Evaluation of Rail-based Multimodal Transportation of Biofuels

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Abstract
This paper aims to analyse the internal and external factors influencing rail-based multimodal transportation of wood biofuel i.e. wood raw materials e.g. chips and branches that are used for production of energy. The analysis is conducted for the Swedish market and by using a bi-sectional qualitative framework. First, a STEEP analysis is conducted in order to analyse the external factors affecting railway transportation of biofuel. STEEP is an acronym for: Social, Technological, Economical, Environmental and Political and it is used as a strategic tool to analyse external factors that influence a business. Second, the internal factors are evaluated through the three main dimensions of sustainability: environmental, economic and social. In essence, it is the factors affecting rail transportation of biofuel and the inherent capability of the rail mode that are addressed. Albeit the two methods are to their nature qualitative approaches, the evaluation is complemented by quantitative analysis of the niche market as well as a case study.

A main conclusion from the qualitative analysis is that rail transportation of biofuel faces a number challenges that in many cases are related to a relatively high share of fixed costs and operational inflexibility. The main drivers for it are commonly associated with economies of scale and the relatively low environmental impact. Estimates from the case study show that the break-even distance i.e. when the cost for intermodal transports equals unimodal road, is 50-55% lower for biofuel transport chains than for other commodities and significantly decreases CO₂ emissions compared to unimodal road.

Keywords
Rail freight, Biofuel, Multimodal transportation, STEEP analysis, Sustainability analysis

1 Introduction

In 2005, the conditions for railway transportation of wood biofuel in Sweden were further developed as a consequence of a storm which took place in southern Sweden. Intermodal biofuel terminals were established in order to handle fallen trees after the storm and linked to biofuel heating plants to which an increasing share of timber was transported. Thus, a market emerged where rail-based multimodal transports were relatively competitive. Rail transportation of wood biofuel is not only essential from an operator perspective in terms of utilization of resources at these terminals and the rolling stock of rail freight operators; but it could also enable the shippers i.e. heating plants, to increase the range of sourcing for their supply of raw material while decreasing the emissions generated by their transports.

In Sweden, the railway is the second mostly used mode for land transportation of biofuels after road haulage. The transport performance of rail for non-finished wood
commodities accounts for approximately 12% (Table 1). However, if non-land modes are also included, where maritime traffic is very dominant on the exports of wood commodities, the modal share of rail is reduced to 5%. (STA (2012))

Table 1: Transport performance for wood commodities in Sweden in 2011 (Excluding finished goods).

<table>
<thead>
<tr>
<th>Mode</th>
<th>Tonne-km (Millions)</th>
<th>Modal share</th>
<th>Modal share - land transports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>1868</td>
<td>35%</td>
<td>88%</td>
</tr>
<tr>
<td>Rail</td>
<td>255</td>
<td>5%</td>
<td>12%</td>
</tr>
<tr>
<td>Sea</td>
<td>3218</td>
<td>60%</td>
<td></td>
</tr>
</tbody>
</table>

This paper aims to analyse internal and external factors influencing rail-based multimodal transportation of biofuel i.e. wood raw materials; chips and branches that are used for production of energy. Moreover, a case study is conducted in order to enable quantitative analysis and design of a biofuel transport chain. This study was conducted within the framework of the European and Swedish research project “Sustainable intermodal supply systems for biofuel and bulk freight”; a project aiming to analyse and develop multimodal biofuel transportation where the characteristics of each transport mode were evaluated in regards to the evaluated commodity.

Rail transportation of biofuel is almost exclusively used in multi- or intermodal transport chains as biofuel transport is dependent by road transportation, at least at the supply end i.e. the transport of biomass from the forests to the terminals. An exception might be system trains for saw dust directly from saw mills to power plants, but the original wood material is moved by road from the forests. Consequently, this study does not use the traditional categorization between system trains, wagonload and intermodal rail. Instead, it deals with all transport chains including railway transportation regardless of the used transport technology, e.g. in bulk or in load units, or the organization of the transport chain. In essence, it is the factors affecting rail transportation of biofuel and the inherent capability of the rail mode that are addressed. Rail transportation of biofuel is not as flexible as road transports due to a more limited network of infrastructure; however as higher levels of economies of scale and energy efficiency are achieved, it can in some relations be both a cheaper and less pollution emitting option (Kreutzberger et. al (2003)). Furthermore, albeit resource and time consuming terminal operations are pre-requisites for railway transportation of biofuel; these are compensated to a certain degree by the fact that a substantial share of wood and wood chips from the forest are brought to a terminal for processing anyway.

Multimodal transport refers to the transport of goods from origin to destination by a sequence of at least two traffic modes; whereas intermodal transport involves the utilization of standardized load units such as; containers, semi-trailers and swap-bodies, and where the transfer from one mode to another is being executed at an intermodal terminal. (UN (2001)) A typical intermodal land transport structure commonly contains three parts; a long distance transport part and two relatively short pre- and post-haulage parts to the intermodal terminals, where rail transport is responsible for long distance transport and road for the short distance transports. This kind of intermodal transport has been proved to be very functional for cross-border and long-distance transport. (Bektas and Crainic (2007)) Nevertheless, as the long haul is reduced, some drawbacks of intermodal transport should be taken into account. First of all, the biggest difference in cost structure between multimodal and unimodal transport is the additional interface cost.
Changing transport modes imply that costs and time are spent. Moreover, intermodal terminals require more investment on infrastructure, resources and staff. Hence, the interface cost and the corresponding emissions that are generated through transshipment will comprise a larger share of the total costs as distances are reduced. (Botekoning and Trip ((2002)) Second, intermodal transport could increase the disturbance sensitivity of the whole transport chain, thus having the capability to switch to unimodal road transports is desirable from an operational point of view. Third, intermodal transports commonly need tight cooperation and coordination among different actors, structured in a functional business model.

2 Evaluation Framework

The evaluation is conducted for the Swedish market and follows a methodology in accordance to (Piotrowicz and Cuthbertson (2012)) and by using a bi-sectional qualitative framework. First, in chapter 2.1, a STEEP analysis is conducted in order to analyse the external factors affecting railway transportation of biofuel. Second, in chapter 2.2, the concept of sustainability is defined and internal factors affecting rail transportation of biofuel are evaluated through the three main dimensions of sustainability: environmental, economic and social (Moldan et. al (2012)). In essence, it is the factors affecting rail transportation of biofuel and the inherent capability of the rail mode that are addressed. Albeit the two methods are to their nature qualitative approaches, the analysis will be complemented by design and quantitative analysis of a case study in chapter 2.3.

2.1 STEEP Analysis

STEEP is an acronym for: Social, Technological, Economical, Environmental and Political. The STEEP acronym is used as a strategic tool to analyse external factors that influence an industry, a firm or a business area. The STEEP framework is used in order to identify two main areas; “Drivers” illustrating the reasons for using and implementing rail transportation of biofuels, while “Challenges and Limitations” emphasize on the obstacles for it. Rail faces a number challenges and limitations, in many cases related to a relatively
high share of fixed costs and operational inflexibility. The main drivers for it are associated with economies of scale and rail freight’s relatively low environmental impact. The result of the STEEP analysis is summarized in Table 2 at the end of the chapter 2.1.

Note that the STEEP framework is used to analyse such factors external to the system, i.e. how the outside affects the industry. The effect of emissions from transport for example, is thus not necessarily included as an environmental factor. A negative attitude of shippers against pollution will be categorized as a social factor influencing the system. Emission regulations imposed by the state will be a political factor. Other known acronyms derived from STEEP are: PEST, PESTL and STEEPLE. The STEEP framework aims at taking a holistic view of the area that is analysed by dividing it into five key factors. The factors are wide areas and their content will depend on the subject that is analysed. However they are some common aspects that are commonly included and which are described for each of the five factors.

Social
The social factors include the societal and cultural factors. Aspects could include cultural beliefs and norms, demographics of consumer groups, attitudes towards work, availability and education level of the workforce, labour regulations, trends in society etc.

Energy consumption and emissions from rail transport are relatively low and perceived positively by the society and it is a main driver regarding the social aspect of biofuel transports by rail. However several studies have indicated that shippers are generally not really willing to pay extra for environmental friendly transport. A number of studies have been conducted regarding shippers’ requirements and their stated preferences. (Bektas and Crainic (2007)) (Lundberg (2006)) The study of (Lundberg (2006)), which was based on surveys and data analysis of 99 shippers in Sweden, states the following requirements and ranks them accordingly:

1. Cost
2. Transport time
3. Reliability
4. Punctuality
5. Flexibility
6. Frequency
7. Environmental impact

However, it is not only these requirements that the shippers base their mode choice upon - the perception of the performance of the modes and services can have an even higher impact on the overall decision making process (Bektas and Crainic (2007)). An example of this phenomenon is the shippers’ perception of the reliability and punctuality of the Swedish rail freight system in general, which has been criticized and scrutinized during the 21th century, mainly due to qualitative problems affecting the punctuality and reliability of the railways e.g. capacity constraints, poor maintenance and harsh winter climate. These aspects need to be improved in order for the railways to gain trust by more shippers.

Regarding the effect on the labour market, rail transportation of wood biofuel has created opportunities in scarcely populated areas in Sweden where intermodal terminals have been established during the latter part of the previous decade, as a consequence a large number of fallen trees due to storms.
Technological
The technological factors include technologies used, infrastructure, tools, rate of change in technology, IT systems, level of automation etc.

From a technological perspective the energy efficiency achieved by rail transportation stems from several facts; having higher volume requirements compared to trucks, are less subject to resistance during transport regarding air and friction.

A technological challenge consists of the fact that potential shippers of biofuel transportation by rail may have to adapt their logistics system and supply chain structures. The inflexibility of rail-based networks for biofuel transportation stems from mainly operational reasons; the mode specific characteristics of railways having a lower market coverage due to limited infrastructure and the commodity specific requirement for biofuels i.e. requiring trucks at least at the supply end in the forest due to lack of tracks. (Björheden (2006)), (Björheden et. al (2010))

Furthermore, the process of allocating a timetable slot for train requires planning well in advance. The inflexibility is also a big concern when handling volume variations, both due to demand variations which commonly are affected by outdoor temperatures as well as seasonal variations as wood biofuel production in Sweden is commonly operational during autumn, winter and early spring. (Awais (2013)) As a result there is a large supply of wood during the spring and very low during the summer. The critical period is just after summer, where the general problem is to have sufficient safety stocks for the month of August and early September. (Awais and Flodén ((2014) The seasonal variation also contributes to problems with low utilization of resources, thus innovative solutions are required e.g. renting out the train engine during summers or offering other transport related services; trucking, bundling, maintenance etc.

Terminals that handle forest products and container terminals vary greatly in terms of equipment and design. For example, container terminals must be designed to withstand a greater ground pressure because of the heavier machines, but the handling at a container terminal on the other hand is very efficient. There are relatively many conventional intermodal terminals in Sweden i.e. terminals based on top-lifting using reach-stackers or cranes, and the use of container terminals for biofuel offers an interesting subject for study.

An option for fully unitized intermodal transport of wood chips is that an already loaded container is simply transferred at a conventional intermodal terminal to a railway wagon and then lifted off during unloading. The train could then be loaded at a intermodal terminal using normal equipment to lift containers. Often, chipping takes place in the forest and the chips are loaded directly into containers that are then pulled up onto the truck by the vehicle itself. These containers are fitted with rollers underneath, with a hook attachment on the front to enable handling by the truck. Some types of containers can also be lifted onto a train using a top-lift or a forklift truck. This type of flexible container could be driven from the forest on a truck and then transferred to a train for transport to the user.

However, there are a number of reasons why this is not common practice in the sector. First, all storage in the chain would take place in containers instead of directly on the ground; this is costly as many containers are required for storage. Containers also have a tendency to generate logistically hot systems (systems where resources are dependent on each other, which can result in waiting times), as there must be sufficient loaded containers when the train arrives, and sufficient empty containers for the next load. Second, there is a greater risk of the material freezing in a container when it is stored for a long time. Loosening frozen material can take a long time, and this is a recognized
problem in the winter when there is a peak in demand for fuel. A third reason is that the containers that fulfil the requirement for road transport cannot also be optimized for rail transport. Permitted dimensions are more generous for rail than road transport. Furthermore, every type of container handling adds extra equipment, such as rollers, forklift tunnels, top attachments, and locks for the container attachments on the wagons. This adds weight to the container and increases costs. Maximizing the loads on trains is important for the profitability of the system.

Environmental
The environmental factors include factors related to the environment, natural resources and geographical locations, climate change, availability of resources, geographical access etc. In system’s engineering, the term environment is often used to denote factors affecting the studied system, which the system cannot control. Hence it is not limited to nature or ecological issues. (Piotrowicz and Cuthbertson (2012)) (Moldan et. al (2012))

The low energy consumption per tonne achieved by rail combined with a more sustainable source of energy i.e. electricity rather than diesel, makes rail the mode generating the least emissions per tonne-km in Sweden. Hence, it is perceived by shippers and society as an option associated with environmental awareness, which could be an appealing feature for shippers intending to implement an environmental policy or achieving positive publicity.

Moreover, after 2005 the conditions for railway transportation of biofuel were further developed as a consequence of the storm ‘Gudrun’ which took place in southern Sweden. Intermodal biofuel terminals were established in order to handle fallen trees after the storm and linked to biofuel plants to which an increasing proportion of timber was transported. In order for the timber to not become damaged by pests or other sources, it was decided that all available transport resources would be mobilized to get the timber away from the forest. It was decided that rail transportation of storm timber would not pay track access charges and corresponding for sea transport and fairway dues. Sea transportation was favoured mostly by the storm as the increase of exports of wood products increased significantly. Road transport was affected rather negatively by reduced imports of wood products to Sweden. (STA (2012))

Albeit the number of transshipment nodes has increased in Sweden during the last decade, a main limitation for rail transport of biofuels is that it is not as flexible as road transportation due to a more limited network of infrastructure. Hence, the pre-haulage by trucks constitutes a prerequisite whereas the post-haulage from the terminal could be carried out by trucks or transported directly to the recipient. There are today in Sweden a number of heating plants i.e. producer of biofuel, who have the capability to receive rail shipments directly to their facilities (Enström and Winberg (2009)).

Economical
The economic factors could include factors such as costs, incomes, interest rate, availability of capital, engineering, inflation, economic trends, state of the market etc.

Biofuel transport by truck is for economic reasons not viable to be transported for long distances. With the railway's low en-route costs, the range increases from short distances (150-250 km) by road up to medium distances around 500 km by rail (Bärthel (2011)). A main cost component limiting the range of intermodal transports is the transshipment cost. Changing modes implies that costs and time are spent as intermodal terminals require investments on infrastructure, resources and staff. Thus as the interface cost and corresponding generated emissions are not proportional to the transport distance, they will
comprise a larger share of the total transport costs as distances are reduced. (Kordnejad (2014))

Moreover, increasing operational costs, mainly considering electricity and track access charges, also constitute challenges for rail freight operators in Sweden.

Furthermore, trucks have a maximum capacity of about 125 cubic meters of biomass and a fully loaded train has capacity of about 3000 cubic meters. Obviously, higher economies of scale will be achieved by rail however at the expense of lower frequencies. This implies in many cases that smaller railway operators need to combine a number of shippers who together can provide a sufficient volume and frequency of profitability. (Bärthel (2011))

The competitiveness of rail freight is obviously affected by its’ context and by the state of the alternatives and the prevailing market. A market that has been characterized by intense price pressure, and with unimodal road haulage being the main competitor. As Sweden allows trucks that are larger than other EU countries, 25.25m long and a gross weight of 60 tonnes, these conditions are quite favourable for road haulers and limit the competitiveness of railway transportation in general. Moreover, even larger trucks are proposed with the concept of High Capacity Transports (HCT) where longer road vehicle combinations allowing trucks to carry two semi-trailers (in all 32 meters long) are currently tested in Sweden. Also heavier vehicle, up to 90 tonne, have be tested.

Political

The political factors include factors such as regulations, legislations, subsidies, union requirements, political party politics, upcoming elections etc.

Efficient rail freight transportation in general and intermodal terminals in particular are factors that are perceived by local authorities and politicians as having a good impact on local industry. This perception could be seen as a main driver for the political aspect of biofuel transports by rail. Contributing further to the willingness of local authorities to attract more rail freight transports to their region is the fact that sawmills and biofuel facilities are commonly owned by local authorities and municipalities.

Moreover, the Swedish rail freight market was deregulated in 1996 and in 2007 the international market in the EU (Vierthe (2012)). Despite the deregulation, the former incumbent rail freight operator in Sweden is still dominant in many aspects of rail freight operations. However, few new actors have entered the market and made it turn towards a situation of oligopoly rather than monopoly. The main motivation for the deregulation of the Swedish rail freight market was based on the notion that increased internal competition would lead to a more competitive market, something seen as necessary as there had been fierce competition from road hauliers, whose prices have been kept very low during the last decade.
### Table 2: STEEP analysis for rail-based multimodal transportation of biofuels.

<table>
<thead>
<tr>
<th>STEEP Criteria</th>
<th>Drivers</th>
<th>Limitations and challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social</td>
<td>Energy consumption and emissions from rail transport are relatively low and perceived positively by shippers and society</td>
<td>Shippers are generally not willing to pay extra for environmental friendly transport. The reliability and punctuality of the Swedish rail freight system should be improved in order to be trusted by more shippers.</td>
</tr>
<tr>
<td>Technological</td>
<td>Low energy consumption. Higher utilization of allowed weight and volume per length compared to trucks.</td>
<td>Higher volume and coordination requirements than for trucks. Shippers may have to adapt their logistics system and supply chain structures.</td>
</tr>
<tr>
<td>Environmental</td>
<td>The mode generating the least emissions. Intermodal terminals can be combined with facilities for processing wood biofuels. This has been further developed as intermodal biofuel terminals were established in order to handle fallen trees after storms.</td>
<td>Emissions and fuel consumption by shunting and transshipment operations could be improved. Inflexible network structures for biofuels transport, requiring trucks at least at the supply end.</td>
</tr>
<tr>
<td>Economic</td>
<td>Economies of scale achieved over long distances. Can increase the distance for sourcing of raw-material supply in biofuel production.</td>
<td>Limited competitiveness over short distances. Long road vehicles are allowed in Sweden. Increasing electricity and track access costs.</td>
</tr>
<tr>
<td>Political</td>
<td>Efficient rail freight transport in general and intermodal terminals in particular are factors that are perceived by local authorities as having a good impact on local industry.</td>
<td>The rail freight market is deregulated but it exhibits signs of oligopoly and have high entry barriers and the former incumbent operator is dominant.</td>
</tr>
</tbody>
</table>

### 2.2 Sustainability Analysis

Sustainability is commonly divided into environmental, economic and social sustainability (Moldan et. al (2012)), (Carter and Rogers (2008)). To be considered sustainable, a traffic mode must perform well in all three areas. The impact will in the analysis further be divided into three levels. Level 1 is the impact within the organization, level 2 is impact on supply chain partners, and level 3 is external impact. The first level includes aspects such as the employees’ working conditions, company profits etc. The second level includes aspects such as customer satisfaction, on-time delivery, flexibility etc. The third
level includes factors such as pollution, use of non-renewable resources, providing employment in geographical areas, supporting local businesses etc. The result of the sustainability analysis is summarized in Table 3 at the end of the chapter 2.2.

Environmental Sustainability

Environmental sustainability concerns the emissions generated by transport as well as the usage of natural resources. In order to reduce the generated emissions, rail transport is the leading option for land transport of biofuel. The energy efficiency achieved by the railway stems from several facts; using economies of scale, are less subject to resistance during transport regarding air and friction (steel against steel versus rubber against asphalt) as well as in Sweden using a more sustainable source of energy i.e. electricity instead of fossil fuels.

However, there are in many cases potential for improvement. First, the usage of diesel in operations can be reduced in two main operations; shunting operations where diesel driven shunting locomotives are required as well in terminal operations that are run on diesel driven transshipment technologies, commonly reach-stackers. Second, the emission factor of the energy source used is obviously of high importance for the generated emissions. Energy consumption and emissions in freight transport do not only occur during the actual shipment. For electrically powered rail transport vehicles, the emissions are produced entirely in the pre-chain whereas for diesel powered transport vehicles, the main part of the emissions are produced during the transport itself. (Hamelinck et. al (2005)) Hence, where and how the electricity is produced affects the level of emissions generated by transport. As European and Nordic electricity exhibit higher emission factors than the electricity produced in Sweden and as the European electricity market gets more integrated; deteriorating emissions factors of the electricity used in Sweden are to be expected (IVL (2012)).

Moreover, there has been an increase in attention by truck producers in reducing energy consumption of trucks and further development will surely take places. Introduction of new energy sources generating less emission is also plausible. Thus albeit rail transport is the leading option for land transport of biofuel regarding environmental sustainability it may face more difficult conditions in the future if these questions do not receive adequate attention by producers as well as users of rail freight. The producers do put efforts in improving energy consumption of the railways by technological and organisational developments; however these innovations are only implemented when the users have enough incentives.

Regarding the usage of natural resources it is not only affected by the energy consumption of rail freight operations, also the spatial perquisites are of concern, mainly regarding the rail infrastructure and intermodal terminals. As for the rail infrastructure, it is more limited than the road network, thus the spatial requirement are not as significant. However, vibration and noise caused by rail operations, particularly freight trains, are issues that are seen as drawbacks and are of concern for the industry and society.

Economic Sustainability

The economic sustainability concerns the long-term profitability and survival of the system. Most modes of transport have a similarly shaped profile of cost (y) vs distance shipped (x), the estimated costs can in their simplest form be expressed in a linear equation:

\[ y = cx + m \]
The intercept of the line at zero distance, “m”, is the fixed cost of shipping a certain amount of biomass regardless of distance. The slope of the line, “c,” is the distance variable cost and is for most transport modes linear due to the distance variable cost components, for rail freight e.g. wages, fuel and capital recovery for the transport equipment are directly proportional to the distance travelled (Mahmudi and Flynn (2006)). However, this is not the case for the transshipment cost in intermodal transports which is proportional to the time and resources spent at the terminals. There are however today a number producers of biofuel in Sweden that are able to receive rail shipments directly to their facilities (Enström and Winberg (2009)).

Furthermore, rail freight operations are associated with high fixed costs and low variable costs whereas as for road, the relation is the contrary. The high fixed costs combined with historical reasons of the rail freight market in Sweden contribute to the rail freight market exhibiting relatively high entry barriers and after being deregulated in 1996 only a few new actors have entered the market and turn it towards oligopoly rather than monopoly. (Troche (2009))

There are also indications that the costs for rail freight operations will increase. Introduction of additional fees for rail freight operator, specifically increased track access charges have been proposed by the Swedish transport administration. Also increasing electricity prices is a concern. After the deregulation of the Swedish electricity market, the electricity price was about 0.25 SEK/kWh. Towards the end of the 1990’s, the price went down to 0.10 SEK/kWh and by 2010 it had increased to just over 0.50 SEK/kWh (SE (2014)). The volatile shifts complicate the task of identifying a trend for electricity prices except that it will most probably increase in the long run.

Hence, albeit rail as a traffic mode is considered economically sustainable, in particular for high volumes and over longer distances, these increasing cost components may constitute even larger obstacles in the future.

Social Sustainability
The social sustainability concerns the society and social responsibility such as health and safety, employment, social equity and human rights.

Many intermodal terminals designed for biofuel transports are located on the countryside and thus an important factor for creating much needed job opportunities there. The rail haulage part is not that labour intensive if you compare it to trucks, as a single engineer is commonly sufficient for freight trains. Nonetheless, there are jobs created when transporting biofuels by rail; being at the terminals, maintenance or administration (Labuschagne (2005)).

However due to the prevailing market conditions and small profit margins, many carriers and operators and their employees can be under considerable pressure, quite often resulting in restructuring of organizations and bankruptcies. Moreover, albeit a few derailments have occurred in the Swedish rail network, commonly affecting the slower freight trains, the safety and the low level of accidents associated with transporting biofuel by rail are seen as factors contributing positively to its’ social sustainability.

Compared to unimodal road, intermodal rail offers fewer jobs to the countryside. As a rather centralized system, rail freight requires personnel for, e.g., planning, purchasing, sales and maintenance but these jobs are often centralized to offices and depots at a few number of locations. Only a small share of the rail staff, such as train engine drivers and terminal workers, is involved in the direct operations. Road, on the other hand, has more work-intensive operations that require many truck drivers, distributed maintenance and
above all, the jobs are more likely to be located on the countryside. On the other hand, if rail facilitates long-distance supply of biofuels to power plants in larger cities, it can be stated that rail provides a larger market for biofuels and thus creates jobs in less populated areas. In addition, rail operators increasingly locate jobs outside the main cities. (Nelldal et al. (2008) Furthermore, rail personnel, particularly drivers, often have to stay away from home due to their working conditions. Hence, the overall social sustainability of rail transport is acceptable, mainly due the employment opportunities created and for the high level of safety achieved, albeit social sustainability is affected negatively due to the tough business conditions in rail freight market.

Table 3. Sustainability analysis for rail-based intermodal transport of biofuel.

<table>
<thead>
<tr>
<th>Pillar</th>
<th>Level</th>
<th>Sustainability</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental</td>
<td>Within the organization</td>
<td>Some tendency to rely on the inherent capabilities of rail not focusing enough on improvements.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>In the supply chain</td>
<td>Resource efficient part of the supply chain lowers total emissions.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>External</td>
<td>Saves CO₂ emissions compared to road transport and often also compared to shipping dependent on transport geography.</td>
<td></td>
</tr>
<tr>
<td>Economic</td>
<td>Within the organization</td>
<td>Difficult to compete for short distances and smaller volumes. High cost for terminal handling and fixed costs in general.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>In the supply chain</td>
<td>Accounts for a small part of total transport costs. Allows for rather distant sourcing of biofuels.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>External</td>
<td>Can increase the range of sourcing of raw material.</td>
<td></td>
</tr>
<tr>
<td>Social</td>
<td>Within the organization</td>
<td>Comparatively few jobs created. Personnel away from home for long times.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>In the supply chain</td>
<td>In a wider sense, if rail provides a larger geographical market for biofuels jobs can be created in less populated areas.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>External</td>
<td>Safe in comparison to many trucks on the road.</td>
<td></td>
</tr>
</tbody>
</table>
2.3 Case Study

A case study has been performed into supplying a heating plant in Sweden by rail. The plant is located at in Gothenburg, Sweden. At full operation, the plant consumes approximately 17 GWh per week and is currently fuelled by wood residue chips, log chips and stump chips. The plant is used for the base load in the district heating grid and is operated from early autumn to late spring. The plant has direct access to the rail network and is located next to a major shunting yard. However, the local rail siding is only about 200 meters and a full length train therefore needs to be split. Approximately 10 four-axle rail wagons can be at the plants rail siding, but there is only room for about five in the unloading area. Therefore, the wagons need to be pushed along the rail siding for all to be unloaded. The shunting yard is electrified, but not the local track. The plant is located adjacent to a residential area.

Local environmental regulations stipulate that chipping is not allowed at the terminal and that delivery only can take place 6 a.m. to 10 p.m. Previously, weekend delivers were not allowed but recently that plant has received a permit to accept delivers during the weekend. However, the plant tries to avoid weekend deliveries not to disturb the neighbours. The storage area is limited to 10 000 m³ or roughly 60 hours supply (Friday evening to Monday morning).

The plant is currently supplied by all-road where all fuel is sourced locally. About 40 trucks deliver at the plant each day. The supplier is responsible for the transport. All fuel is chipped road-side in the forest. The plant is interested in investigating using rail transport for the fuel supply. Stated reasons include increasing their possible sourcing range making it possible to take advantage of potential fuel surplus in other regions and source other types of fuel, e.g. waste products from the forest industry, that are too far away to source economically by road. A lower environmental impact from transport is also considered beneficial along with potentially lower transport costs.

![Figure 2. Local track layout and the adjacent shunting yard](image)

**Case study methodology**

A potential rail system for the plant is designed which is subjected to a sensitivity analysis where key variables are changed to determine the key factors for a successful intermodal transport. The potential rail system is designed by estimating the break-even distance between road and rail transport and CO₂ emissions. Within the region a search is made for potential terminals and sourcing locations and a detailed rail system is designed.
Calculations and data
An extensive model was developed in order to calculate the different scenarios. Based on Flodén (2011) and Kordnejad (2014), detailed cost and emission estimations are conducted with a focus on the rail part of the system. Much care has been taken in finding good input data for the model, in particular the cost data. Costs are always a sensitive issue why multiple sources have been used. Data has been collected from the literature and directly from the industry in Sweden. Real cost data have gratefully been received from four industry actors, covering different parts of the supply chain. Some reported data for only parts of the operations. As can be expected, the cost estimates varied between the different sources.

The cost data was refined by combining the data from the industry and the literature, and checking the results against own calculations of expected costs. This resulted in data set for the cases containing a reasonable appreciation of the costs. Thus, the data used in the scenario does not represent the costs of any specific actor but can be viewed as an average cost level in the industry. All the selected data have been validated with at least two industry representatives independently, while some data have been validated with as much as 4-5 representatives. The selected cost levels have also been validated with a reference group of biofuel industry actors from road, rail, power plant and forest sectors.

Fuel densities are based on the WeCalc tool (Larsson and Nylinder, 2014) and data from COFORD (2003). Road transport costs have been calculated using the FLIS-model developed by Skogforsk. The FLIS model is built to represent the special characteristic in the forest industry with waiting times etc. It is assumed that the truck returns empty and therefore that the cost of the return trip also must be covered. Rail costs are based on Flodén (2011) and Kordnejad (2014) have been updated to represent the current situation for biofuel transport. Engine and wagons costs are based on calculations of purchase price, service life, depreciation, expected utilization per year, infrastructure charges etc. Emissions are based on the Swedish electricity mix.

Note that the train is assumed to run in loops based on a 24 hour cycle, which is the common way to operate biofuel trains. A typical setup would be arrival at the heating plant in the morning, unloading and departing again at lunchtime to the forest terminal. Loading at the terminal in the evening and departing again during the night. Interviews with actors reveal that the engine and wagon remains at the terminal during the loading/unloading process. This impacts the allocation of the fixed costs as the train is “locked” in the current system. The calculations therefore not only consider the driving time, but also the waiting time and likelihood to find alternative use of the train during e.g. idle weekends. Similarly, biofuel trains are normally operated during the winter months and not during the summer which also impacts the potential utilization, depending on the likelihood to find alternative use during the summer. Shunting costs are calculated for both electric shunting and diesel shunting, based on Flodén (2011).

Terminal costs were collected from several actors, and it is clear that the variation in cost is particularly high. Costs were estimated based on the industry data, data from Asmoarp (2013) and calculations on the cost for handling equipment. Emission data comes from Skogforsk FLIS-model. Cost includes all activities such as stacking, repositioning, loading, unloading etc.

Break-even distance and CO2 emission
The break-even distance between road and rail transport is of key importance to determine the minimum length of a rail transport, as a first step in designing the base scenario. Several studies have made contributions in finding general results for the minimum
distance that intermodal rail–road transport can compete with unimodal truck services. The European results are found in the range 400-600 km (Klink and van den Berg, 1998; Nelldal et al., 2008).

A typical biofuel train is selected for the case, consisting of 22 wagons type Sgns, electric engine type Rd, Innofreight XXL load units, transporting 2 300 MWh of logging residue chips. Rail has a 50km pre-haulage by road to the rail terminal, using a 93 MWh woodchip container truck. The train runs directly to the heating plant and is unloaded at the plant. Diesel shunting is used at both the terminal and plant. The train is assumed to run three days per week, 26 weeks per year. The full round trip, including cost of the empty return transport is included. Road transport is represented by a wood chip truck carrying 103 MWh where 40% of the flow is transhipped at a road-road terminal. 23 trucks are needed for the road transport and are assumed to return empty. Chipping is assumed to take place roadside in the forest in both systems. The calculations show the break even distance at 250 km.

Extending the train operations to five days per week pushes the break-even distance down to 180 km, showing the positive effect of a high train utilisation. Thus the results of the case study show that the break-even distance is considerably lower for biofuel transport chains than for other commodities; 180-250 km compared to 400-600 km.
From an environmental perspective, the advantage of the intermodal solution is clear. The intermodal solution produces significantly lower CO₂ emission compared to the all-road solution. The majority of this comes from the pre-haulage by road, chipping and terminal handling as the rail transport in Sweden generate very low en-route CO₂ emission. Hence the emission for the intermodal chain is almost constant for the estimated distances.

**Base scenario**

The base scenario design is based on interviews with the heating plant and terminals in the area. The break-even distance analysis show that distances should be kept above 250 km. Among the major sourcing areas for biofuel in Sweden, the two closest areas above 250km are the regions of Dalarna and Småland, in figure 6 illustrated by (A) respectively (B). Due to the importance of a high utilization of the train, a five day per week scenario is selected operating three days a week to Småland and two days a week to Dalarna. In Småland, logging residue wood chips are picked up, which is the most common biofuel in Sweden. In Dalarna bark is picked up. Dalarna is rich in wood industries, whose by-products are the second most common fuel (Awais and Flodén, 2014).
1. The train is a typical train, consisting of 20 wagons type Sgns, electric engine type Rd, 60 Innofreight XXL load units, transporting 2 100 MWh of logging residue chips or 1 750 MWh of bark. All load units are fully loaded. Train weight are 1 447 ton for the logging residues and 1 594 ton for the bark. In total, the system delivers 9.8 GWh per week. The train distance to the Småland terminal is 265 km and to the Dalarna terminal is 471 km. The same train set is used for both destinations.

2. The terminal in Småland has an electrified rail track, thus eliminating the need for diesel shunting. The terminal in Dalarna has a non-electrified track and requires diesel shunting. At both terminals, the fuel is handled by wheel loader. Loading time is 4 hours.

3. Road transport to the terminal is 40km by wood chip container truck carrying 93 MWh, which is the average setup according to the interviewed terminals. Chipping is assumed to take place road-side in the forest for the wood residues. The bark requires no further chipping.

4. The heating plant has direct access via a non-electrified rail siding. Unloading takes place by a forklift truck with a rotator adapted to handling Innofreight containers. Unloading time is 4 hours.

The cost per MWh for the analysed system is 99.95. This includes all activities, including chipping, road transport, terminal handling etc. See figure 7 for the cost and CO2 emission allocation. Noteworthy are the high costs associated with chipping and the sending terminal. From an environmental perspective, the CO2 emission are 2.92 kg per MWh transported. The major sources are the road transport and chipping. Noteworthy is the low CO2 emission from the train transport, as a consequence of the clean Swedish electricity mix.

![Figure 7. Costs and emissions in the base scenario](image-url)
3 CONCLUSIONS

Rail transportation of wood biofuel in the Swedish market is not only an important subject for research from an operator perspective in terms of utilization of resources at the terminals that where established in order to handle fallen trees after a major storm in 2005 as well as the rolling stock of rail freight operators; but it could also enable the shippers i.e. heating plants, to increase the range of sourcing for their supply of raw material while decreasing the emissions generated by their transports. Rail-based transportation can increase the geographical range that is economically viable for the sourcing for biofuel production, from short distances (150-250 km) by road and up to medium distances around 500 km by rail.

The STEEP analysis albeit generic and wide, offers a structured approach for qualitatively analysing external factors influencing a business. A main conclusion from the result of STEEP analysis is that rail transportation of biofuel faces a number challenges and limitations and in many cases these are related to a relatively high share of fixed costs and operational inflexibility. The main drivers and motivations for it are commonly associated with rail freight’s relatively low environmental impact and economies of scale.

The sustainability analysis on the other hand, enabled qualitatively analysing the internal factors influencing a business. The results of the sustainability analysis indicate that rail transportation of biofuels in the environmental dimension is highly competitive, albeit there are a few areas with potential of improvement e.g. in shunting and terminal operations. However regarding the other two dimensions; economic and social, the competitiveness of rail transportation is not as strong and there are several areas requiring improvement. Albeit rail as a traffic mode is considered economically sustainable, in particular for large volumes and over longer distance relations, there are some cost components e.g. transshipment cost and train utilization, which constitute obstacles for the competitiveness of rail transportation of biofuels. The overall social sustainability is also acceptable, mainly due to the employment opportunities created and for the high level of safety achieved, albeit the social sustainability is affected negatively by the tough business conditions in the Swedish rail freight market.

The case study offered an opportunity of designing a rail-based multimodal transport chain for the supply of a heating plant in Sweden. Much care has been taken in finding good input data for modelling the transport alternatives, in particular the cost data. The model is a combination of several models developed by researchers in their field of expertise, where each handled distinct parts of the intermodal transport chain; rail, road and terminal handling. The results of the case study show that the break-even distance i.e. when intermodal transports equal unimodal road, is considerably lower for biofuel transport chains than for other commodities; 180-250 km compared to 400-600 km i.e. 50-55% lower. The intermodal solution produces as expected significantly lower CO₂ emission compared to the unimodal road solution. Hence, albeit being generally more beneficial both from environmental and economic perspective, the competitiveness of intermodal transportation is still restricted for short distances and smaller volumes due to high cost for terminal handling as well as due to high fixed costs and qualitative factors e.g. low operational flexibility and reliability.
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