (n=32). The survey contained 30-38 questions and was made adaptive to the answers given. For example, if the respondent did not use a certain type of fuel the survey adapted and removed related questions.

3.2.3. Case Study

Yin (2009) describes case studies as rich in empirical descriptions of particular instances of a phenomenon that are typically based upon different data sources. Case studies are excellent for building empirical evidence, which helps in building understanding of a particular phenomenon and seeking its application to a more general level. Case studies provide the simplicity and ease of trying and analysing different scenarios before implementing them on a general level.

For this purpose a case study was developed based upon the operations at a plant in Gothenburg, Sweden, owned by Göteborg Energi. The plant provides an opportunity to study intermodal and sustainable chains as it has both rail and road access, along with storage capacities vital in the wood biofuel supply chain. The case study investigates the various costs and environmental effects of transporting wood biofuels to the plant based upon different quantities and sources of wood biofuels. This would be achieved by analysing different scenarios in terms of costs and CO_2 emissions for supplying the plant with wood biofuels.

Social sustainability has been left out of the case study as wood biofuel supply chains have few details on what can be considered socially sustainable. Labuschagne et al. (2005) described social sustainability as involving three major themes: internal human resources, external population, and macro social performance. It is difficult to define the social performance of the supply chains of CHPs except in terms of providing employment in rural areas. The CHPs' contribution to the social sustainability is highly limited as the plants are rarely involved in welfare activities. Defining social sustainable aspects of wood biofuel supply chains are also difficult as this involves investigating the attitude of the whole Swedish population towards the use of wood biofuels, which would require a separate study. The contributions of the wood biofuel supply chain actors to social sustainability would also require detailed study with different actors focusing on the main themes of social sustainability.

The methodology for the case study involved designing a potential rail delivery system and then subjecting it to a sensitivity analysis in which different variables were changed in order to find the key factors influencing the intermodal transport. The potential rail system is designed by finding a break-even point between the road and rail transport. In this regard a search for the local terminals and sourcing options was made in order to have a detailed rail system. The variables were later changed to see the influence on the system, which helped in the formulation of a best-case scenario. Storage levels were subjected to a similar analysis in which scenarios of missing train deliveries were assessed. In this scenario the after effects of missing train deliveries were analysed and various options available were also discussed. The detailed cost and emission data can be found in appendix.

3.3. Validity and reliability

The research process consists of the measurement tools required to obtain the necessary data. It is vital for the measurement tools to be not only accurate but effective as well. Reliability and validity are two important aspects of any research. Detailed attention to these concepts marks the differences between a good and a poor research, thus developing the credibility of the scientific results. In a qualitative research perspective these sections need extra attention as the scientific society requires detailed explanation of the concepts in perspective to the study (Brink, 1993). Validity and reliability are not necessarily symmetrical, as it is possible to obtain reliable results without any validity; for example, a broken thermometer may give results but they will not be valid. Conversely, perfect validity yields perfect reliability, as absolute truth is measured. In social science reliability is assured by various means; however, since perfect validity is not even theoretically possible this always leaves room for improvement (Kirk and Miller, 1986). Validity and reliability are described as follows and their role has been discussed in the light of the current thesis.

3.3.1. Validity

Concept of validity relates to the truthfulness and accuracy of the findings in the research process (Lecompte and Goetz, 1982). A valid study gives results, which exist in reality, and the instruments used in such a study measures exactly what they were designed for. Many different forms of validity are mentioned in the literature; however, the two basic types of validity are external validity and internal validity, as described by Campbell and Stanley (1963). Denzin (1970) applied the distinction between the two types of validity to qualitative studies. The truthfulness of a study and the extent to which the study reflects the reality is referred to as internal validity. External validity refers the extent of the results applicable across different groups (Brink, 1993).

In the current study internal validity has been emphasized, as compared to external validity. For the current study external validity would require validation of the study's findings from additional studies. Applicability of results to different groups requires further studies, which can be carried out in the future. Internal validity, however, is described in detail and has been ensured to the most possible extent in the current study.

Internal validity can be further divided into three different groups: content, criterion, and construct. Content validity refers to the selection of the right content to be asked of the respondents. Analysing the right content is highly judgmental and can be approached in many ways, all while requiring clear understanding of the topic under study. A panel of experts can also be used to judge the relevance of the content used in an instrument to collect data.

Nunnally (1959) described criterion validity as the ability of a measurement procedure to generate results similar to an alternative procedure, which is valid. Blumberg et al. (2005) refer to criterion validity as an instrument's ability to predict or estimate. In order to have criterion validity the instruments should be relevant, free from bias, reliable, and available. Relevance aspect of a measurement tool requires it to cover the necessary topics related to the study. Freedom from bias refers to the aspect that respondents can give uninfluenced information and their analysis should be done on equal terms. Finally, the availability aspect refers to the availability of information required by the measurement tool.

Cronbach and Meehl (1955) describe criterion validity as the ability of a measurement tool to generate results, which can correspond to the theoretical aspects of the phenomenon studied. Blumberg et al. (2005) elaborates that in order for a measurement tool to have construct validity it should be in line with the theoretical definitions of the phenomenon. For example, in order to measure ceremony in an organizational culture, the tool should be aligned with the definition of ceremony in the theory.

The three different types of validity are interrelated; however, which type of validity needs to be focussed on depends upon the nature of the study. It would be hard to say that any of the types of the validity can be ignored completely since they are interrelated.

In the current study the measurement tools used include the three types of validity in certain ways. A literature review study was conducted to have the required topics needed to be covered in the survey and the case study in order to have content validity. In addition to the literature review, the survey study also went through a panel of experts that provided their insights on the topics to be included or omitted from the survey.

Defining key search words helped in obtaining the relevant articles, which insured the relevance aspect of criterion validity in the literature review. Freedom of bias of the articles was maintained by selecting articles from different journals, thus reducing a certain focus of the journal in the phenomenon under research. Since all of the articles and reports used to gather the relevant information are published and available online, the reliability and availability aspect of the criterion validity is also fulfilled.

Surveys maintained a relevance aspect of criterion validity by not only taking advantage of the information gathered through the literature review but also by going through a panel of experts that contributed and assured that the content of the surveys would generate information relevant to the supply chains of wood biofuels. Freedom from bias of the surveys was assured by the use of adaptive online surveys. The online adaptive surveys selected the relevant questions depending upon the characteristics of a plant. For example, if a respondent did not have access to rail transportation, no rail related questions were asked so that speculation could not be part of the information gathered. During the development phase of the survey special consideration was given to the aspect of speculation so that such questions would not be asked of a respondent who might not know the answer to a specific question. Plant managers were the target respondents of the surveys, which maintained the information availability aspect of the criterion validity of the topics covered in the surveys.

Criterion validity in the case study followed the measures taken during the development of the survey study. The relevance aspect can be seen by the characteristics of the plant selected for the case study, such as access to intermodal transport options along with high consumption of wood biofuels. Freedom from bias can be a critical part of a case study, as the company under investigation can influence the content covered in the research. Therefore, separate academic and company report documents were developed in order to keep the academic and industrial focus separate during the case study. The calculations and analysis done in the case study are based upon a previously developed model and was academically valid. Usage of the previously published and known model reinforces the reliability of the results generated in the case study. Criterion validity of the study lacked the predictability of the phenomenon measured. The instruments were designed to give a description of the phenomenon under study rather than the prediction of the future.

In the literature review focus on the articles relevant to the subject area of logistics and wood biofuels ensured construct validity. The survey study maintained construct validity by focusing on the current operations of power plants and their attitudes towards various sustainable activities. This helped in attaining the objectives of the survey study set by the research questions. The results of the case study highly relied on the selection of the already published and established model, which helped in getting accurate results.

3.3.2. Reliability

A general definition of reliability is the consistency of a measurement procedure to give results, which correspond to the results of a similar procedure. Comprehensive understanding of the reliability can only be achieved by specifying the research process completely from which scientific results have been generated (Meyer, 2010). Abell et al. (2009) argue that a measurement tool is reliable if it produces similar results used independently among different groups. Reliability means different things to different studies, depending upon the nature of the study. In general it is said to be the consistency of the results obtained from a study. Reliability is an important aspect to the results but may not insure the validity of the results. Consider a bathroom scale that measures one weight 3 kg more every time it is used. The number given by the scale is reliable but it is not valid as it gives the incorrect weight. Measurement tools need to be reliable in order to give accurate results with changes in time and conditions. The dependence of reliability over time and conditions highlights the three aspects of stability, equivalence, and internal consistency in a measurement tool. An instrument is said to be stable if it can obtain the same results from the same person over and over again. Equivalence refers to the consistency of the measurement procedures for a similar group of respondents. Equivalence depends upon the measurement tools being used and the way in which they are used. Internal consistency describes the homogeneity in the items included in the measurement tools. The correlation between the items used in a measurement tool can be said to be representative of the internal consistency. Homogeneity of the items used in a measurement tool also depends upon their relevance to a certain phenomenon under study (Blumberg et al., 2005).

The measurement tools used in the current study involved surveys and interviews. Since the tools have not been assessed over a time period it is hard to define their reliability in terms of passage of time. However, the results obtained from the two tools are consistent and complimentary for the different topics discussed by each tool. The use of web surveys also insured the equivalence aspect of reliability by providing the same surveys to the different respondents, thus removing any chance of error in conduction of surveys. Interviews, in contrast, followed a list of topics identified through the use of the literature study and included topics that were discussed in the survey as well. Since the current study is descriptive in nature it is not possible to describe its reliability in terms of prediction.

4. Summary of appended papers

The following section provides the results obtained from the literature review, survey study and case study. In addition, a section 4.8 is included that is based on the work in a report that is not appended to the thesis.

4.1. The appended papers in brief

Three papers are appended to the thesis. In addition, the research has been presented in a number of project reports.

4.1.1. Wood biofuels logistical challenges in Sweden

Author: Awais, Fawad.

The basic purpose of the paper is to review the current literature on wood biofuels and identify key logistical challenges for different types of biofuel supply chains. The paper incorporates an investigation of the definitions used for wood biofuels and their raw materials in research on the logistics of wood biofuels. The generally-used distribution networks are identified and analysed. The paper concludes with a consideration of the various logistical challenges that are present in the wood biofuel industry. Information and data are obtained through a literature review study. This paper contributes to the field by analysing the supply chain for wood biofuel from a holistic perspective and providing a solid foundation for further research on how these challenges can be solved.

Findings: This paper introduces definitions related to wood biofuels and raw materials. It also outlines the various logistical problems that arise in the distribution of wood biofuels and raw materials for use in heating and power plants in Sweden. Key challenges identified include seasonal variations, storage, the chipping process, the low density of wood biofuels, term standardisation, supply sources and dependence on policies.

4.1.2. Logistic requirements and characteristics of the Swedish wood biofuel industry

Authors: Awais, Fawad & Flodén, Jonas.

Sweden has a substantial utilisation of forest fuels in district heating plants and combined heat and power plants. This places large demands on the logistics system supplying these plants with fuel. The aim of this paper is to identify the effect of industry actors' requirements, constraints and preferences on the wood biofuel supply chain and to identify the logistical challenges this entails. To achieve this, a survey was sent to all Swedish CHPs, and six interviews were conducted with transport companies, terminal operators and forest companies.

Findings: This study shows that the industry has a local-market focus, mostly utilising truck transport with direct transport from the forest. Road transport is rated highly favourable, with reliability as the most important factor. Storage is used to overcome fluctuations in demand and is an essential part of the supply chain, and most CHPs have storage facilities. The forest is the preferred location for chipping. Challenges include determining the size and location of storage facilities and identifying transport alternatives that might improve the transport chain and reduce environmental impact, while at the same time maintaining flexibility.

4.1.3. Meeting the challenges for intermodal transportation of biofuel

Author: Flodén, Jonas & Awais, Fawad.

The use of solid biofuels for energy in heating plants has increased drastically in recent decades. This substantial and increasing demand has drawn focus to delivering the supply to the plants, as logistics issues are considered one of the key challenges for further increased use of biofuels. Environmental concerns, the increasing size of power plants, and challenges in sourcing enough fuel locally have sparked an interest in using intermodal road-rail transport. A case study was conducted at a Swedish district heating plant to investigate the potential for introducing intermodal transport. Extensive calculations were performed for the design and operation of an intermodal system, showing both costs and CO_2 emissions. The results are analysed in relation to key logistical challenges in the industry, and a best feasible case scenario is identified.

Findings: Conclusions are that the potential for intermodal transport is greatest among the largest plants with large volumes to achieve high resource utilisation. An advantage of intermodal transport is that large flows currently pass through a terminal, which improves the competitiveness with road transport and allows for the use of efficient resources at the terminal. This study leads to a better understanding of the strengths and weaknesses of intermodal biofuel transport and has practical implications for anyone in the process of designing such systems.

4.1.4. Project reports

This thesis is part of the project titled, "Sustainable Intermodal Supply Systems for Biofuel and Bulk Freight," which involves research about the intermodal transportation of biofuels. Therefore, separate reports were generated in collaboration with partners in the project. The reports most helpful to the compilation of this thesis are as follows:

- WP 1 Report: Biofuels,

Authors: Fredrik Bärthel, Fawad Awais and Jonas Flodén (Editor) from School of Business, Economics and Law, University of Gothenburg, Dag Hersle and Moa Berglund from WSP.

Aim: The aim of this report is to introduce the concept of bio-based materials. Biofuels and the characteristics of these goods are mapped. This mapping is followed by a literature review incorporating past research, market information and current intermodal transport systems and supply chains for bio-based materials in Sweden. A concluding analysis is made.

- WP 2 Report: Logistic Requirements and Characteristics in the Swedish Wood Biofuel Industry.

Authors: Fawad Awais and Jonas Flodén from School of Business, Economics and Law, University of Gothenburg.

Aim: The aim of this paper is to identify the effects of industry actors' requirements, constraints and preferences on the wood biofuel supply chain and to identify the logistical challenges this entails.

- WP 3 Report: Designing Intermodal Supply Chains

Authors: Jonas Flodén (Editor), Johan Woxenius, Fawad Awais and Jon Williamsson from School of Business, Economics and Law, University of Gothenburg, Moa Berglund, Helena Billing Clason and Dag Hersle from WSP,Johanna Enström from Skogforsk, Behzad Kordnejad from Royal Institute of Technology, KTH.

Aim: The aim of this report is to analyse the logistical challenges in designing a sustainable intermodal supply chain for biofuel. The concept of sustainability is explained and the characteristics of each transport mode for biofuel transport are evaluated. Business models in the industry are mapped and intermodal business models are further developed. The possibility of return flows is investigated, followed by a case study of a large power plant.

- Report to Göteborg Energi: Possibilities for intermodal transport of biofuel in Sweden, a case study on Göteborg's Energi plant Sävenäs.

Authors: Jonas Flodén and Fawad Awais from School of Business, Economics and Law, University of Gothenburg.

Aim: The aim of this report is to investigate the potential use of the intermodal transport of biofuel for use in HPs. This study leads to a better understanding of the strengths and weaknesses of intermodal biofuel transport and has practical implications for anyone in the process of designing such systems. The study is set under Swedish conditions as the use of biofuel for HPs is particularly well-established in Sweden.

These reports were a vital part of shaping this thesis and therefore must be mentioned for the sake of better understanding of the concepts discussed in the current study.

4.2. Logistics in wood biofuel transportation

Gold and Seuring (2011) describe two main objectives of the biomass supply chain: keeping biofuel costs competitive and ensuring continuous supply. The different logistical steps in the wood biofuel supply chain can be divided into four steps. These four steps, along with descriptions, have been summarized in Table 3.

Table 3: Various steps of SCM/logistics and bio-energy. Adapted from (Gold and Seuring, 2011).

Category	Description
Collecting/ harvesting	This part of the supply chain is located in the forest where the wood is collected, and is more focussed on forest management than logistics. The chipping process taking place in the forest affects the handling and cost of the wood biofuel transportation.
Pre-treatment activities	This step involves the chipping, drying and conversion of wood biomass to densified biofuels such as wood pellets. These activities have economic, environmental and social impacts on the other operations of the biofuel supply chain.
Transport	Transport takes place between various points of the wood biofuel supply chain, such as the forests, storage terminals, heating plants, etc. The form of wood biofuels along with the mode used for transportation are key components.
Storage	This is a key step in the supply chain as it is useful when encountering seasonal variations in the demand and supply of wood biofuels, as well as providing another point for the chipping process.
Overall supply system	This refers to the challenging task of effectively and efficiently designing and operating bio-energy production.

Most of the literature on biomass supply focuses on the overall supply chain rather than components. Energy plants and biomass suppliers are the most important actors in the chains and are interdependent. The logistics of the biomass supply chain are more complex than for fossil fuels, as the biomass supply chain involves more deliveries (Gold and Seuring, 2011). Consider one TWh, which is equivalent to 86,000 tonnes of the equivalent of oil. One tonne of wood pellets holds 4.6 megawatt hour (MWh) of energy, which means one TWh corresponds to 217,000 tonnes of wood pellets (Andersson, 2012). Low transport costs help the biofuel plants to work at optimum levels. Economies of scale and increased efficiency of logistical activities are critical to the biomass supply chain (Gold and Seuring, 2011).

Gunnarsson et al. (2004) describe the different decisions involved in wood biofuel chains, such as which fuel type to use, the time required for the movement of the biofuels, whether or not to employ the process of chipping, the location of the chipping process, storage at terminals, the design of the transportation network, the need to establish contracts with the forest and sawmill owners and restrictions regarding the capacities for chipping, forwarding and storage at terminals. Gunnarsson et al. (2004) also identify key strategic planning situations for the supplying companies involved in the wood biofuel chains: submitting competitive prices, finding a solution to varying demand for wood biofuels—e.g. in colder-than-usual months, adopting a new storage terminal or altering the capacity of the already existing storage terminal, altering the capacities of the chipping sites and the modes of transportation, changing costs due to the change in the chipping technology and negotiating with transport companies.

A general representation of the transportation activities involved in a wood biofuel supply chain is presented in Figure 5, which was developed by the author for this study.

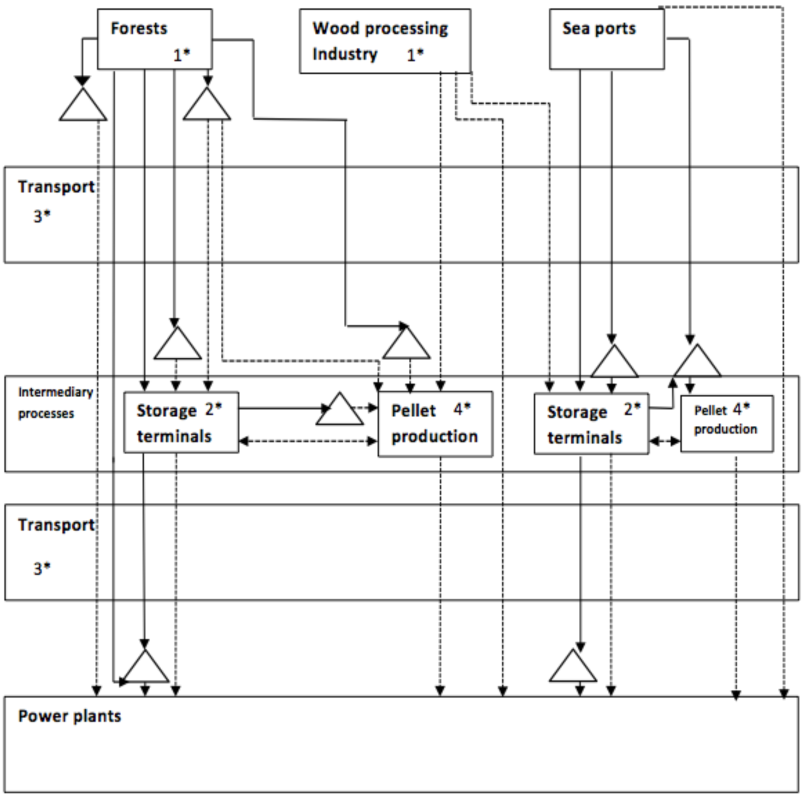

Figure 5: National supply chains under focus. Triangles represent onsite chipping and dotted lines represent chipped biomass.

1* Operation 1: Harvesting and collecting biomass

2* Operation 2: Storage

3* Operation 3: Transport

4* Operation 4: Pre-treatment techniques

The arrows in the diagram represent the flow of the wood biofuel raw materials and products. The triangles in the diagram represent the onsite chipping process, e.g. the triangles adjacent to the forests represent roadside chipping done in the forest. The logistical activities that take place between the origins and destinations of the wood biofuels include transport and intermediary activities such storage. It should be noted that transports may be carried directly from the location of origin to the power plants or may pass through storage terminals.

4.2.1. Harvesting and collecting biomass

Harvesting and collecting biomass is the first step in the logistics of any biofuel supply chain. Transportation and chipping play a vital role in the production of wood biomass. Utilising efficient equipment and methods can lead to reduced costs—for instance, the use of chipper trucks can reduce overall costs by 20-40%. These chipper trucks can be competitive for distances of 100-120 km (Björheden et al., 2010). Routa et al. (2012) note chipping location as a major factor in the overall layout of the wood biofuel supply chain.

4.2.2. Storage

Storage is required to ensure a smooth supply of biofuels. The number of storage terminals generally increases if the harvest period is short (Gold and Seuring, 2011). Stockpiles along roadsides can be considered a type of storage. Storage plays a vital role in the drying of wood biofuels without extra costs. Unprocessed wood biomass can be left outside, whereas processed wood biomass such as wood pellets needs to be stored in covered places (Hamelinck et al., 2005). Wood biofuel demands are the highest during autumn and winter; therefore, the biofuels are stored for at least few months. The moisture content normally decreases with increased storage time, although it may also rise due to weather conditions, which may mean even longer storage times (Anerud and Jirjis, 2011).

4.2.3. Transport in the bio-energy chain

Transport issues related to the bioenergy chain can be divided into categories of infrastructure framework, transport operations and social and environmental impacts (Gold and Seuring, 2011). Road transportation is utilised for short distances or as the initial or final haulage of biofuels over longer distances for plants that lack rail and sea infrastructure. Using trucks to satisfy the demand of large CHPs can result in congestion problems (Mahmudi and Flynn, 2006). Johansson et al. (2006) describe the typical road vehicles used in Sweden as having a maximum length and width of 25.25 and 2.60 metres respectively, with an allowable carrying weight of 60 tonnes. Longer distances and huge volumes can balance out the costs incurred due to rail and sea transportation for large power plants. The factors that influence the costs for the rail transportation of wood biofuels are deliveries made by the train units per unit time, the utilisation of load capacity, transport distance, storage terminal handling (loading and unloading) and conditions of train shunting at storage terminal points (Björheden et al., 2010). Two common container systems for wood biofuels are described in Table 4.

Table 4: Main loading and unloading techniques of wood biofuels (Björheden et al., 2010).

System	**Advantages**	**Disadvantages**
Rotary system	Specially designed containers mean greater volumes on each wagon. Efficient unloading with turntable forks.	The unloading forklift truck is specialised and has few other uses. The forklifts are designed for rotary containers and cannot handle other containers.
Container system for switch-body trucks	Long-distance transportation of containers by trucks is possible, as containers are designed for both trucks and trains. Includes standard components.	Longer loading and unloading times are required compared to the rotary system. Load capacity cannot be utilised to the maximum of the train, as the weight and width limit of the containers on trucks and trains are different (trains have wider limits).

4.2.4. Pre-treatment techniques

Pre-treatment activities for wood biomass include drying and pelletisation. Drying helps reduce the moisture content of the wood biomass, thus improving the combustion efficiency along with transportation. Pelletisation involves converting biomass to densified material, improving energy content and handling. Open-air drying does not incur any costs, however it is dependent upon climatic conditions. Pelletisation incurs extra costs in the process of converting wood biomass to pellets. (Gold and Seuring, 2011).

4.3. Logistical Challenges

Rentizelas et al. (2009) highlight that a significant amount of the costs of biofuel energy are due to the logistical activities involved in the process. Storage is a major concern, mainly due to the seasonal variations of the biofuels. The different forms of biomass require different equipment for handling (e.g. chips require different handling equipment than logs). The list of logistical challenges discussed below was selected based on the literature review, and the challenges are described according to the literature.

4.3.1. Seasonal variations

Carlsson and Rönnqvist (2004) note that seasonal variations impact the amount of stock present in the wood biofuel supply chain. In Sweden, the traditional harvesting period for wood biofuels is autumn, winter and early spring. The difficulty of harvesting wood during winters along with growing energy demands result in large stockpiles during spring and very small ones during summer. The period between August and early September is critical, with the possibility of a shortage of wood biomass before the harvesting process begins again. Gold and Seuring (2011) elaborate that seasonal variations in the demand and supply of wood biofuels result in the underutilisation of equipment and labour. Furthermore, the shorter the harvest periods, the greater the period of stock retention, resulting in higher storage costs and dry matter losses. The large volumes of stock in winter are suited to rail transportation, but rail transportation cannot be used in summer when the demand is low.

4.3.2. Storage

The necessity of storage facilities for the wood biofuel chains involves a number of logistical decisions regarding the location, size and equipment present at a storage facility. Storage facilities deserve special attention as they directly affect the overall cost of the supply chain.

4.3.3. Chipping process

Hamelinck et al. (2005) argue that the chipping process strongly affects the transport and handling costs of the wood biomass and presents decision-making scenarios. Chipping is typically performed at the roadside, the terminal or the power plants. The physical form of the wood biomass affects handling and transportation activities and costs, so where chipping occurs has implications. Asikainen (1998) notes that chipping at a terminal or plant is only efficient for large volumes due to the high fixed costs of the large chipping equipment, whereas when chipping at the forest the equipment can be hired on an hourly basis. Terminal and plant chipping provide more control over the quality of the wood chips and require no setup costs or allocated space for chipping equipment, while in forests the chipping location can vary due to weather and the surrounding conditions. Waiting times due to delays may result in added costs and reduced efficiency.

4.3.4. Low density of wood biofuels

Wood biomass and the wood chips produced from it are low-density goods and require capacity management in vehicles and at storage terminals, resulting in different handling. As illustrated in Figure 6, different forms of the wood biomass occupy different amounts of space but contain the same amount of biomass.

Figure 6: The differences between different types of biomass (Björheden et al., 2010). All loads contain the same amount of biomass, but in different forms they occupy different amounts of space.

The low energy density of the wood biofuels makes transportation an important cost factor in the supply chains (Gold and Seuring, 2011). Bradley et al. (2009a) note the problem of the low density of wood biofuels in ships.

4.3.5. Term standardisation

Frosch and Thorén (2010) argue that the lack of standard terms of wood biofuels makes it difficult to estimate the consumption and production of wood biofuels within different regions. A standardised catalogue of the various wood biofuels would help enable clear comparisons and trade among the wood biofuel entities. Jungingera et al. (2008) argue that a lack of standardised terms in the direct trade of round wood also generates complications, as the sawdust produced from round wood is also used for energy generation.

4.3.6. Sources of supply

Hirsmark (2002) points out that increases in the demand of wood biofuels in exporting countries can affect the imports of wood biofuels to Sweden. Imports can also be affected by increases in international demand. If more countries demand wood biofuels with no more suppliers, the prices of wood biofuels will rise in local markets, and biofuel quantities will shrink.

4.3.7. Dependence on policies

Jungingera et al. (2008) point out the dependence of biofuel utilisation on policies. European Union member states are trying to increase the use of biofuels for the purpose of achieving sustainability. However, some cases show that varying policies can result in increased biofuel prices while disturbing the market mechanism. Selkimaki et al. (2010) also highlight that Swedish authorities have shaped their policies for the propagation of biofuels in the district-heating sector, mainly due to fossil fuel taxation and subsidies.

4.3.8. Logistical challenges identified from survey study

The challenges mentioned in the literature were also investigated in detail in the survey study to test their validly, and as a result the challenges were narrowed down to the major ones. The survey also helped by ranking the challenges from most to least problematic. The following tables provide the ranking of logistical challenges identified in the survey study.

Table 5: Issues in the Swedish biofuel industry (1=least problematic, 6=most problematic).

Issue	Mean rating
Seasonal variations in the demand for heating	4.3
Dependence on Swedish political decisions on biofuels	4.0
Dependence on foreign policy decisions on biofuels	4.0
Biodegradation of the biofuel	3.9
Contamination of the biofuel at delivery, e.g. stones	3.8
Drying of the biofuel	3.3
Impact on the Swedish biofuel market from increased global demand for biofuels	3.1
Cooperation between actors in the industry	3.0
Standardised terms and definitions for biofuels and raw materials	2.7
Availability of biomass	2.6

The location and size of the storage facilities are significant issues regarding the storage of wood biofuels. The following ranking of storage issues is for storage facilities both at the plant and at off-site storage facilities. Table 6 provides the ranking of storage issues provided by survey respondents.

Table 6: Mean ranking of storage problems (1=least problematic, 6=most problematic).

Storage issues	Total	Small CHP	Medium CPH	Large CHP
Size of storage facilities	3.8	3.8	3.5	4.8
Location of storage facilities	3.7	3.4	3.5	4.8
Handling of biofuel at storage facilities	3.4	3.2	3.3	4.0
Availability of equipment at storage facilities	3.2	2.9	3.4	3.5

Table 7: Mean ranking of transport problems (1=least problematic, 6=most problematic).

	Total	Small CHP	Medium CHP	Large CHP
Low density of biofuel	3.6	3.3	3.7	4.0
Risk of contamination of the biofuel during transport, e.g. stones	3.5	3.6	3.3	3.3
Transport of tree parts	3.1	2.9	3.4	3.5
Transport of forest residues	3.0	2.8	3.3	3.5
Availability of suitable transport	3.0	2.7	4.0	2.3
Transport of wood chips	2.5	2.5	2.7	2.5
Transport of pellets	2.3	2.1	2.5	3.0

The ranking of transport issues in Table 7 shows that the transport of wood biofuels is considered more problematic by the larger CHPs with larger flows. Tree parts and forest residues are the most problematic fuels. The ranking corresponds well to the density of the fuels, itself ranked as a top problem. The survey revealed that on a more general level, the largest problem perceived was the seasonal variation in demand (see Table 5). In general the market appears well-functioning with, no major cooperation problems or lack of fuel.

4.4. Swedish wood biofuel logistics

This section describes the results of the survey with a description of the industry situation in Sweden. The total energy produced by the CHPs in the survey was 12.6 TWh (9.4 TWh in winter [October-March], 3.2 TWh in summer [April-September]), or 26% of the total energy production (48.1 TWh) by CHPs and HPs in Sweden (Svensk Fjärrvärme, 2010). The majority (74%) of this type of energy is produced during the winter. The respondents can be classified into three sizes based on winter energy production as shown in Table 8.

Table 8: CHP size.

Plant size in winter	Percentage of population	Number of respondents
Small (0-250 GWh)	50%	16
Medium (251-500 GWh)	31%	10
Large (>500 GWh)	13%	4
Unknown	6%	2
Total	100%	32

Table 9 shows the percentage of energy produced by different fuels according to the survey distributed among the Swedish combined heating plants. Fuel use is dominated by logging residue chips followed by other wood chips. Wood residue chips were the most widely used fuel, with 75% of the respondents using this fuel, followed by chips of other wood (68%) and stem ships (50%). Essentially the same fuel mix is used in summer and winter.

Table 9: Fuel used.

Fuels	Heat generated in winters	Heat generated in summers
Stem chips	9%	6%
Logging residue chips	24%	22%
Stub chips	2%	1%
Chips of other wood	21%	25%
Chips of unknown wood	9%	10%
Pellets	2%	3%
Peat	7%	3%
Waste burnt to produce energy	8%	16%
Bio gas	0%	0%
Natural gas	0%	0%
Bio oil	1%	0%
Coal	1%	0%
Oil	5%	0%
Other fuels:	11%	14%
Total	100%	100%

4.4.1. Operation 1: Harvesting and collection

Plants know the origin of the wood biomass they receive, as prior planning is done to secure the supply. Contracts are generally established on a yearly basis, often with the same suppliers. Local suppliers and buyers are preferred, thus creating monopoly/oligopoly relationships. The preference for local sourcing is understandable, as it lowers transport costs and ensures quick deliveries, however, larger plants have to source over longer distances. Purchase of fuel is commonly made in terms of energy content, though some traditional units persist (e.g., firewood is by tradition traded in solid m^3). Competition from other industries is expected to present risks due to economic fluctuations or increased production of bioethanol (as it requires raw materials such as sawdust and popular tree species). Exports are not considered feasible at the moment due to the high prices of biofuel in Sweden along with a limited demand for biofuels in the rest of Europe. This limits the import of biofuels as well, but import is economically possible despite the challenge of keeping transport costs low.

4.4.2. Operation 2: Storage

Storage was an essential component for most of the respondents, and it is present both on the plant premises and at other locations. Tables 10 and 11 highlight the storage locations and time of the power plants. Storage is typically found at both the plant location and at an off-site location. The average storage time in winter is low because of the high demand as compared to the low demand of summer.

Table 10: Share of respondents having storage.

CHP sizes	At the CHP	At the CHP and nearby	Nearby	No storage
All	59%	28%	6%	6%
Small	69%	25%	0%	6%
Medium	80%	20%	0%	0%
Large	0%	75%	25%	0%

Table 11: Average storage time in days.

Storage location		Average storage time (days) in winter	Average storage time (days) in summer
CHP storage	All	36	55
	Small	50	63
	Medium	26	49
	Large	3	60
Close-by storage	All	89	137
	Small	113	114
	Medium	137	183
	Large	47	131

4.4.3. Operation 3: Transport

Swedish forests and wood industries (sawmills, paper mills, etc.) produce the majority of the wood biofuels used at power plants. The supply chain design is dominated by direct shipments from forests to power plants. Use of terminals results in extra costs and is avoided if possible. Table 12 shows the percentage of respondents using various supply chain designs. The table also elaborates the energy that is produced by using different supply chain designs, helping to illustrate the feasible supply chain structures currently in use.

Table 12: Transport chains used.

	Winter		Summer	
	CHPs using the chain	Energy produced	CHPs using the chain	Energy produced
Directly from the forest	69%	26%	63%	39%
From the forest via storage terminal	34%	12%	19%	3%
From the forest via transhipment terminal	21%	7%	15%	8%
From the forest via both storage and tran-shipment terminal	7%	6%	7%	6%
Directly from a forest industry, such as sawmills	59%	23%	56%	21%
From a forest industry via storage termi-nal	3%	0%	4%	0%
From a forest industry via transhipment terminal	3%	0%	4%	0%
From a forest industry via both storage and transhipment terminal	3%	6%	4%	6%
From abroad	14%	1%	7%	1%
Unknown chain	24%	19%	22%	16%

Table 13 shows that road transport is the most commonly used mode of transport; larger plants have access to other modes of transport such as rail and sea, but these are rarely used. The daily number of trucks for large plants can range between 50-70 trucks per day. Road transport distances are generally less than 250 km and are kept minimal due to the low value and energy density of wood biofuel. The management and presence of unloading and loading equipment at both terminals and plants are not an issue for the supply chain.

Table 13: Transport distances.

	Truck only						**Train only**		**Ship only**		**Train, then delivery by road**			**Truck, then delivery by train**		**Truck, then ship, then delivered by truck**			**Delivery by truck, previous steps unknown**	
Distance (km)	Total	<100 N=23	100-250 N=15	250-500 N=3	>500 N=3	Unknown N=3	Total	Unknown	Total	500-750	Total N=	250-500 N=1	500-750 N=1	Total	Unknown	Total N=	<250 N=1	Unknown	Total	<250 N=1
Percent of respondents	94	75	50	9	6	22	3	3	6	3	3	3	3	3	3	9	3	6	6	3
Percent of energy in winter	84	47	17	3	3	14	2	2	1	1	4	2	2	5	5	2	1	1	2	2

The percentage of respondents in Table 13 represents the percentage of a certain mode or combination of modes from the total population. Therefore, the sum is not at 100%, as many respondents use different modes or combination of modes. This means that a respondent may be using both a “road only” option and a “rail only” option. The results show that a certain mode or combination of modes is represented by a percentage of the total population. As is often the case in logistics (e.g.,Lammgård (2007); Saxin et al., (2004)), the most important factor for the respondents is reliability. Respondents were asked to rank different factors associated with transportation, and environmental sustainability received the lowest ranking in terms of importance. However, most CHPs are municipality-owned and are thus required to follow certain purchasing and environmental standards.

Table 14: Ranking of important modal choice factors and service received (1=least fulfilled/important, 6=most fulfilled/important).

Service	Importance				Service received			
	Total	Small CHP	Medium CPH	Large CHP	Total	Small CHP	Medium CPH	Large CHP
Low cost	4.7	4.5	4.9	5.0	3.8	4.1	3.5	4.0
Short transport time	3.8	4.0	3.4	3.8	4.5	4.6	4.4	4.8
High reliability	5.1	5.1	4.9	5.5	4.7	4.9	4.3	4.5
High frequency	4.2	3.9	4.0	5.0	4.6	4.9	4.4	4.5
Few contaminations in the fuel, e.g. stones	4.9	4.8	4.5	6.0	4.1	4.4	3.6	4.0
Environmental sustainability	4.5	4.0	4.7	5.8	3.9	4.3	3.2	4.0
Good access to the transport system, such as infrastructure	4.7	4.3	4.9	5.8	4.7	4.7	4.6	4.8

Table 14 describes the percentage of respondents that agree with the characteristics of different transport modes. The results have been further broken down based on the categorisation of plant sizes. The percentages shown are the respondents in agreement with a certain characteristic of a particular mode. Road transportation was rated as having the maximum benefits, though it was rated poorly in terms of environmental sustainability and transport costs. Rail and sea transport, on the other hand, lack the benefits of road transport but are perceived as environmentally sustainable. Large power plants have more experience with rail and sea transport, as can be seen in their ranking of the various benefits of these transport modes. The perception of the various characteristics presented in Table 15 helps with understanding the important factors in considering the selection of transport modes. The preference of modal choice factors has been mostly paired with road transportation, as shown in Table 15.

Table 15: Qualities of different transport chains.

Qualities	Total	Small CHP	Medium CHP	Large CHP
Trucks have low cost	16%	13%	10%	50%
Trucks have short transport time	52%	50%	60%	50%
Trucks have high reliability	64%	60%	70%	100%
Trucks have high frequency	55%	50%	60%	75%
Trucks have good access to the transport system, such as infrastructure	68%	63%	80%	75%
Trains are environmentally sustainable	48%	40%	60%	75%
Trains have none of the specified characteristics	42%	50%	40%	0%
Ships have none of the specified characteristics	45%	50%	40%	25%
A combination of trucks, trains and ships have none of the specified characteristics	61%	63%	60%	25%
A combination of trucks and trains have none of the specified characteristics	58%	63%	40%	25%
A combination of trucks and ships have none of the specified characteristics	52%	13%	10%	50%

The ranking of preferred transport modes in Table 16 shows a very clear advantage for road transport and supports the preference for truck transport.

Table 16: Mean ranking of preferred transport mode (1=least preferred, 6=most preferred).

Mode of transport	Ranking
Road	5.5
Rail	2.5
Truck and ship combined	2.5
Ship	2.3
Truck and rail combined	2.3
Truck, rail and ship combined	2.2

Of respondents, 37% and 41% consider the use of rail and sea transport, respectively; however, the majority of CHPs let their suppliers arrange the transport modes to be used for delivery. Table 17 shows that the most commonly used load units for the delivery of wood biofuels are fixed/tilting trucks followed by switch-body trucks. The most common load unit for rail transport is the rotary container. These statistics are helpful for the determination of preferred load units by power plants.

Table 17: Load units/vehicles used.

Load units for trucks	Percentage of energy produced	Percentage of usage		
		Small CHP	Medium CHP	Large CHP
Truck with fixed/tilting superstructure, e.g. side-dump truck	67%	75%	100%	100%
Container truck with switch body, e.g. wood chip container	25%	69%	90%	100%
Other	6%	19%	0%	25%
Do not know	2%	6%	0%	0%

Delivery times for the biofuels are flexible along with unloading times for the different modes. Trucks have the lowest average time for unloading, followed by trains.

4.4.4. Operation 4: Pre-treatment techniques

The chipping of wood biofuels is mostly performed in the forest, and this is also the option preferred by most respondents. Chipping is often considered a part of harvesting (Gold and Seuring, 2011), but can also occur at other locations in the chain as a pre-treatment activity. Table 18 reveals that forests are the preferred location for chipping, though large plants prefer to chip at the plants in order to have better control over the quality of the wood biofuels. Local restrictions can affect chipping on plant premises, as power plants may be located in residential areas.

Table 18: Share of energy produced by various chipping locations and their preference (1=least preferred, 6=most preferred).

	Total			Small CHP		Medium CHP		Large CHP	
Chipping location	CHPs using	Share of energy	Preference	CHPs using	Preference	CHPs using	Preference	CHPs using	Preference
Chipped at the forest	66%	42%	4.6	53%	4.4	80%	5.1	75%	3.8
Chipped at the terminal	55%	18%	4.1	47%	4.6	60%	3.8	50%	3.0
Chipped at the CHP	41%	19%	3.4	27%	2.8	50%	3.6	75%	5.0
Chipping location unknown	41%	19%	-	53%	-	20%	-	25%	-

4.4.5. Overall operation of the supply chain

Uneven demand and supply is a major challenge for wood biofuel supply chains, and Table 19 shows what options plants use to handle this challenge. The fluctuating demand for biofuels is handled similarly by the different categories of plants. Cooperation with other plants and storage of produced energy are more common among the larger plants, while smaller plants rely more on buffer stocks and deliveries.

Table 19: Handling fluctuations in demand, with percentage of respondents using the option.

Options used	Total
Buffer stocks	74%
Extra deliveries	71%
Energy storage	35%
Use of fossil fuels	29%
Cooperation with other heating plants	13%

Table 20 shows what transport services are important to the power plants and to what extent these services are currently provided. The most important factors in the biofuel supply chain are on-time deliveries, fuel quality and no contamination in the fuel. Comparing the preferences and services received reveals that the CHPs are in general satisfied with their supply chain.

Table 20: Services received and their importance (1=least fulfilled/important, 6=most fulfilled/important)

Service	Service received				Importance			
	Total	Small CHP	Medium CPH	Large CHP	Total	Small CHP	Medium CPH	Large CHP
Flexibility concerning delivery options	4.3	4.3	4.3	4.3	4.3	4.3	4.1	5.0
Flexibility concerning ordered volumes	4.4	4.8	4.1	4.3	5.0	4.9	5.1	5.3
On-time deliveries	4.4	4.8	4.4	3.8	5.4	5.4	5.2	5.8
Low transport cost	3.6	3.9	3.4	3.3	4.8	4.6	4.9	5.0
Low biofuel price	3.5	3.9	3.2	2.8	5.4	5.4	5.7	5.0
Small environmental impact	4.2	4.3	4.1	4.3	5.0	4.8	5.2	5.5
Good quality biofuel	4.5	4.5	4.5	4.3	5.5	5.6	5.4	5.8
No contamination in the delivered fuel, e.g., no stones	4.1	4.1	4.1	3.5	5.6	5.6	6.0	6.0
Deliveries evenly distributed over time	3.9	4.0	4.0	3.0	4.8	4.7	5.0	5.0

4.5. Case of Sävenäs Power plant

The plant selected for the case study is located at Sävenäs in the city of Gothenburg, Sweden, and is owned by Göteborg Energi. The plant provides an ideal situation to study intermodal transport chains as it has access to rail transport and has a relatively large consumption of wood biofuels. In addition, Göteborg Energi provided full cooperation and funding in order to study their currently used and potential supply chains. The plant was constructed as a coal plant to supply heat in 1985, and was later converted to a biofuel plant.

4.5.1. Case introduction

The Sävenäs plant has access to a rail network, although a full-length train has to be split, as the rail sidings are just 200 meters long. The plant is located adjacent to a residential area, which has certain restrictions that affect the plant. Chipping is forbidden by local environmental regulations. Fuel deliveries can be made to the plant during weekdays and weekends, but weekend deliveries are avoided to prevent complaints from the neighbouring residential areas. The plant receives deliveries between 6 A.M. and 10 P.M., resulting in a 16-hour window for deliveries during weekdays.

The plant is currently fuelled by wood residue chips, log chips and stump chips. The plant is currently supplied entirely by road through local sourcing. About forty trucks are used daily to deliver wood biofuels to the plant.

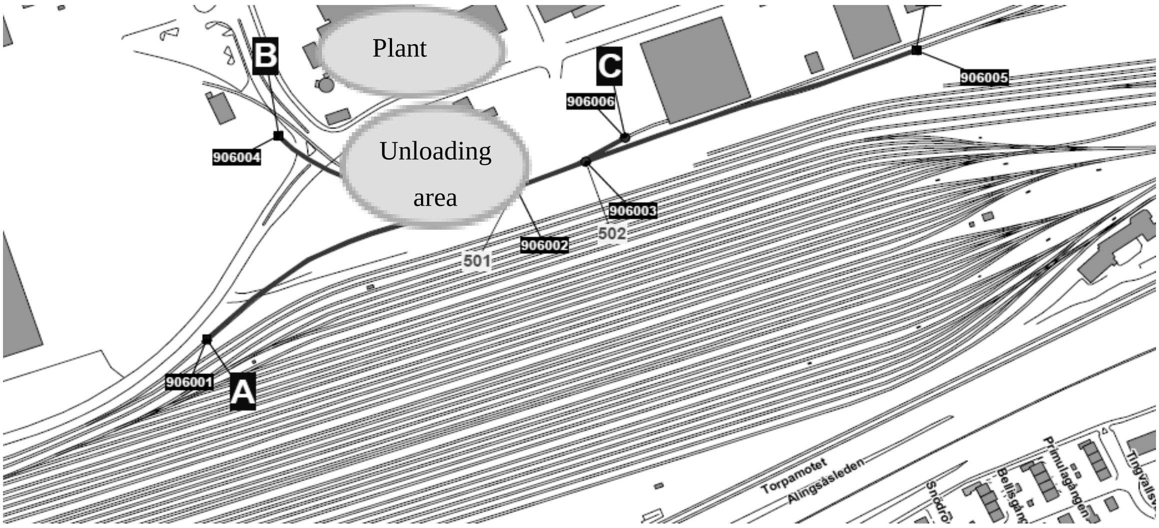

Figure 7: Local track layout and adjacent shunting yard.

The plant produces 17 GWh of energy every week (seven days) when working at full capacity. The plant has on-site storage that is 10,000 m^3 in volume and holds fuel for about 60 hours of energy production. In our assumed scenario, the plant can alternate between two types of train deliveries. One train contains wood chips and the total energy carried by this train is 2.1 GWh. The train coming the next day carries 1.75 GWh of energy in the form of bark wood.

These foundational facts are helpful in determining the various possibilities for road and rail operations. Storage at the plant is 10,000 m^3, which in the form of grot chips or logging chips is equivalent to 7.79 GWh of energy with minor variations. The 7.79 GWh of storage can provide 3.2 days (7.79/2.429) of energy production. Table 21 summarises some basic facts about the power plant under study.

Table 21: Energy when plant operating at maximum capacity.

Total energy produced in a week	17 GWh
Total energy produced daily	2.43 GWh
Total storage in terms of energy (in form of chips)	7.79 GWh
Number of days that can be supplied by storage	3.2 days
Energy carried by a wood chip train	2.1 GWh
Energy carried by a bark train	1.75 GWh
Energy carried by a truck	0.093 GWh

The assumption that a train can carry 2-2.5 GWh of energy implies that 150-190 trains are needed annually, or roughly one train per day during the operational season. Like all systems, train deliveries are vulnerable to unexpected events such as delays, accidents or shutdowns. Therefore, total dependence on train deliveries is not preferable.

The non-electrified local rail siding is also a challenge for the plant, as it requires time-consuming and expensive shunting operations. Rail transport is not currently utilised at the plant—a successful rail transport test was conducted, but the associated costs were very high. The test included standard all-round $35m^3$ containers. The containers were transferred to a switch-body truck by forklift. The unloading operation by truck was efficient, but the containers did not utilise the full capacity of the train. The shunting and splitting operations required for the train to enter the short local rail sidings were also time-consuming and expensive.

4.5.2. Case methodology

Once the information on current plant operations along with current challenges was laid out, it was time to move to the analysis phase of the case study. The next step involved the estimation of the costs and CO_2 emissions during the different processes in the plant's supply chain. Microsoft Excel was used to develop a modelling tool based upon Flodén (2011) for the case study. Considerable attention was given to the input data for the model, and particularly to the cost data. Six telephone interviews and an email interview were conducted to better understand the operations. The interviews conducted were with road (1), rail

(1) and sea (e-mail) biofuel transport companies, and with a terminal company (1), a forest company (1) and energy companies (2). The interviews were 60 minutes long and were recorded. Input data were collected from the literature (Table 22) and from the Swedish biofuel industry actors. Original cost data were obtained from four industry actors regarding different parts of the supply chain. Variations in cost estimates were expected between different data sources. Combining the data from the literature and from the industry refined variations in the cost data. The resulting data were checked against the author's own calculations of expected costs. The resulting data set contained a reasonable representation of the costs to be included in the case study. This data can be viewed as an average cost level in the Swedish industry rather than any actor-specific data. The selected data were validated by at least two independent industry representatives, and some data were validated by as many as five industry representatives. Selected cost data were also validated by a reference group of biofuel industry actors from road, rail, power plant and forest sectors. Cost estimations were made in SEK, Swedish kronor, kr (2014: approx. 9 kr = 1€).

Table 22 Cost literature sources

Data	Literature sources	Assumptions
Biofuel densities	Larsson and Nylinder (2014), COFORD (2003).	Swedish conditions.
Road costs	Skogforsk (2011), Flodén (2011)	Waiting times, etc. considered. Empty returns.
Rail costs	Flodén (2011)	Waiting times, etc. considered. Emissions from Swedish electricity mix.
Terminals	Asmoarp (2013), Skogforsk (2011), Sommar (2010), Bäckström et al. (2009)	
Chipping	Johansson and Mortazavi (2011), Eliasson et al. (2012), Lombardini et al. (2013) Bioenergiportalen (2013)	

4.5.3. *Break-even distance*

A break-even distance, above which the intermodal transport was less costly than all-road transport, had to be developed in order to demonstrate the economical viability of intermodal transport. The plant is currently supplied by trucks only, which meant a certain scenario has to be developed in which intermodal transport could be said to be economically acceptable. The break-even distance also depends on the equipment used. In this regard, the typical biofuel train was considered to consist of 22 Sgns wagons with an engine type Rd and rotary load units carrying 2.3 GWh of logging residue chips. A pre-haul of 50 km by road with a capacity of 0.093 GWh was also considered in the rail system of wood chips. This pre-haul distance was considered because the forest or the sourcing locations seldom have railway lines and have to be transported a short distance to be loaded on a train. Diesel shunting is considered at the terminals and heating plants. Three train deliveries are considered per week for the 26 active weeks per year. The empty return costs were also included. Roadside chipping is considered in every case. A break-even distance of 250 km was calculated through analysis involving cost comparison of the all-road solution and three train deliveries per week. The break-even distance represents the minimum distance at which the intermodal distance becomes competitive with the all-road solution. Figure 8 shows the break-even comparison of intermodal transport and the all-road solution.

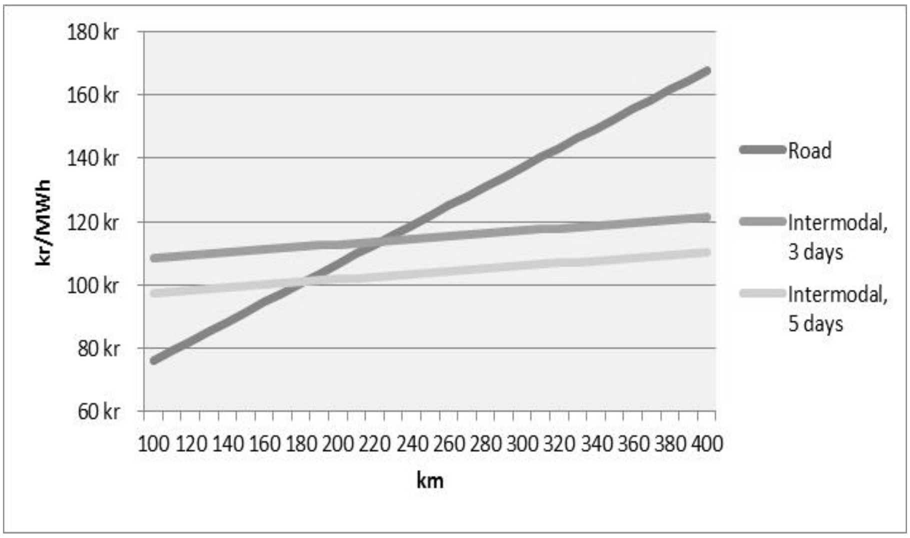

Figure 8: Break-even analysis of road and intermodal solutions.

The break-even distance becomes 180 km if five train deliveries per week are made. CO_2 emissions are less in intermodal chains compared to the all-road option. Trucks and the chipping process generate the majority of CO_2 emissions in an intermodal chain.

4.5.4. *Base scenario*

The determined break-even distance of 180-250 km resulted in the selection of the two nearest sourcing areas of Småland and Dalarna, shown in Figure 9. The selection of these sourcing locations was made due to their minimum distance above the break-even distance for intermodal transport. Five train deliveries per week consisting of three train deliveries from Småland (265km) carrying wood residues and two from Dalarna (471) carrying bark was considered for the base scenario. The 180-250 km break-even point provides a safety margin, and is a realistic approach as it provides the option of being economically feasible with the least number of trains per week.

Certain unexpected scenarios such as strikes or weather conditions can hinder the delivery process. Therefore, two sourcing locations were considered in order to have a smooth supply of wood biofuels through the use of rail transport. The selection of the two sources demonstrates that few suppliers can provide alone the amount of fuel needed to make train transport viable. Småland can provide logging residues, the most commonly used biofuel in Sweden, while Dalarna, with a large number of wood industries, can provide the second-most commonly used biofuel, wood by-products. The system can provide 58% of the weekly demand of the power plant when operating at full capacity, i.e. 9.8 GWh/week. Göteborg Energi has validated the developed base scenario.

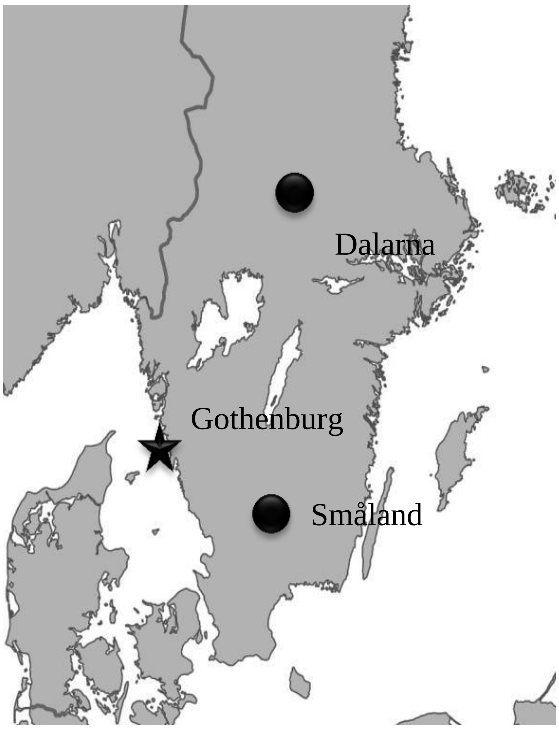

Figure 9: The plant and sourcing locations. The star denotes the power plant.

This base system cost consists of all the processes involved, such as chipping, road haulage, terminal operations, rail costs, etc. The base scenario includes road haulage of 40 km to the terminal at the sources with trucks carrying 0.093 GWh of energy. Chipping takes place in the forests for wood residues, and bark does not require chipping.

Terminal operations at Småland involve electric shunting, while Dalarna uses diesel shunting. Fuel at both sources is loaded with a wheel loader, which takes four hours to load a full train. The train used in the base scenario consists of 20 Sgns wagons pulled by a type Rd electric engine with sixty 45-m^3-load units with rotary unloading. A train carrying logging residues with these characteristics would carry 2.1 GWh of energy, while a comparable train carrying bark would have an energy value of 1.75 GWh. The train arriving at the plant utilises diesel shunting and takes four hours to be unloaded by a rotator.

The base scenario cost calculated for the potential intermodal system is 99 kr/MWh. The rail costs are 35 kr/MWh, which involves shunting, rail transport and load units. The CO_2 emissions of the system were calculated as 2.92 kg/MWh, with the majority of CO_2 generated by road transport and the chipping process. Figure 10 shows the cost allocations of the chain in which high costs are associated with chipping and the sending terminal.

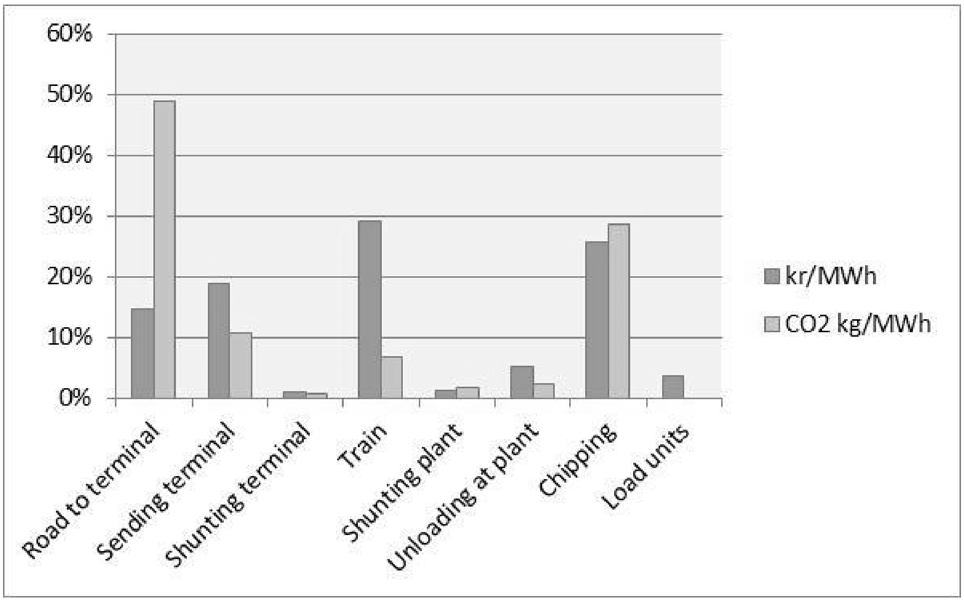

Figure 10: Costs and emissions in the base scenario.

4.6. Base scenario variations

Different variations in the base scenario have been considered in the different parts of the supply chain. The variations are detailed in the appended paper three along with the system costs based upon the variations.

The variations in the supply chain activities are based upon the possible options in which each activity can be carried out. The variations helped in the calculations of different costs and CO_2 emission estimates and helped in the selection of a best feasible case scenario. The graphic representation of the rail and system costs is summarised in Figures 11 and 12.

Name	System: Cost % of base scenario	System: CO2 % of base scenario	Rail: Cost % of base scenario	Rail: CO2 % of base scenario	Break even distance road, km
Full returnload, train and trucks	-25%	-28%	-49%	-36%	97
Seven days per week	-23%	-25%	-25%	-15%	102
Roundwood chipped at terminal with low costs	-23%	-20%	-9%	-12%	104
Full returnload, train	-17%	-3%	-49%	-36%	121
New rail engine and extra wagon	-17%	-24%	-10%	-14%	122
Roundwood chipped at terminal	-14%	-20%	-9%	-12%	133
Base scenario 10km road haulage to terminal	-11%	-37%	0%	0%	142
High utilisation, engine, wagons and load units	-9%	0%	-26%	0%	148
Low terminal cost	-9%	0%	0%	0%	149
52 week utilisation	-8%	0%	-19%	0%	151
Full returnload, trucks	-7%	-25%	0%	0%	154
High utilisation, engine and wagons	-7%	0%	-19%	0%	156
Old engine and wagons	-4%	0%	-12%	-3%	166
High utilisation, engine	-3%	0%	-9%	0%	167
30 week utilisation	-2%	0%	-5%	0%	171
Chipping at terminal	-1%	21%	0%	0%	174
Efficient shunting	-1%	-1%	-3%	-7%	175
Rotary container with intermodal transshipment	-1%	16%	10%	0%	175
Electrified shunting	0%	-2%	-1%	-24%	177
Base scenario	**0%**	**0%**	**0%**	**0%**	**178**
Diesel shunting	0%	1%	1%	10%	179
40m3 container, intermodal transshipment with extra wagons	1%	5%	21%	2%	183
40m3 container, swtich body truck at plant extra wagons	2%	0%	4%	2%	184
New rail engine	4%	0%	10%	0%	190
40m3 container, swtich body truck at plant	4%	1%	9%	6%	191
Road haulage in both ends, 10km	8%	-18%	0%	0%	205
Via intermodal terminal in Göteborg, 6km	12%	-2%	10%	0%	218
Chipping at terminal, 80km haulage	17%	77%	0%	0%	233
Three days per week, Småland	17%	8%	9%	-32%	235
40m3 container, swtich body truck at plant extra wagons, no Dalarna	18%	8%	14%	-31%	237
Via intermodal terminal in Göteborg, 20km	19%	-2%	10%	0%	239
Via terminal Göteborg, 10km haulage to terminal	19%	19%	0%	0%	241
Base scenario 100km road haulage to terminal	22%	74%	0%	0%	251
Via receiving terminal	23%	31%	0%	0%	252
Via terminal Göteborg, 100km haulage to terminal	50%	125%	0%	0%	343
Road haulage in both ends, 100km	72%	198%	0%	0%	415

Figure 11: Summary of costs based on variations in the base scenario.

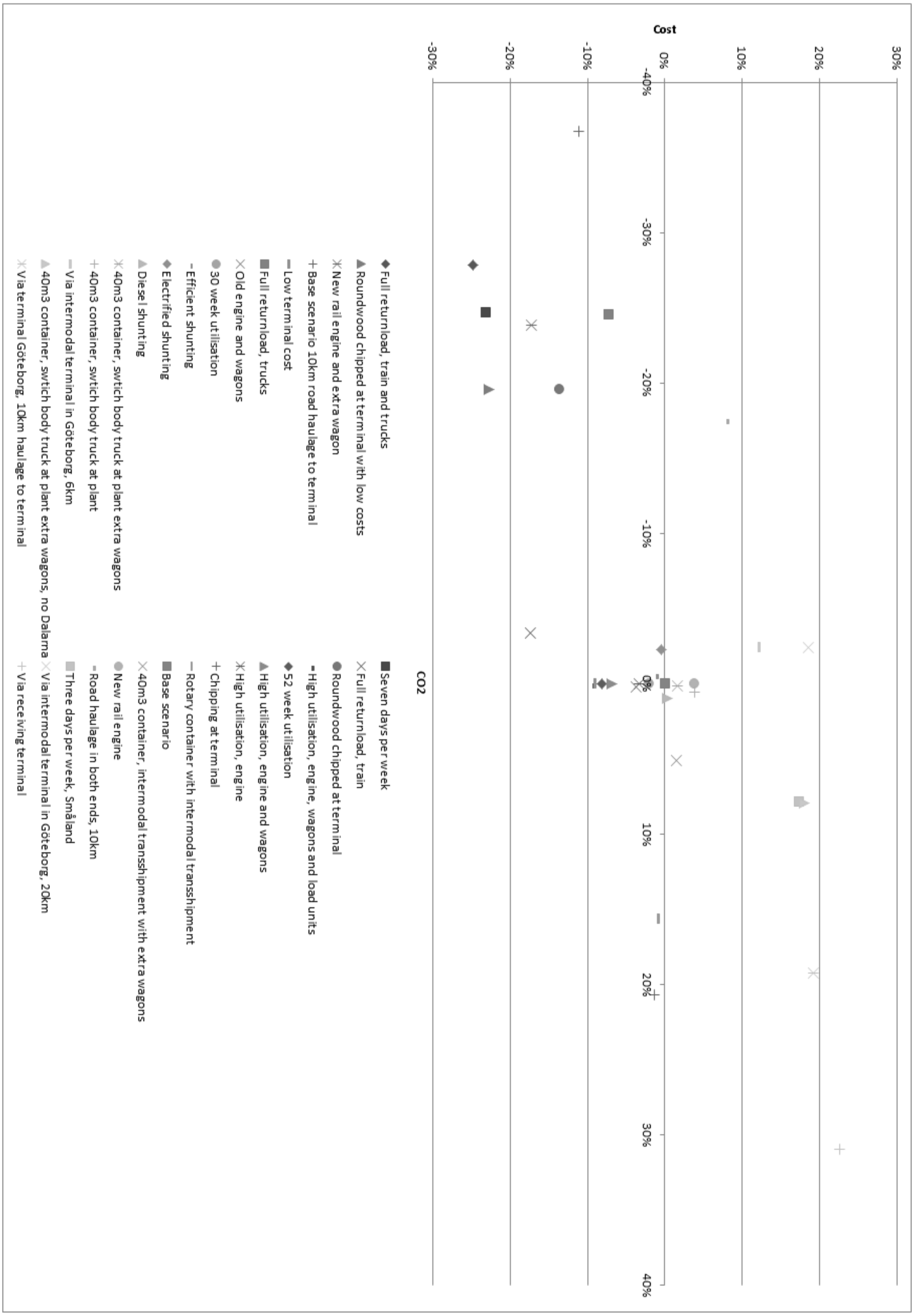

Figure 12: Change in costs and emissions from the base scenario for tested cases without outliers.

4.7. Best feasible case scenario

The cost calculations done based on the variations can be used to find the best feasible case scenario for the plant, which has high utilisation along with low system costs and emissions. A seven-day train operation would deliver 14 GWh or 82% of the plant's needed fuel at full capacity. However, the plant would rarely operate at full capacity, and thus a five-day per week operation is more realistic, with three days to Småland and two days to Dalarna. The seven-day train operation would also pose risks to trains as it would be hard to manage a 24-hour cycle with tight schedules and with little room to deal with uncertain situations as strikes, bad weather, etc. Chipping of round wood is highly efficient in comparison with logging residue chips regarding Småland and has been selected for the best feasible scenario.

Large trains with new engines are not selected as they are large in size which are not suitable for the current tracks and infrastructure at the plant, however they would lower costs by increasing the loading capacity and volume delivered (15.2 GWh or 89% of maximum need) by trains. The extra volume provided through the use of new engines is not needed, as they will bring stocks greater than the need of the plant. Older engines and wagons may reduce costs, but they are more susceptible to failure and should not be included in the best feasible case scenario. Thus the engine used in the base scenario, the type Rd electric engine, has been selected for the best feasible case scenario.

Rotary containers are considered to be the most effective load units. Return flows are hard to find and thus cannot be included in the best feasible case scenario. Reducing road haulage distances would reduce costs, but the distance of 40 km in the base scenario can be seen as the realistic option as it is the average distance to terminals today. Selecting a supplier with rail access would reduce costs therefore, in the best feasible case scenario bark is transported from Dalarna from a supplier having rail access. The use of trains outside the system and a longer season would further reduce costs. In this best feasible case scenario, a slightly longer season of 28 weeks (vs. 26) is assumed. The rest of the aspects are kept the same as in the base scenario. The distribution of costs and CO_2 emissions are graphically presented in Figure 13.

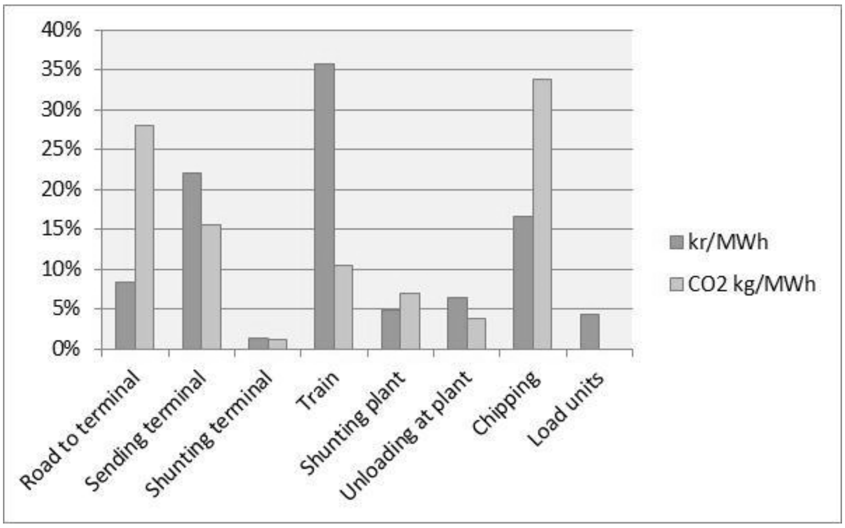

Figure 13: Distribution of costs and CO_2 emissions for the best feasible case scenario.

The best feasible case scenario gives a cost of 77.89 kr/MWh with CO_2 emissions of 1.79 kg/MWh. A rough break-even point against all-road transport is at 106 km. Train costs are 36.13 kr/MWh.

As major CO_2 emissions are generated by the chipping process and road haulage in the chain, electric chipping rather than diesel-powered chipping would greatly reduce emissions, though electric chippers require large volumes to stay economical. If these large use volumes could be maintained, a switch to electric chipping would also reduce costs. In the current scenario, the emissions could be drastically reduced to 1.18 CO_2 kg/MWh and costs to 68.20 kr/MWh with electric chipping at the terminal. The same principle can be applicable to electric shunting compared to diesel-powered shunting. In addition to electric shunting if rail sidings can be extended to avoid splitting the train that will further reduce operational costs.

4.8. Supply risk analysis

The supply risk analysis is introduced in addition to the appended articles as a part of the report submitted to Göteborg Energi. The analysis elaborates on the risks associated with missed train deliveries and builds on the effects on the storage and consumption of the plant if certain numbers of train deliveries are missed in a week. The intermodal system delivers 9.8 GWh per week or 58% of the plant’s demand when operating at full capacity. From a risk perspective, the plant is therefore not completely dependent on the train. Figure 14 shows the storage levels at the end of the day when all deliveries have been received. As the plant consumes fuel all day, there can be a risk of low stored levels until the deliveries have been made, as shown by the theoretical minimum in Figure 15, with deliveries being made at the closing time. Obviously that is not possible, however it indicates the risk of late deliveries. Figure 16 shows the stock level on a Monday, assuming that the train arrives in the late afternoon. Road deliveries are evenly spread from Monday to Friday. Consumption is assumed through the week and across the day. It is assumed that the storage is completely filled by Friday evening, which is the normal procedure since the plant tries to avoid deliveries during the weekend.

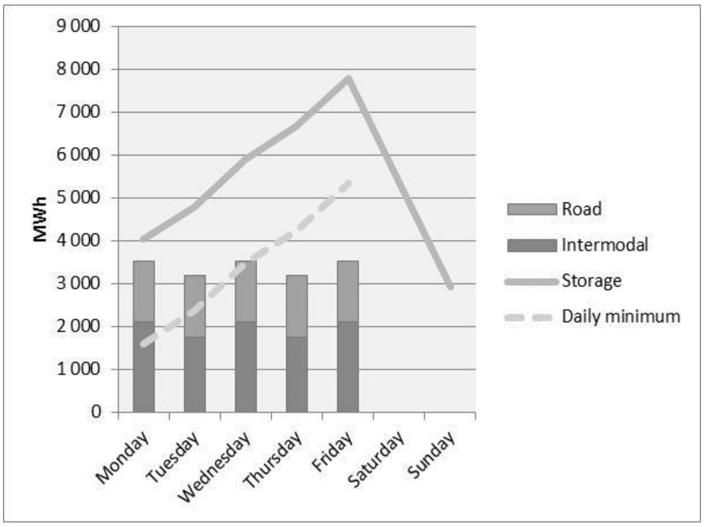

Figure 14: Deliveries and storage levels (evening) in the base scenario.

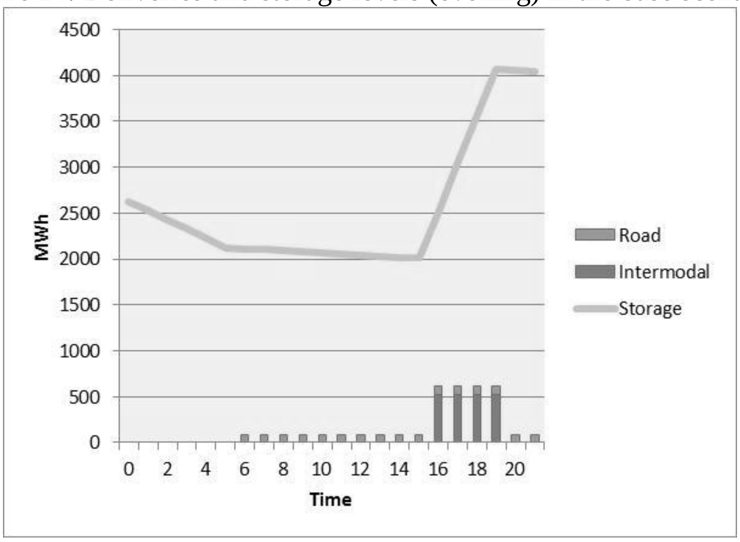

Figure 15: Example of possible storage and deliveries during one day.

Due to seasonal variation, the plant would not operate at full capacity all the time. The minimum point at which the plant is considered to operate is 30% of maximum capacity, below which the plant needs to be shut down. Figure 16 demonstrates the increase in costs with half-full trains over a number of weeks.

The reduction in demand can be tackled by reducing the fuels brought in or by cancelling train deliveries. This is difficult as contracts are made in advance with these possible considerations. Whatever strategy is adopted, it will result in an increase of transport costs, as cancelling a train would mean bearing costs due to contract terms with the operator.

A sensitivity analysis has been presented based on the number of trains not operating at full capacity. The train costs remain the same as full trains apart from a reduction in energy consumption. Terminal, handling, pre-haulage and other costs are reduced due to lower volumes. System costs increase by 36% from 99.95 kr/MWh to 135.90 kr/MWh when the train is 50% full, while rail costs increase by 87% from 35.18 kr/MWh to 65.84 kr/MWh

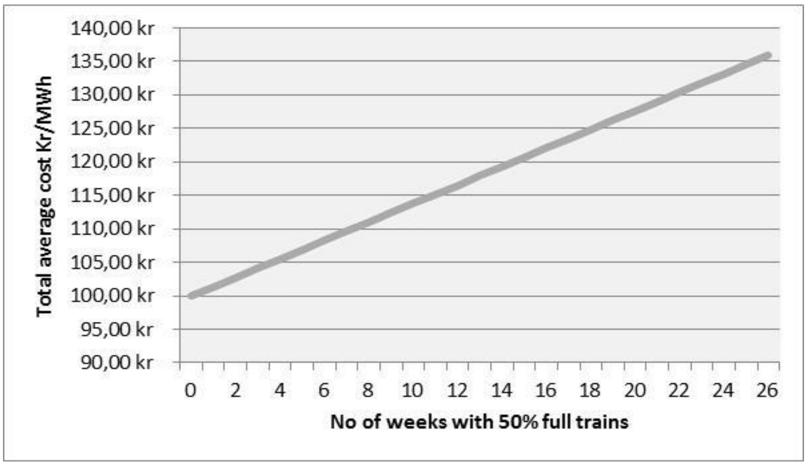

Figure 16: Increasing costs based on number of weeks with 50% full trains.

The different storage scenarios are based on the absence of one or more train deliveries in a week, which can happen due to strikes, technical breakdowns or inclement climate conditions. The different scenarios developed based upon the absence of train deliveries are as follows:

1. One, two or three consecutive train deliveries missed.
2. Four or five consecutive train deliveries missed.

The storage is considered to be 7.79 GWh on Friday, which is the maximum stock (desirable weekend stock), and this serves as the starting point for the scenarios. The daily delivery for one train needs to be complemented with 15 trucks, which are sourced locally to provide the remaining energy for the level considered desirable. During the weekends, the stock levels are reduced to 2.933 GWh of energy as no deliveries are made. The same pattern of one train and 15 trucks can be ordered the next week as well. Through such a combination, by the end of the second week a stock of 2.933 GWh is achieved, the same as the first week, and thus the combination become repetitive and sustainable.

4.8.1. One, two or three consecutive train deliveries missed

In the case of one missing train not much needs to be done, as the new stock level of 5.69 GWh at Friday can be maintained over a number of weeks without consequence. Missing two trains does not present a major problem, as the stocks only become negative on Sunday only if no extra deliveries are ordered. Thus, in the case of one or two missing trains, compensation can be accomplished by ordering extra trucks or by train deliveries over the weekend. The number of trucks can be raised to 21 (in case of one missing train) or 29 (in case of two missing trains) for the remaining weekdays. This will bring the stock levels to 7.79 GWh on the Friday of the first week, which is a normal stock for weekend operations.

Missing three consecutive trains will cause stocks to be depleted by Wednesday, and the plant would fail to provide 0.033 GWh of energy to be produced at full capacity. In this scenario, the absence/presence of weekend train deliveries would result in different options. The deficiency could be filled with extra trucks. If the option of weekend train deliveries is not possible, then the 15 trucks that were ordered normally would need to be raised to 37 trucks daily for the last three days of the week. This would bring the stock levels to the normal 7.79 GWh at the end of the first week. If weekend train deliveries are possible, then extra trucks should be ordered only to deliver the fuel needed for production until Friday. It is of no use to have the maximum number of deliveries by truck as trains on the weekend can bring more stock and are a more sustainable option than maximising truck deliveries.

4.8.2. Four or five consecutive trains missed

If four trains are missing for the first four consecutive days of the week, then the stock will run out by Wednesday. This means that either stock should be ordered on Wednesday or the plant should have ordered more trucks after missing the first train delivery of bark, i.e. more trucks should have been ordered on Tuesday. The situation would be grim if the plant did not order extra trucks on Tuesday or Wednesday. Options available in this case are either to order the entire stock by truck without weekend deliveries, or to order limited stock so that weekend train deliveries could replenish the stock. The deficiency would be filled with the extra number of trucks. The 15 trucks that were ordered previously would need to be raised to 28 trucks daily for the first week.

In the case of five trains missing, the number of trucks daily would need to be raised to 33. This would bring the stock levels to 7.79 GWh at the end of the first week. The following week the usual 15 trucks and one train per day could be ordered. This results in the same ending stock of 0.0029 GWh on Monday, which can be recovered as stated earlier. If weekend deliveries are considered for trains and trucks, then a different combination is needed. It is not possible to have truck deliveries throughout the week, as if the 2.2 GWh is not ordered on Wednesday then the stocks would be negative, and the objective is to bring the stock levels on Monday to the normal of 4.059 GWh.

4.8.3. Missing train analysis at the Sävenäs plant

The number of train deliveries missed is more important than the day of week they are missed for one week. Since five train deliveries are made in a week with large volumes, missing stocks for at least a couple of days can be compensated for by the remaining deliveries. The missing deliveries can also be compensated for by extra truck deliveries, which can be distributed evenly throughout a week. Thus the frequency of train deliveries is more important than the specific day on which a delivery is missed. Extra trucks can handle the missing train deliveries, or weekend deliveries can make up the lost loads; however, these solutions are hard to implement on short notice, especially for rail transport. The option of ordering extra trucks depends on the availability of trucks. In this case, weekend deliveries can be used, as the trucks might not have any engagements during the weekends, as the usual schedule will not include weekend deliveries, but this may not always be the case.

The plant can also lease trucks to fetch goods from the terminals. This approach would definitely result in more costs to the plant and would result in under-utilisation of the vehicles when train deliveries are being made smoothly. The waiting period for the plant to decide upon extra deliveries is very limited, as seen in Table 23, as stocks come quite close to depletion if no deliveries are made—thus prior planning is required rather than on-going management.

Table 23: Number of trucks and trains needed in different scenarios.

	One train missing	Two trains missing	Three trains missing	Four trains missing	Five trains missing
Latest delivery point	No specific delivery point	Saturday evening	Tuesday evening or Wednesday morning	Tuesday evening or Wednesday morning	Tuesday evening or Wednesday morning
Number of trucks per week	100	118	141	160	182

Extra deliveries would reduce both environment sustainability and economic sustainability Replacing trains with trucks would result in more CO_2 emissions and costs along with possible congestion problems. The absence of trains could lead to the need for up to 183 trucks per week. The option of having daily train deliveries may not be always possible in real situations, but theoretically this can be attained due to a 24-hour cycle.

The train delivery timings would become important in this case, as at least an 18-hour gap is needed for another train delivery to be made at the plant from the moment a train is completely unloaded. The unloading times of the vehicles at the plant are not a major concern, as the unloading times for trains (four hours) and trucks (15 minutes) are within the working hours of the plant as long as the vehicles arrive significantly before closing time. An assumption in this case needs to be that trucks and trains should arrive and get unloaded at the plant before the closing time (22:00). The minimum time period in this regard would depend upon the number of vehicles required by the plant on a particular day. The time at which the vehicle arrives at the plant is also important for the lead times of the vehicles. For example, if a train arrives at the plant in the evening (no later than 18:00, as four hours are needed to unload the train), it would not be possible to have the same train back at the plant before the 24 hour wait time based upon the sourcing locations mentioned in the case study. The train timetable will affect the return of the same train depending upon the locations from which biofuels are picked up and delivered to the plant. This means the same train can only arrive back after 18:00 the next day. A different train could be used to deliver biofuels to the plant before that time, however that would depend upon train timetables and availability.

The train schedules, the unloading times of the vehicles and the arrival times of the vehicles all affect the storage levels. It would be favourable for sustainability to replace the missing trains with extra trains, as this would result in lower emissions and costs, but it may not be a realistic option as the train schedules are mostly pre-defined and it is not possible to order extra trains on short notice. Having extra trains available in the system to just replace missing train deliveries would mean significant costs and under-utilisation of resources. The number of trucks depends upon the availability of trucks, as during peak season (winter) it would be hard to get extra trucks because of their busy timetable.

5. Conclusions and future research

The following section provides the conclusions to the findings mentioned in the previous section about the appended papers.

5.1. Research questions answered

The different research questions developed were answered through the development of the three articles. The summary of the findings is presented in Table 24, along with the relevant research questions. The first article identified the key definitions, activities and issues in the wood biofuel supply chain in the literature. The second article helped by describing the industry situation in terms of applied practices and opinions. The third article suggested sustainable solutions based on cost calculations and CO_2 emissions calculations for supplying wood biofuels to a large power plant in Gothenburg.

Table 24: Summary of the research questions along with their answers developed through different papers:

Research questions	Paper	Short Answer
RQ 1: What are the different actors and practices involved in wood biofuel supply systems for heating plants?	Paper 1: Wood biofuels logistical challenges in Sweden	The supply chain of wood biofuels consists of five steps, which are collection/harvesting, storage, transport, pre-treatment activities and overall supply chain design. The main actors are the forest sector, the wood processing industry and district heating. The supply chain faces a number of problems of which key challenges are seasonal variations, storage, the chipping process, the low density of wood biofuels, term standardisation, sources of supply and dependency on policies.
RQ 2: What are the main preferences, requirements, and logistical challenges in the wood biofuel supply system for heating plants?	Paper 2: Logistic requirements and characteristics of the Swedish wood biofuel industry	The survey study shows that the industry has a local market focus, mostly utilising truck transport with direct transport from the forest. Road transport is rated as highly favourable, with reliability as the most important factor. Storage is used to overcome fluctuations in demand and is an essential part of the supply chain with most CHPs having storage facilities. The forest is the preferred location for chipping. The challenges to the supply chain are determining the size and location of storage facilities. On a more general level, the largest problem perceived was seasonal variation in demand. Transport of tree parts and forest residues is the most problematic.
RQ 3: How can sustainable intermodal transport options be designed for a wood biofuel supply system for heating plants?	Paper 3: Meeting the challenges of intermodal transportation of biofuel	High utilisation and keeping transport distances short play an important role in keeping costs down. Large emissions are associated with the terminals and the chipping process. Some activities in all road systems and intermodal systems are common, such as the passage of goods via terminals, which affords an intermodal system potential.. Storage levels play an important role in the ordering of shipments.

5.2. Logistics processes

A clear understanding of biofuel market operations would aid managers in planning and managing the wood biofuel supply chain (Roos et al., 2000). The actor's preferences and supply chain characteristics, as described in the previous section, can be used to highlight important challenges for the logistics system.

5.2.1. Operation 1: Harvesting and collection

The local supply options are clearly visible in the supply chains. Trucks are suitable for shorter distances while other modes require higher transport volumes. This restricts the market for smaller CHPs who source from a distance of 100-150 km, while larger plants have more sourcing options. Large CHPs do prefer local sourcing as well, if possible. Lack of local sources is the main reason for sourcing from longer distances.

There are clear differences in terms of procurement between products directly from the forest and the forest industry. The chains starting in the forest are pull chains, in which consumers order what they need. On the other hand, the products from the forest industry have a push chain, where the industry production determines the pace of fuel production. Contracts normally state that plants will use all the by-products from the forest industry, as they are waste for the forest industry. The power in the forest-based chain lies with the CHPs, while in the forest industry chain, the industry has the most power as it sets the pace of fuel production.

5.2.2. Operation 2: Storage

Logistically, storage helps in the efficient and smooth flow of fuels and in the handling of excess fuel, which may not be needed immediately (e.g. deliveries from ships and trains that may bring fuels in excess of the daily consumption). Although storage provides flexibility in the supply chain, it is also a major cost factor. Storage demands significant space as well, which is not always possible for the CHPs, resulting in offsite storage options. Rentizelas et al. (2009) conclude that cheap storage solutions can help in reducing overall costs, which could even compensate for the material losses and increased handling at the storage terminals.

5.2.3. Operation 3: Transport

A combination of rail and road can transport large volumes of biofuel with lower energy use over longer distances (Lindholm and Berg, 2005). The CHPs in the survey prefer reliable transport with good access, low costs and few contaminations in the fuel, and perceive that they receive this from road transport. Using road transport to satisfy the demand of large CHPs can result in congestion problems (Mahmudi and Flynn, 2006). The survey study showed that the large plants could receive up to 70 trucks per day. Shifting the loads from roads to other transport modes is one alternative solution.

The survey demonstrated that rail and sea are perceived as environmentally sustainable, but have problems in price, access, flexibility and other areas in comparison to road transport, which is rated low in terms of environmental friendliness. Ships designed for ore transport have handling problems with full loads of wood pellets, and must carry other heavy materials as well (Bradley et al., 2009a). Application of intermodal solutions require large volumes and transport distances, as rail/sea transport has low distance-dependant costs but high fixed costs (Flodén, 2007). Long-distance intermodal transport solutions are slower than the local road solutions, but survey respondents rated fast transport to be of little importance. Suppliers usually decide the transport mode to be used, thus making them an important actor in the supply chain, however abrupt changes in the chain would require approval from the CHPs. The variable demand of biofuels presents transport problems in terms of under-utilisation of machinery causing unnecessary costs.

The transport preference of the CHPs found in the survey corresponds well with other industries, as transport quality and reliability were rated as highly important. Transport selection is a two-step process in which first the preferences have to be met, after which the transport options are evaluated on price (Flodén et al., 2010).

5.2.4. Operation 4: Pre-treatment techniques

Terminal or plant chipping is high in productivity and requires large volumes to stay competitive in comparison with forest chipping. This produces good quality control with no setup time or allocated space needed for chipping, but delays dues to waiting times can reduce efficiency, resulting in extra costs (Asikainen, 1998). The chipping location greatly impacts the supply chain in terms of cost and quality. Biomass chipped earlier in the supply chain affords more flexible and cost-efficient transport options, while chipping later provides more quality control. The survey showed that the majority of chipping takes place in the forest, which suggests the balance of efficiency lies here, while terminal or CHP chipping present logistical challenges in terms of transport utilisation.

The location of the chipping process affects the CO_2 emissions produced by the wood biofuel supply chains. Chipping at terminals and power plants can be performed by electric chippers, which greatly reduce the CO_2 emissions that would be generated if the same biomass were chipped in the forest using fossil fuels. This is a trade-off situation between lower costs and lower emissions, as chipping at a terminal/power plant means low emissions but increased transport costs due to power capacity utilisation. Chipping in the forest would reduce costs by providing better capacity utilisation, but would greatly increase the emissions released in the wood biofuel supply chain.

5.2.5. Overall operation of the supply chain

The extensive use of biofuels has been largely attributed to the high carbon tax. The survey revealed that the wood biofuel supply is characterised by uneven demand and dependency on buffer stocks and deliveries. Road transport in this regard provides flexibility in comparison to rail and sea. The respondents in the survey also believe that a sudden change in the policies would present operational difficulties.

5.3. Challenges Explained

The issues identified by the literature can be related to the supply chain management interfaces identified by Gold and Seuring (2011) in the bioenergy supply chains. Table 25 provides a summary. The following discussion relates to the logistical challenges identified by the literature review.

Table 25: Logistical issues in the SCM steps. "X" denotes the presence of the issue.

Logistical issues	Op 1	Op 2	Op 3	Op 4	Overall supply system design	Difficulties
Storage		**X**				Location, storage time, estimations, size, underutilisation of resources
Seasonal variability					**X**	Keeping buffer stocks, uneven supply, increased storage costs
Chipping process	**X**	**X**	**X**	**X**		Uneven quality, location of the process, handling difficulties
Low density of the wood biofuels			**X**			Handling complications, capacity management requirements both in vehicles and at storage terminals
Term standardisation					**X**	Difficulties in generating statistics
Sources of supply	**X**					Shortage of wood biofuels
Dependency on policies					**X**	Change in policies leading to loss of interest in using wood biofuels

Seasonal variations in the wood biofuel supply chain present problems with stock planning for energy production. A shortage of biofuels leads to the utilisation of fossil fuels to fill the energy demand, which reduces environment sustainability. Seasonal variations also mean that the demand is high in winter and almost zero in summer. Low demand means under-utilization of the equipment with fixed annual costs. Seasonal variations influence the mode of transport used as well, as during high demand seasons rail can be used while, in summer this might not be a viable solution. Seasonal variations affect almost every part of the supply chain.

Storage terminals are an integral part of the wood biofuel supply chain, as they help in dealing with seasonal variability. A number of decisions regarding storage such as location, capacity and accessibility of different modes require advance planning. Low demand may lead to under-utilisation of the storage terminals.

The chipping process in the supply chain affects the overall costs depending on the location of the process. Chipped biomass is easier to transport due to improved handling. Chipping can be performed at three different locations: forests (roadside), terminals or power plants. The quality of the wood chips produced is also affected by the location, as the chips produced at the terminals and plants are better in quality with more control as compared to the roadside chipping. Roadside chipping, on the other hand, does provide efficient handling in the rest of the supply chain. The location of the chipping process also effects the CO_2 emissions produced, as forest chipping utilises fossil fuels while a terminal or a plant chipper may be powered by electricity. This presents a trade-off scenario between costs and CO_2 emissions: forest chipping results in low costs and high emissions while terminal or plant chipping result in higher costs but lower CO_2 emissions.

The low density of wood biofuels affects the transport cost as well. Logging residues occupy more space and have lower energy content as compared to chipped wood biomass.

The use of standardised terms for biofuels is important for reporting purposes, as in any business. A lack of standardised terms can lead to inaccurate reporting of what type of biofuel is needed and in what quantity. This could provide planning problems for the consumers (HPs and CHPs). A lack of standardised terms globally would result in a hindrance of trade due to the uncertainty of terms being used for reporting and communication between industries.

The successful use of wood biofuels is largely due to European Union policies along with Swedish energy policies. Carbon tax has been the major motivator in this regard for the use of biofuels in Sweden. These environmentally friendly policies together with subsidies helped in discouraging the use of fossil fuels. A sudden change in the policies would present difficulties in keeping biofuels competitive with fossil fuels, as fossil fuels are more efficient in terms of energy density and logistics. The dependence of biofuels on policies makes them vulnerable to abrupt changes. Consistency in Swedish policies, including legislation, taxation, certificate systems, fees and subsidies, has greatly affected the success of biofuels (Björheden et al., 2010).

The survey revealed that the logistical challenges could be further narrowed down to several major issues. Table 26 provides a summary of the challenges identified by the survey study.

Table 26. Logistical challenges identified from the survey study.

Operations	Current situation	Logistical challenges
Harvesting and collection	Local market focus with truck transport.	Local focus limits the possible logistical and sourcing solutions.
Storage	Essential in the supply chain at both plants and terminals.	Balancing size and location against extra costs.
Transport	Highly dominated by road. The supply chain structure is mainly transport directly from the forests.	Finding possibilities for other transport modes to potentially improve the chain, e.g. intermodal transport. Reducing environmental impact from road transport.
Pre-treatment	Most common and preferred locations are the forests and the terminals.	Balancing between more efficient chipping and more efficient transport.
Overall supply chain	Fluctuating demand and buffer stocks. Influenced by political decisions.	Flexibility in the supply chain to adapt to changes.

The focused and detailed logistical challenges identified by the survey study approve some of the challenges present in the literature, such as seasonal variations, low density of wood biofuels and use of standardised terms. Other challenges such as storage, chipping process and dependence on policies are described in more detail in the survey study. The storage challenge has been narrowed down to the location and size of the storage facilities. The chipping process requires a balance between efficient chipping and transport. Dependence on policies highlights the need for flexibility in the supply chains to respond to changes. Harvesting and collection of biofuels is highly focussed on local sourcing, which limits sourcing options. Regarding the transport of wood biofuels, key challenges are shifting loads from road transport to other transport modes, e.g. intermodal transport along with reduction of environmental impact.

5.3.1. *Sustainability in wood biofuel supply chains*

Different supply chain options can be developed based on the CO_2 emission and cost calculations in the case study of Göteborg Energi plant in the city of Gothenburg. The study demonstrates how economically and environmentally sustainable transport solutions could be developed for a CHP utilising wood biofuels. High utilisation of the resources is key to keeping costs down. The case study shows that road distances to terminals should be kept as low as possible, as long haulage distances of 80-100 km will generate higher costs for the system. Rail access both at the plant and near the forest is preferred. The road haulage distance to the receiving terminal is of great importance, as increasing these distances to 100 km will double the costs of the system even if return flows to both trucks and trains are maintained, which is not a realistic option. Biofuels delivered without the use of terminals and road haulage have the greatest potential, for instance products from the forest industry with rail access. Terminals have the largest costs, followed by chipping. A large range of terminal costs can be found in the literature and the industry, which makes the selection of the right terminal important. Terminal costs also depend on how costs are shared among different wood products at the terminal, e.g. pulpwood and biofuel.

It is important to consider that an all-road solution has many activities in common with intermodal solutions, such as the use of terminals that may also have rail access. The presence of terminal costs in the system makes the additional costs low in an intermodal setting where the product has to be loaded onto a train. Therefore, intermodal solutions are competitive in comparison to flows already passing through a terminal, especially for round wood, which always passes through a terminal. In an intermodal setting, cost-saving options should be utilised whenever possible, such as low-cost terminal chipping (preferably with an electric chipper) compared to roadside chipping. The price of biofuel also plays a role in the transport cost, e.g. if sourcing from a low-priced region can be done using an intermodal solution while the local all-road sourcing price is expensive and the price difference is significant, the intermodal solution becomes more attractive.

The storage options available at Göteborg Energi contributed to the following conclusions about a large HP:

- Storage capacity plays an important role in the ordering of shipments.
- Missing train deliveries can be managed with a compensating number of trucks, which would lead to less sustainable economic and environmental solutions..

This study addressed many aspects of wood biofuel supply chains, beginning by assembling the available literature, collecting market description data, and finishing with a focussed case study. The literature review part of the study provides an introduction notes important aspects of the wood biofuel supply chains. The survey study gathered industry data and lays out the preferences, attitudes and challenges found in the current supply chains. The case study helps in tackling the logistical challenges along with the investigation of potential sustainable intermodal transport options. This study provides a platform for future research endeavours in the field of wood biofuel supply, which can be both specific and general. The sustainability aspect of the study highlights the potential for making wood biofuel supply chains sustainable. This aspect is interesting within the current topic as it is at the heart of utilising wood biofuels and is still open to further exploration. The following section discusses some of the future research endeavours that could be attempted based on the current study.

5.4. Future research

Some suggestions for future research based on the findings of this study are as follows:

5.4.1. Sustainable international intermodal chains

A future research effort could involve an extension of intermodal solutions to an international context. Solutions based upon both rail and sea transportation could be explored. Involvement of sea transport would provide further investigation in terms of load units, terminals, storage handling equipment, etc.

5.4.2. Supply chain development based on fuel type

This study focuses on the logistics of wood biofuels. A future study could incorporate different biofuels such as liquid biofuels and note the similarities and differences based on the different biofuels used at the power plants. This would help in giving direction towards specific biofuels that are high in energy content and can be transported efficiently and sustainably.

5.4.3. Development of business models

This study outlines the various activities and problems present in the wood biofuel supply chain and presents options for sustainable transport. One future endeavour could be the development of business models that define the practicalities of demand and supply along with contract specifications. These business models could focus on making the business profitable without the biofuel-friendly policies, which are currently a cornerstone in the success of wood biofuels.

5.4.4. Social sustainability

Further investigation into the evaluation and specification of the social sustainability of the freight transport chains should be developed, as this knowledge can help in better defining socially sustainable supply chains.

5.4.5. GIS based study

This study provided a lot of information about the various power plants in Sweden in regards to their operations and locations along with their suppliers and distribution options. The development of a geographical information system for the supply of wood biofuels would help the supply chain managers to properly analyse and manage flows in a more efficient way. A GIS could be used to share the inventory levels of the various storage terminals from which the power plants can source their biofuels. It would also help in planning the shipments required by the power plants, which could mean using fewer vehicles and shifting loads to rail transportation. In addition to these primary benefits, plants would be able to track and monitor their shipments via the GIS, and the system would assist in dealing with the varying demands in a timely manner, thus saving costs.

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Appendices

Survey

FÖRHANDSGRANSKNING

GÖTEBORGS UNIVERSITET

Tack för att Ni tar er tid att besvara enkäten.

Enkäten avser verksamheten vid Er anläggning [Anläggning]. Vi ber er besvara enkäten utifrån den nuvarande verksamheten vid anläggningen. Om ni inte känner till de exakta uppgifterna ber vi er uppskatta efter bästa förmåga.

I enkäten kommer vi att fråga om bränslevolymer, producerad energi, transportavstånd m.m. Om möjligt ange sifferuppgifter (volymer etc.) från år 2012. Det går även att i kommentarsfältet vid varje fråga ange vilket år svaret avser.

(XXXX, tex 2009)

Om detta inte är möjligt, vänligen ange här vilket år som avses:

Denna enkät besvaras av:

e-mail adress:

Titel:

Var vänlig beskriv mycket kortfattat dina ansvarsområden:

Del 1. Frågor om anläggningen

1. Hur mycket energi (både värme och eventuell elektricitet) producerar er anläggning sommarhalvåret, respektive vinterhalvåret, och hur stor andel av detta kommer från biobränsle?

Med sommarhalvåret avses cirka april-september. Med vinterhalvåret avses cirka oktober-mars.

Var vänlig ange även enhet. Summan av vinter och sommarhalvåret skall motsvara hela er årsproduktion.

	Producerad värme	Enhet värme	Producerad elektricitet	Enhet elektricitet
Total energi vinterlid				
Total energi sommarlid				

2. Var vänlig ange andelen energi producerad vid er anläggning från de olika bränslena nedan i %.

Observera att varje kolumn ska summeras till 100%

	Andel sommartid i %	Andel vintertid i %
Stamvedflis		
Grotflis		
Stubbflis		
Flis av annan trärávara:		
Flis av okänd trärávara		
Pellets		
Torv		
Avfall		
Biogas		
Naturgas		
Bioolja		
Kol		
Olja		
Andra bränslen:		
Summa		

Du har angett Flis av annan trärávara. Vilken/vilka trärávaror avses?

Du har angett Andra bränslen. Vilket/vilka andra bränslen avses?

Använder inte er anläggning någon form av biobränsle av träråvara eller torv?

(t.ex. någon typ av träflis, pellets eller torv)

- Ja
- Nej

Var vänlig och gå tillbaka till fråga 2 för att ange andelen energi producerad vid er anläggning från bränslena flis, pellets och torv.

4. Har ni lagringsmöjligheter för biobränsle vid Er anläggning?

Med biobränsle menas i denna enkät träbränslen som träflis, träpellets samt torv.

- Ja
- Ja, vi har både lager direkt vid anläggningen samt ett eget lager i nära anslutning till anläggningen.
- Nej, inte direkt vid anläggningen men vi har ett eget lager i nära anslutning till anläggningen
- Nej

Kommentarer:

Var vänlig ange kortfattat var Ert externa lager ligger i kommentarsfältet.

5. Var vänlig ange lagringskapacitet och enhet vid Er anläggning.

Lagringskapacitet	Enhet

5b. Var vänlig ange lagringskapacitet och enhet vid Ert externa lager.

Lagringskapacitet	Enhet

6. Vilken infrastruktur har ni tillgång till vid Er anläggning?

Var vänlig ange även om de används för inkommande transporter.

- Väg — Används för närvarande.
- Järnväg — Används för närvarande.
- Sjöfart (kaj) — Används för närvarande.

Kommentarer:

6b. Vilken infrastruktur har ni tillgång till vid Ert externa lager?

Var vänlig ange även om de används för inkommande transporter.

- Väg — Används för närvarande.
- Järnväg — Används för närvarande.
- Sjöfart (kaj) — Används för närvarande.

Kommentarer:

7. Var vänlig ange vilka hanteringsmöjligheter ni har för biobränsle vid Er anläggning.

Mer än ett alternativ kan väljas.

- ☐ Hjullastare finns på anläggningen
- ☐ Fast kran finns på anläggningen
- ☐ Truck för hantering av lastbärare finns på anläggningen
- ☐ Terminalyta, t.ex. för uppställning av containers etc.
- ☐ Rullflak/lastväxlare etc. kan hanteras
- ☐ Övrigt: ____

Kommentarer:

7b. Var vänlig ange vilka hanteringsmöjligheter ni har för biobränsle vid Ert externa lager.

Mer än ett alternativ kan väljas.

- ☐ Hjullastare finns på anläggningen
- ☐ Fast kran finns på anläggningen
- ☐ Truck för hantering av lastbärare finns på anläggningen
- ☐ Terminalyta, t.ex. för uppställning av containers etc.
- ☐ Rullflak/lastväxlare etc. kan hanteras
- ☐ Övrigt: ____

Kommentarer:

8. Hur länge lagrar ni i genomsnitt biobränslet på Er anläggning innan det används?

	Månader	Veckor	Dagar	Timmar
Under vinterhalvåret:				
Under sommarhalvåret:				

8b. Hur länge lagrar ni i genomsnitt biobränslet på Ert externa lager innan det används?

	Månader	Veckor	Dagar	Timmar
Under vinterhalvåret:				
Under sommarhalvåret:				

9. Hur mycket tid går åt från att ett fordon anländer lastat med biobränsle till Er anläggning fram till att det är avlastat för olika transportslag?

Här kan ingå t.ex. registrering av mottaget gods, flytt av fordon, avlastning etc.

	Timmar	Minuter
Lastbil		
Tåg		
Fartyg		

9b. Hur mycket tid går åt från att ett fordon anländer lastas med biobränsle till Ert externa lager fram till att det är avlastat för olika transportslag?

Här kan ingå t.ex. registrering av mottaget gods, flytt av fordon, avlastning etc.

	Timmar	Minuter
Lastbil		
Tåg		
Fartyg		

Var vänlig ange genomsnittligt antal lastbärare på tågen.

Var vänlig ange genomsnittlig storlek på fartygen.

10. Var vänlig ange hur ni hanterar den varierande efterfrågan på energi vid Er anläggning.

	Används vid vår anläggning
Säkerhetslager av biobränsle	☐
Extra leveranser av biobränsle i rätt tid	☐

	Används vid vår anläggning	
Användande av fossila bränslen	☐	
Energilagring	☐	
Sammarbete med andra värmeverk etc.	☐	
Annat:	☐	

Kommentarer:

Del 2: Frågor om transporterna

Nu följer några frågor angående Era transporter av biobränsle där Ni uppmanas att svara i procent av Era biobränslen, t.ex. vilken andel av Era bränslen som transporteras med olika transportslag. Vi ser helst att ni svarar i andel av energi producerad. Om ni svarar i andel av någon annan enhet, t.ex. andel av volym eller vikt, var vänlig ange enhet här och använd denna enhet i resten av enkäten. Ni kommer även att ges möjlighet att byta enhet vid varje följande fråga i enkäten.

Med biobränsle menas i denna enkät träbränslen som träflis, träpellets samt torv.

Annan enhet, tex. volym eller vikt:

11. Var vänlig ange andelen biobränsle som kommer till er anläggning via de olika kedjorna nedan.

Observera att varje kolumn ska summeras till 100%

Kedja

	Vinter halvåret i %	Sommar halvåret i %
Direkt från skog (inom Sverige)		
Från skog via lagringsanläggning (inom Sverige)		
Från skog via omlastningsterminal (inom Sverige)		
Från skog via både lagringsansläggning och omlastningsterminal (inom Sverige)		
Direkt från skogsindustri, t.ex. sågverk, (inom Sverige)		
Från skogindustri via lagringsanläggning (inom Sverige)		
Från skogsindustri via omlastningsterminal (inom Sverige)		
Fån skogsindustri via både lagringsansläggning och omlastningsterminal (inom Sverige)		
Från utlandet		
Vet ej kedja		
Summa:		

12. Hur stor andel av Ert biobränsle kommer från Era tre största leverantörer och hur många leverantörer har ni totalt per år?

Andelen biobränsle ska summeras till 100%

	Andel biobränsle i %
Den största leverantören	
Den näst största	
Den tredje största	
Övriga	
Vet ej leverantör	
Summa:	
Totalt antal leverantörer:	
Vald enhet om annan än [Enhet]:	

13. Var vänlig ange andelen biobränsle som levereras genom olika transportkedjor från er leverantör till er anläggning.

Observera att varje kolumn ska summeras till 100%

Transportkedja

	Vintertid i %	Sommartid i %
Lastbil hela vägen		
Tåg hela vägen		
Fartyg hela vägen		
Först med tåg och sedan leverans med lastbil		
Först med lastbil och sedan leverans med tåg		
Först med lastbil, sedan med tåg och sedan leverans med lastbil		
Först med lastbil och sedan leverans med fartyg		
Först med tåg och sedan leverans med fartyg		
Först med lastbil, sedan med tåg och sedan leverans med fartyg		
Först med lastbil, sedan med fartyg och sedan leverans med lastbil		

	Vintertid i %	Sommartid i %
Först med lastbil, sedan med fartyg och sedan leverans med tåg		
Levereras med lastbil, men tidigare steg okända		
Summa:		
Vald enhet om annan än [Enhet]:		

14. Var vänlig ange vilka lastbärare som används vid leverans till Er anläggning.

Transportsätt Lastbil

Andel av biobränslen levererade med denna lastbärare

Observera att kolumnen ska summeras till 100%.

Lastbil med fast/tippbart flak, t.ex. sidotippande lastbil		%
Rullflak/lastväxlarflak, t.ex. fliscontainer		%
Sjöfartscontainer, t.ex. 20 fot ISO container		%
Annat:		%
Vet ej		%
Summa:		
Vald enhet om annan än [Enhet]:		

15. Var vänlig ange vilka lastbärare som används vid leverans till Er anläggning.

Transportsätt Tåg

Andel av biobränslen levererade med denna lastbärare

Observera att kolumnen ska summeras till 100%.

Rullflak/lastväxlarflak, t.ex. fliscontainer		%
Sjöfartscontainer, t.ex. 20 fot ISO container		%
Innofreightcontainer		%
Container med vridtunnel		%
Annan typ av container:		%
Vet ej		%
Summa:		
Vald enhet om annan än [Enhet]:		

Du har angett Annat som lastbärare för Lastbil. Vilken/vilka typer av lastbärare avses?

Du har angett annan typ av container. Vilken/vilka andra container typer avses?

16. Var vänlig ange hur ofta ni får leverans av biobränsle med Lastbil och med hur många fordon.

Lastbil

Om leveranserna varierar, så ange det vanligaste upplägget. T.ex. om ni i genomsnitt får leverans av två lastbilar varannan dag, så anger ni 2 i raden "Varannan dag". Ange bara ett värde per kolumn.

	Sommar Antal fordon - Flis	Sommar Antal fordon - Pellets	Sommar Antal fordon - Torv	Sommar Antal fordon - Annat:	Vinter Antal fordon - Flis	Vinter Antal fordon - Pellets	Vinter Antal fordon - Torv	Vinter Antal fordon - Annat:
Dagligen								
Varannan dag								
Var tredje dag								
En gång i veckan								
Annan frekvens Var vänlig ange								

16. Var vänlig ange hur ofta ni får leverans av biobränsle med Tåg och med hur många fordon.

Tåg (OBS! antal tåg)

Om leveranserna varierar, så ange det vanligaste upplägget. T.ex. om ni i genomsnitt får leverans av två lastbilar varannan dag, så anger ni 2 i raden "Varannan dag". Ange bara ett värde per kolumn.

	Sommar Antal fordon - Flis	Sommar Antal fordon - Pellets	Sommar Antal fordon - Torv	Sommar Antal fordon - Annat:	Vinter Antal fordon - Flis	Vinter Antal fordon - Pellets	Vinter Antal fordon - Torv	Vinter Antal fordon - Annat:
Dagligen								
Varannan dag								
Var tredje dag								
En gång i veckan								
Annan frekvens Var vänlig ange								

16. Var vänlig ange hur ofta ni får leverans av biobränsle med Fartyg och med hur många fordon.

Fartyg

Om leveranserna varierar, så ange det vanligaste upplägget. T.ex. om ni i genomsnitt får leverans av två lastbilar varannan dag, så anger ni 2 i raden "Varannan dag". Ange bara ett värde per kolumn.

	Sommar Antal fordon - Flis	Sommar Antal fordon - Pellets	Sommar Antal fordon - Torv	Sommar Antal fordon - Annat:	Vinter Antal fordon - Flis	Vinter Antal fordon - Pellets	Vinter Antal fordon - Torv	Vinter Antal fordon - Annat:
Dagligen								
Varannan dag								
Var tredje dag								
En gång i veckan								
Annan frekvens Var vänlig ange								

Du har angett annat biobränsle. Vilket/vilka biobränslen avses?

17. Var vänlig ange hur era biobränsletransporter planeras och utförs. Vänligen ange andel av Era totala biobränsletransporter.

	Andel av Era totala biobränsletransporter
Våra leverantörer arrangerar och planerar transporten.	
Vi planerar och utför transporterna inom vårt företag - Med inhyrd transporttjänst	
Vi planerar och utför transporterna inom vårt företag - Med egna (eller leasade) fordon	
Vi ansvarar för transporterna men låter speditörer/transportörer planera och utföra transporterna	
Annat sätt:	
Summa:	
Vald enhet om annan än [Enhet]:	

Du har angett att ni använder er av Annat sätt att transportera biobränsle på. Vilket/vilka sätt?

18. Vilka öppettider har ni för att ta emot leveranser av biobränslen?

Vid val av annat skriv in vad som gäller, tex varannan dag 13-16.

	Från klockan:	Till klockan:
Vardagar		
Alla dagar		
Annat :		

Vi tar emot biobränsle jämt fördelat under våra öppettider.

- Ja
- Nej

Var vänlig ange de vanligaste leveranstiderna.

	Från klockan:	Till klockan:
Vanlig leverantstid 1:		
Vanlig leverantstid 2:		
Vanlig leverantstid 3:		

19. Hur långt I förväg måste ni informera era leverantörer om ökningar/minskningar av era planerade leveranser?

Observera att kolumnen ska summeras till 100%

	Andel av biobränsle i %
Samma dag	
Nästa dag	
Inom två dagar	
Inom tre dagar	
Annat:	
Summa:	
Vald enhet om annan än [Enhet]:	

Du har angett Annat som leveranstid. Vänligen ange hur lång leveranstid som avses.

20. Var vänlig ange hur många transportörer ni har.

Totalt antal transportörer:

21. Var vänlig ange hur långa de längsta kontrakten är med Era transportörer? Var vänlig ange även mängden biobränsle transporterad under varje kontrakt.

	Kontraktslängd i år	& månader	Mängd biobränsle årligen	i enhet
Det längsta kontraktet				
Det näst längsta kontraktet				
Det tredje längsta kontraktet				
Hyr in vid behov utan fast kontrakt				
Vet ej				

22. Vem betalar transportkostnaderna för transporterna av biobränsle till Er anläggning/externa lager?

	Andel biobränsle i %
Vi (värmeverk)	
Leverantörer	
Annan:	
Vet ej	
Summa:	

23. Var vänlig ange avstånden ert biobränsle transporteras till er anläggning från er leverantör för de transportslag ni använder. Ange även volymerna.

Lastbil hela vägen

	Vintertid i %	Sommartid i %
Kortare än 100km		
100- 250 km		
250 -500 km		
Över 500 km		
Vet ej		
Summa:		
Vald enhet om annan än [Enhet]:		

23. Var vänlig ange avstånden ert biobränsle transporteras till er anläggning från er leverantör för de transportslag ni använder. Ange även volymerna.

Tåg hela vägen

	Vintertid i %	Sommartid i %
Kortare än 250 km		
250 -500 km		
500 - 750 km		
Över 750 km		

	Vintertid i %	Sommartid i %
Vet ej		
Summa:		
Vald enhet om annan än [Enhet]:		

23. Var vänlig ange avstånden ert biobränsle transporteras till er anläggning från er leverantör för de transportslag ni använder. Ange även volymerna.

Fartyg hela vägen

	Vintertid i %	Sommartid i %
Kortare än 250 km		
250 -500 km		
500 - 750 km		
Över 750 km		
Vet ej		
Summa:		
Vald enhet om annan än [Enhet]:		

23. Var vänlig ange avstånden ert biobränsle transporteras till er anläggning från er leverantör för de transportslag ni använder. Ange även volymerna.

Först med tåg och sedan leverans med lastbil

	Vintertid i %	Sommartid i %
Kortare än 250 km		
250 -500 km		
500 - 750 km		
Över 750 km		
Vet ej		
Summa:		
Vald enhet om annan än [Enhet]:		

23. Var vänlig ange avstånden ert biobränsle transporteras till er anläggning från er leverantör för de transportslag ni använder. Ange även volymerna.

Först med lastbil och sedan leverans med tåg

	Vintertid i %	Sommartid i %
Kortare än 250 km		
250 -500 km		
500 - 750 km		
Över 750 km		
Vet ej		
Summa:		
Vald enhet om annan än [Enhet]:		

23. Var vänlig ange avstånden ert biobränsle transporteras till er anläggning från er leverantör för de transportslag ni använder. Ange även volymerna.

Först med lastbil, sedan med tåg och sedan leverans med lastbil

	Vintertid i %	Sommartid i %
Kortare än 250 km		
250 -500 km		
500 - 750 km		
Över 750 km		
Vet ej		
Summa:		
Vald enhet om annan än [Enhet]:		

23. Var vänlig ange avstånden ert biobränsle transporteras till er anläggning från er leverantör för de transportslag ni använder. Ange även volymerna.

Först med lastbil och sedan leverans med fartyg

	Vintertid i %	Sommartid i %
Kortare än 250 km		
250 -500 km		
500 - 750 km		
Över 750 km		
Vet ej		
Summa:		
Vald enhet om annan än [Enhet]:		

23. Var vänlig ange avstånden ert biobränsle transporteras till er anläggning från er leverantör för de transportslag ni använder. Ange även volymerna.

Först med tåg och sedan leverans med fartyg

	Vintertid i %	Sommartid i %
Kortare än 250 km		
250 -500 km		
500 - 750 km		
Över 750 km		
Vet ej		
Summa:		
Vald enhet om annan än [Enhet]:		

23. Var vänlig ange avstånden ert biobränsle transporteras till er anläggning från er leverantör för de transportslag ni använder. Ange även volymerna.

Först med lastbil, sedan med tåg och sedan leverans med fartyg

	Vintertid i %	Sommartid i %
Kortare än 250 km		
250 -500 km		
500 - 750 km		
Över 750 km		
Vet ej		
Summa:		
Vald enhet om annan än [Enhet]:		

23. Var vänlig ange avstånden ert biobränsle transporteras till er anläggning från er leverantör för de transportslag ni använder. Ange även volymerna.

Först med lastbil, sedan med fartyg och sedan leverans med lastbil

	Vintertid i %	Sommartid i %
Kortare än 250 km		
250 -500 km		
500 - 750 km		
Över 750 km		
Vet ej		
Summa:		
Vald enhet om annan än [Enhet]:		

23. Var vänlig ange avstånden ert biobränsle transporteras till er anläggning från er leverantör för de transportslag ni använder. Ange även volymerna.

Först med lastbil, sedan med fartyg och sedan leverans med tåg

	Vintertid i %	Sommartid i %
Kortare än 250 km		
250 -500 km		
500 - 750 km		
Över 750 km		
Vet ej		
Summa:		
Vald enhet om annan än [Enhet]:		

23. Var vänlig ange avstånden ert biobränsle transporteras till er anläggning från er leverantör för de transportslag ni använder. Ange även volymerna.

Levereras med lastbil, men tidigare steg okända

	Vintertid i %	Sommartid i %
Kortare än 250 km		
250 -500 km		
500 - 750 km		
Över 750 km		
Vet ej		
Summa:		
Vald enhet om annan än [Enhet]:		

24. Hur uppfattar du kostnadsnivån för de olika transportslagen per transporterad enhet bränsle?

	Låg kostnad 0	1	2	3	4	**Hög kostnad** 5	Känner ej till kostnaden
Lastbil vintertid	○	○	○	○	○	○	○

	Låg kostnad 0	1	2	3	4	Hög kostnad 5	Känner ej till kostnaden
Lastbil sommartid							
Tåg sommartid							
Tåg vintertid							
Fartyg sommartid							
Fartyg vintertid							

Kommentarer:

25. Vem beslutar normalt om transportsättet (t.ex. lastbil eller tåg) för era biobränsletransporter?

- Vi (värmeverket)
- Lagringsterminalen
- Transportören
- Vet ej
- Leverantören
- Annan, var vänlig ange:

Kommentarer:

26. Var sker flisningen av ert biobränsle?

Andel av flisad biomassa ...

Observera att kolumnen ska summeras till 100%

	Andel av flisad biomassa
... flisad i skogen	
... flisad på terminal	
... flisad på värmeverket	
... som vi inte vet var flisningen skett	
Summa:	
Vald enhet om annan än [Enhet]:	

27. Vänligen ange dina önskemål för var flisningen bör ske i kedjan.

	Föredrar minst 0	1	2	3	4	Föredrar mest 5
Skogen						
Terminal						
Värmeverk						

Kommentarer:

Del 3. Era åsikter kring dagens biobränsletransporter

28. Var vänlig ange hur nöjd ni är mer den service ni får från era nuvarande leverantörer och transportföretag.

Om ni väljer Annat. Vänligen skiv i vad i rutan till höger om tabellen.

Nivå på service

	Mycket dålig service 0	1	2	3	4	Mycket bra service 5	
Flexibilitet gällande leveransalternativ							
Flexibilitet gällande beställda volymer							
Leveranser i rätt tid							
Billiga transporter							
Lågt biobränslepris							
Liten miljöpåverkan							
Bra kvalité på biobränslet							
Inga föroreningar i det levererade bränslet, t.ex. inga stenar							
Leveranserna kommer jämt fördelade över tiden							
Annat:							
Annat:							
Annat:							

Ange hur viktiga de olika faktorerna är för er.

Om ni väljer Annat. Vänligen skriv i vad i rutan till höger om matrisen.

Egenskapens vikt

	Mycket liten vikt 0	1	2	3	4	Mycket stor vikt 5	
Flexibilitet gällande leveransalternativ							
Flexibilitet gällande beställda volymer							
Leveranser i rätt tid							
Billiga transporter							
Lågt biobränslepris							
Liten miljöpåverkan							
Bra kvalité på biobränslet							
Inga föroreningar i det levererade bränslet, t.ex. inga stenar							
Leveranserna kommer jämt fördelade över tiden							
Annat:							
Annat:							
Annat:							

29. Vilka övriga tjänster skulle du vilja att dina transportörer och leverantörer erbjöd?

30. Vilka är dina preferenser för olika transportsätt att ta emot biobränsle?

	Föredrar minst 0	1	2	3	4	Föredrar mest 5
Lastbil						
Tåg						
Fartyg						
Lastbil och tåg kombinerat						
Lastbil och fartyg kombinerat						
Lastbil, tåg och fartyg kombinerat						

31. Vilka egenskaper anser du att de olika transportsätten har?

Det är möjligt att markera flera egenskaper per transportsätt.

	Låg kostnad	Kort transporttid	Hög tillförlitlighet	Hög frekvens	Lite föroreningar, t.ex. sten, i bränslet	Miljömässig hållbarhet	Bra tillgång till transportsystemet	Annat:	Ingen av de angivna egenskaperna
Lastbil									
Tåg									
Fartyg									
Lastbil och tåg kombinerat									
Lastbil och fartyg kombinerat									
Lastbil, tåg och fartyg kombinerat									

Kommentarer:

Du satte annat som egenskap för Lastbil. Vänligen ange vilken/vilka andra egenskaper som avses.

Du satte annat som egenskap för Tåg. Vänligen ange vilken/vilka andra egenskaper som avses.

Du satte annat som egenskap för Fartyg. Vänligen ange vilken/vilka andra egenskaper som avses.

Du satte annat som egenskap för Lastbil och tåg kombinerat. Vänligen ange vilken/vilka andra egenskaper som avses.

Du satte annat som egenskap för Lastbil och fartyg kombinerat. Vänligen ange vilken/vilka andra egenskaper som avses.

Du satte annat som egenskap för Lastbil, tåg och fartyg kombinerat. Vänligen ange vilken/vilka andra egenskaper som avses.

32. Var vänlig ange hur viktiga nedanstående skäl är för er när ni väljer transportupplägg.

	Mycket liten vikt 0	1	2	3	Mycket hög vikt 4	5
Låg kostnad						
Kort transporttid						
Hög tillförlitlighet						
Hög frekvens						
Lite föroreningar, t.ex. sten i bränslet						
Miljömässig hållbarhet						
Bra tillgång till transportsystemet, t.ex. infrastruktur						
Annat:						
Annat:						
Annat:						

33. Hur väl anser ni att era nuvarande transporter uppfyller dessa krav.

	Uppfylls mycket lite 0	1	2	3	4	Uppfylls väldigt mycket 5
Låg kostnad						
Kort transporttid						
Hög tillförlitlighet						
Hög frekvens						
Lite föroreningar, t.ex. sten i bränslet						
Miljömässig hållbarhet						
Bra tillgång till transportsystemet, t.ex. infrastruktur						
Annat:						
Annat:						
Annat:						

Kommentarer:

34. Har Ni någonsin övervägt att använda järnvägstransporter som en del i transportkedjan för Ert biobränsle?

Ja

Nej

Kommentarer:

35. Har Ni någonsin övervägt att använda fartygstransporter som en del i transportkedjan för Ert biobränsle?

Ja

Nej

Kommentarer:

36. Var vänlig ange hur problematiska du anser att nedanstående frågor är för den svenska biobränslebranschen.

Väljer ni annat, vänligen skriv vad i rutorna till höger om tabellen.

	Lite problematisk				Mycket problematisk			
	0	1	2	3	4	5	Vet ej	Ej relevant för oss
Säsongsmässiga variationer i efterfrågan på värme är:								
Placeringen av lagringsanläggningar för biobränsle är								
Storleken på lagringsanläggningar för biobränsle är								
Hanteringen av biobränsle på lagringsanläggningarna är								
Tillgången på utrustning på lagringsanläggningar är								
Den biologiska nedbrytningen av biobränslet är								
Torkningen av biobränslet är								
Mängden föroreningar i biobränslet vid leverans, t.ex. sten i materialet, är								
Risk för föroreningar i biobränslet under transport, t.ex. sten i materialet, är								
Transport av grot är								
Transport av träddelar är								
Transport av flis är								
Transport av pellets är								
Tillgången till standardiserade termer och definitioner för biobränslen och råmaterial är								
Påverkan på den svenska biobränslemarkanden från en ökad internationell efterfrågan på biobränsle är								
Beroendet av svenska politiska beslut kring biobränslen är								
Beroendet av utländska politiska beslut kring biobränslen är								
Biobränslets låga densitet är								
Tillgången på biobränsle är								
Tillgången på passande transportlösningar är								
Sammarbetet mellan aktörerna i branschen är								
Annat:								
Annat:								

37. Vad anser du är det huvudsakliga problemen inom biobränsleindustrin idag?

38. Har du några ytterligare kommentarer kring det som har tagit upp i denna enkät?

Vill Ni ta del av en sammanfattning av resultaten från denna studie?

- Ja
- Nej

Klar

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Cost Data

Input data

Density kg/loose m3: Bark 350, Log chips 271, Logging residue chips 295, Saw residue chips 300, Sawdust 30, Stump chips 288, Whole three chips 300, Wood residue chips 225, Logg 367

Energy MWH/m3: Bark 0.65, Log chips 0.79, Logging residue chips 0.78, Saw residue chips 0.65, Sawdust 0.58 Stump chips 0.77, Whole three chips 0.8, Wood residue chips 0.8, Logg 1.07

Truck cost considering empty return, kr/km: Wood chip container truck 29.57 kr, Wood chip truck 30.77 kr, Forest residue truck 34.45 kr, Timber truck 29.57 kr

Truck emissions considering empty return, CO_2 kg/km: Wood chip container truck 2.95, Wood chip truck 3.02, Forest residue truck 3.13, Timber truck 2.24

Rail engine annual fixed costs: Rd 2 149 868 kr, Modern engine 3 426 462 kr

Rail engine variable costs, kr/km: Rd 16.44 kr, Modern engine 19.08 kr

Rail staff cost: 692,79 kr/train hour

Wagon annual fixed costs: Lgns 41 221 kr, Sgns 63 119 kr

Wagon variable costs, kr/km: Lgns 0.23 kr, Sgns 0.31 kr

Load unit annual costs: Rotary container 13 100 kr, 40m3 container 11 521 kr

Terminal costs, kr/MWh: Road to road 14 kr, Road to rail 19 kr, Rail to road 21 kr

Fork lift truck annual fixed costs: Heavy truck with rotator 764 141 kr, Light truck 192 920 kr

Fork lift truck staff cost: 310 kr/hour

Chipping cost, logging residues, kr/MWh: Mobile chipper at terminal 23 kr, stationary electric chipper 7 kr, roadside chipping 40 kr

Chipping cost, Logg, kr/MWh: Mobile chipper at terminal 20 kr, stationary electric chipper 5 kr, roadside chipping 35 kr