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Sustainability analysis of High Capacity Transport truck and combi transport on the route Gothenburg to Umeå

Master's thesis in Sustainable Energy System

ISABELL JOBSON

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Abstract

One of Sweden's goals for 2030 is to have a fossil independent vehicle fleet and with an increased demand for transports High Capacity Transport (HCT) vehicles are introduced. HCT trucks are trucks which are longer and heavier, they have a greater capacity than the trucks on the roads today.

This thesis examines the potential of long-distance HCT transport between Gothenburg and Umeå, and compares it with combi transport (combi transport can be defined as a transport service involving two or several transport modes) on the aspects of:

- Social and environmental care
- Function, reliability and service
- Transport logistic cost

Network of transport measures was used as a simulation tool to calculate the emissions of the combi transport. Volvo contributed with fuel consumption data for the HCT truck. Cost calculations were done by two different methods. The cost calculations for the HCT vehicle used a calculation tool called SåCalc developed by AB Åkerikonsult. The combi transport also used this calculation tool for the road transport, but also used key data from a report written by Jonas Flodén at Gothenburg University.

The emissions of transporting 1 tonne of cargo between Gothenburg and Umeå with combi transport is (for a cargo density of 150 kg/m^3) 35.52 kg CO_2eq (European electricity mix) and 4.38 kg CO_2eq (Swedish electricity mix), the emissions for HCT trucks are 45.37 kg CO_2eq (MK1 diesel) and 7.96 kg CO_2eq (HVO 100).

The cost of transport is 40 kr/m^3 for combi transport and 69 kr/m^3 for HCT trucks although the price of combi transport would be more than three times the cost due to large differences in the price and cost of the railway transport.

Keywords: HCT, Transport, Modal Choice, NTM, HVO, Combi transport, goods, environmental impact

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Isabell Jobson, Gothenburg, December 2017

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Acronyms

CH_4 methane. 11, 12, 24
CO carbon monoxide. 10–12, 24, 25
CO_2 carbon dioxide. 11, 12

FAME Fatty Acid Methyl Ester. 9

GHG Greenhouse Gases. xii, 1, 10, 24, 50

HC Hydro Carbons. 10–12, 24, 25

JIT Just In Time. 13

N_2O nitrous oxide. 24
NH_3 ammonia. 10, 25
NO_x nitrogen oxide. 10–12, 24, 25
NTM Network for Transport Measures. xiii, 10, 21, 23

PFAD Palm Fatty Acid Distillates. 10
PM particulate matter. 10–12, 24, 25

SO_2 sulfur dioxide. 11, 12, 24

TEU Twenty-foot Equivalent Unit. xiii, 12, 19, 21
TTW Tank to Wheel. xiii, 9, 23, 30, 32, 35, 36

VAT Value Added Tax. 19, 27, 41, 45, 46
VOT Value of time. 18

WTT Well to Tank. 9
WTW Well to Wheel. xiii, 9, 10, 23, 30, 32, 35

Glossary

Agenda 21 is an action plan for sustainable development formulated during the Earth Summit in Rio de Janeiro 1992. 8

allocation factor is a factor which parts emissions or other measures into different areas.. 23

BK1 Bärklass 1, is a road classification and allows a maximum of 64 gross tonne [1]. 2, 25

calorific value is a measure of the energy content in a fuel.. 35

CO_2eq is a standard unit where the amount or concentration of carbon dioxide (CO_2) is the reference. v, xi, xiii, 8–10, 25, 29, 31–33, 35

deductible is the amount an individual/organization has to pay out of pocket before an insurance provider will start to pay. 41

Dolly is a trailing unit which enables to tow a semi-trailer behind a vehicle equipped with a tow member. 40–42

DUO 2 is part of a Vinnova FFI project run by Volvo Technology AB (registration no: 2016-05383). The aim is to reduce CO2 emissions by increasing the load capacity by adding additional trailing units. There are two field test vehicle combinations that run on special permits on E6 Gothenburg – Helsingborg – Malmö. 6, 24, 27

load carrier is an unit in which cargo can be placed during transport. 21, 27

multimodal transport is when the transport is carried out under a single contractor but by at least two different means of transport. 17

Seko Swedish Union for Service and Communications Employees is a Swedish trade union for employees in nine different branches. 13

STM sammanvägt tillförlitlighetsmått Weighted reliability measure. 15

WHTC (World Harmonized Transient Cycle) is a transient test cycle which requires both hot and cold starts [2]. xiii, 10

1

Introduction

1.1 Background

The transport sector can be seen as the artery in the Swedish industry and enterprise, it connects the suppliers with the manufacturers and finally the end consumer. Sweden has a large import and export sector and hence are largely dependent on the transport sector, at the same time the world is facing the challenge of global warming and Sweden has set up goals to reduce the share of green house gases emitted from the transport sector. In 2009 the European Union stipulated all member states, including Sweden, to meet a target of 10 % renewables in the transport sector by 2020 [3] , this goal was reached in Sweden 2012 when 12.5 % renewable energy was used in the transport sector, where a large share of the renewable energy originates from rail transport electricity [4]. To reduce the Greenhouse Gases (GHG) even further, Sweden has an ambition to have a fossil independent vehicle fleet by 2030 [5]. In 2016 Sweden also incorporated an ambition of a zero netto emission of GHG into the atmosphere [6].

The total amount of transported cargo in 2014 was 630 million tonne [7]. In 2016 the total energy use by the domestic transport sector was 95.2 TWh of which 23.7 % was renewable energy. 93.6 % of the total energy was used by road vehicles, 3.5 % by railroad, 0.6 % by sea and 2.3 % by air transport [8]. The demand for cargo transport is expected to increase by about 50 % until 2030 and of the total 154 billion tonne-km transported in 2030 41 % will be driven by road vehicles [9]. An efficiency increase for the road vehicle and a shift towards renewable fuels has to be made in order to reach the goal of a fossil-free vehicle fleet and be able to deliver the 154 billion tonne-km cargo.

The railway capacity increased in 2016, the capacity of transport is defined as the ability to handle the asked volumes of travels and transport [10]. Figure 1.1 indicates that there are capacity limitations on the railway all over Sweden and the capacity limitations between Gothenburg and Falköping are high.

Figure 1.1: Capacity limitations for the Swedish railroad network for 2016 [10].

In the spring/summer of 2018 Trafikverket is expected to grant a road network for a new load class (for longer and heavier vehicles). The road network will be limited in the beginning but will gradually increase and the long-term vision is to grant the new road class on the whole BK1 network. The new road class network will have a gross weight of 74 tonnes and be named BK4 [11]. Those types of vehicles are today called HCT vehicles and have a maximum total gross weight heavier than 64 tonne and/or longer than 25.25 m. The discussion about HCT vehicles in this report refer to trucks with longer and/or heavier gross cargo.

The transport of freight goods are increasing, therefore companies have to decide what transport mode will be the most appropriate in terms of the key aspects of the transport. A survey about mode choice was published in 2014 by Dan Andersson and Linda Styhre [12] where transport cost was accounting for 5 % of the total product cost, the transport cost was then expected to increase within the next five years and hence the transport choice would then be more important for the transport buyer. In the survey the companies were asked to distribute 100 % on four important aspect of the transport choice in order of relevance; price, transport time from door to door, time precision from door to door and environmental efficiency represented by CO_2 emissions. The price was the most important aspect with 54 % of the total weight followed by time precision from door to door, transport time from door to door and the least important aspect for the transport buyer was the environmental aspect with only 8 % of the total weight. Although 83 % of the transport buyers required some environmental certification from the transport supplier (ISO 14001 certificate or equivalent). The survey also showed that the major transport supplier was at an average the major transport supplier supplying more than half of the transport buyers total transport. The relationship between the transport buyer and supplier has at an average lasted 10 years. 22 % of the asked companies had bought services form their major transport supplier for 20-40 years, a long-lasting relationship has therefore been developed where both parts are pleased.

With an increasing transport of freight goods and with an increased need for renewable fuels for the transport sector the mode choice will be more important. What will be the best choice and at what circumstances?

1.2 Scope

The purpose of this report was to develop a sustainability analysis which compares combi transport with HCT vehicles on the transport route between Gothenburg and Umeå, to see if HCT vehicles is a suitable transport choice for certain cargo given the transport route. The sustainability analysis was adapted for transport and focus on:

- Environmental and social care - What are the emissions and social aspects of each transport choice?
- Function, reliability, and service - How are the parameters and values for each transport choice affecting mode choice in terms of function, reliability and service?
- Transport logistic cost - What will be the transport logistics cost for each transport choice?

The starting point was at Schenker's terminal in Gothenburg and the endpoint was at Schenker's terminal in Umeå, as can be seen in Figure 1.2 where Gulbersvassen and Fraktvägen are combi terminals where the load carriers are loaded on and off between railway and road vehicles. In addition to the two different transport choices was also two different kinds of fuels analyzed to give a broader picture. The total route for the combi transport and HCT transport is 1047 and 993 respectively. The route for the combi transport is longer due to the fact that the cargo passes two extra terminals and the train passes trough Bergsslagen, which is a longer route compared to the route which the HCT truck takes.

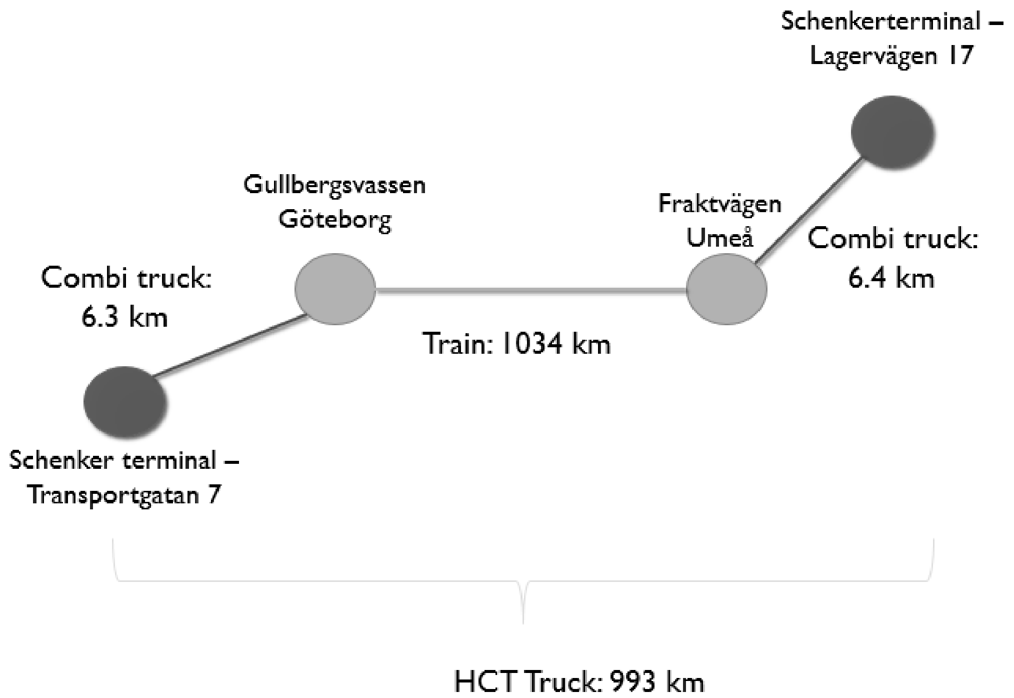

Figure 1.2: The route for the combi and HCT transport, the HCT truck followed the roads to Umeå and the train transport passes trough Bergslagen.

1.3 Limitations and boundaries

- The load carrier will be focused on 40-foot container for railway transport and semitrailers for HCT transport. The volume of the cargo are different for the two different options.
- The cargo will have a certain delivery time when the goods is expected to be delivered.
- The cost calculations will not include the social cost for infrastructure, such as noise and accidents. Taxes and fees includes some of the social cost.

2
Theory

The decision process of transport choice for companies is complex, several shipments have to be planned and fitted within the transport of choice. To make this a long-term vision a transport strategy has to be implemented, the parameters of the transport are

- Restrictions - physical restrictions such as location, transport time and shipment size.
- Choice - the customer can choose from several different possibilities with different cost, time, reliability etc.
- Inertia - which is the theoretical best solution is not the choice due to limitations in data provided or the slowness of changing habits[13].

2.1 Intermodal transport

Intermodal transportation is defined as the shipping of a cargo with more than one form of carrier, eg. first with road vehicles changed to rail and from the combi terminal to the costumer [14].

2.2 High Capacity Transport (HCT)

The maximum load for a truck today is 60 ton and/or 25.25 m [15], transport vehicles with higher maximum load is called High Capacity Transport vehicles. Some of the advantages mention in a pre-study about HCT vehicles are:

- Higher traffic efficiency - higher transport work, tonne-km, per vehicle, vehicle km
- Higher security on the road - there are less trucks on the road and the surveillance on the HCT vehicles are higher
- Better infrastructure efficiency - more cargo on a shorter road distance, less investment on the infrastructure and less congestion
- Less wear on the road- lower axle pressue due to the increased number of axle per vehicle
- Higher transport productivity - gives a higher transport profitability to transport companies
- Less environmental impact - higher energy efficiency because of a more favorable ratio payload/total weight and also because one powertrains consumes less fuel than two [16]

The HCT vehicles need a new road classification to be able to be used and a report from Trafikverket in 2014 [17] stated that a new road BK4, that can carry vehicles with a maximum total weight of 74 tonnes, could be established in Sweden. The roads which in the report was mentioned as potential roads for the new classification was E6, E4, E10, E18, E20 and some parts of the roads 40 (between Gothenburg and Jönköping), 50 (between Mjölby and Örebro), 55 (between Strängnäs och Enköping) and 56 (between Eskilstuna and Gävle). A socioeconomic calculation showed that the benefits from reparations and preparations are the greatest at these roads, due to the high utilization of cargo transported. 97 bridges have to be prepared for the new road classification which would cost approximately 2.2 billion SEK[17]. This is in line with Trafikverkets investments to reach the fossil independent goal. A higher efficiency for the transport network will be reached with the new classification. Volvo and Schenker are today running a trial between Schenker's terminals in Gothenburg and Malmö/Helsingborg, so the route from Schenker's terminal out to E20 is already prepared for the new HCT vehicles. The same trail is not running in Umeå and the bridges there are not prepared for the new road classification. In Table 2.1 the roads used for transport between Gothenburg and Umeå is presented.

Table 2.1: Roads between Gothenburg and Umeå [17].

Gothenburg - Örebro	E20
Örebro - Västerås	E18
Västerås - Gävle	56
Gävle - Umeå	E4

DUO 2 is a a project which aims to develop and try two different vehicle combinations, it also collects data from the field test of the two combinations on the road Gothenburg Malmö, the two different HCT vehicle projects are displayed in Figure 2.1 and 2.2. The project started with the "DUO2-trailer", Figure 2.1, which has a tractor unit, a dolly and a double trailer. It has been tested since February 2012 and gives double the cargo load in comparison to a standard European truck and single trailer vehicle. The trailers installed on the trucks are called semitrailers and are permanently installed on the truck chassis, the total volume of a semi-trailer is 95.5 m^3. The other vehicle, Figure 2.2, has a lorry unit and two trolleys [18].

Figure 2.1: The first vehicle on the road in the DUO2 project [19].

Figure 2.2: The latest vehicle in the DUO2 project [20].

2.3 Sustainable transportation

Transportation is important for the development in countries, it connects people and ship goods from industries to customers. A country without transportation is standing still. One could say that development is driven by transportation, and in order to get sustainable development, one needs to have sustainable transportation. Sweden is an exporting country and has since the 80th been making more money from the exporting goods than the cost of the goods imported, but to export the goods that are refined in Sweden there has to be some kind of import [21]. In 2014 Sweden exported goods to a value of 1 700 billion SEK, which is 45 % of Sweden's GDP. The import of goods and services corresponds to 41 % of Sweden's GDP. Transport work is a necessity for all the imported and exported goods [22].

After the Agenda 21 meeting in 1992, there was a second conference to implement the decisions made. The meeting took place in 1997 and as a part of this meeting, transportation was discussed. It was stated that a large increase of energy in developing countries was needed to improve the standard of living in those countries, this increase in energy consumption would improve the transportation, health and education in these countries [23].

The United Nations describes sustainable transportation as:

"Sustainable transport is the provision of services and infrastructure for the mobility of people and goods— advancing economic and social development to benefit today's and future generations—in a manner that is safe, affordable, accessible, efficient, and resilient while minimizing carbon and other emissions and environmental impacts." [24]

Environmental, social and economical sustainability is often discussed as aspect for a sustainable development, in this report all three will be included in the basic pillars for sustainable transport which is described in Section 1.2 [25]. Indicators for each pillar will help the analysis and comparison and are shown in Table 2.2. All these aspects will be discussed further in the sections below.

Table 2.2: Indicators for sustainable transportation [25].

Function, reliability and service	**Social and environmental care**	**Transport logistic cost**
Lead time [h]	Emissions of GHG [gCO_2eq]	Competitive cost [SEK]
Capacity	Safety	Alternative cost for non delivery [SEK]
Delivery on time [%]	Security risk	
Right place & condition		
Flexibility		

2.3.1 Social and environmental care

3.5 million people in the world die prematurely every year due to outdoor pollution, 23 % of the energy related GHG emissions come from the transportation sector [24].

According to a survey by Dan Andersson and Linda Styhre [12] it is found that although there is a requirement on the supplier to have an environmental certificate, transportation by environmental efficient transport is often not prioritized in favor of price and time aspects.

2.3.1.1 Fuels

There are several ways to determine emissions from vehicles. One way is known as the Well to Wheel (WTW) analysis, the assessment takes into account all emissions coming from the fuel production, distribution and use. The WTW assessment can be split into two separate assessments, Well to Tank (WTT) and Tank to Wheel (TTW). WTT focus on the emissions from the production and distribution of the fuels, it is known as the upstream stage. TTW analysis focus on the emissions from the vehicle when the fuel is used and is known as the downstream stage.

Drivmedelslagen [26] in Sweden states the different environmental classes on the diesel in Sweden, MK1 is a fuel blend with 21 % renewable and HVO100 is 100 % Hydrogenated Vegetable Oils. The fuel consumption in Sweden has increased by 4 TWh the last four years of which 18.8 % are biofuels. Diesel MK1 accounted for 62 % (56.9 TWh) of total fuel consumption in 2016 and the diesel use has increased with 17 % between 2012 and 2016. [27]. These numbers are excluding the use of electricity, and if electricity would be included the share of renewable energy in the transport sector is 30.9 % in 2016 [28]. The share of renewable energy in the transport sector was 23.7 % in 2015, including electricity. No energy or carbon tax had to be paid for biofuels until 2013. Taxes in some biofuels was implemented in 2013 because of the risk of over compensation [4].

When blending diesel MK1 both Fatty Acid Methyl Ester (FAME) and HVO is used as renewable components because of the similarities in characteristics and properties with fossil-based diesel. According to Swedish standard, the maximum percentage of FAME in the diesel blend is 7 vol-% and the percentage of HVO in MK1 2016 was 21 %. Pure HVO and FAME are called XLT/HVO100 and B100 however both are used more in blends than as pure components in the engines [27]. Table 2.3 shows the properties for diesel MK1 and HVO. The CO_2 equivalents are carbon dioxide, methane and nitrous oxide converted to its corresponding carbon dioxide value. The lower heating value of diesel is 36.2 MJ/l, all properties for diesel MK1 are taken from Preems information sheet [29]. The HVO100 delivery in the Swedish fuel system was 2 566 GWh in 2016, which makes it the third most common fuel and accounted for 2.7 % of the total fuel consumption. The delivery of FAME^{100} was 760 GWhin 2016 [27].

To produce 1 GJ of fossil Diesel, 1.09 GJ of raw oil is needed.[30]

Table 2.3: Share of renewable energy in different types of fuel and volume 2016 [27].

Fuel type	**Share renewable [vol%]**	**Total volume [m^3]**	**Emissions [g CO_2eq/MJ]**
Diesel MK1	21	5 784 710	80.4
HVO 100	100	266 930	14.0

Table 2.4 shows the shares from each raw material in HVO. The share of palm oil

in HVO has been reduced to zero by 2016 and been replaced by Palm Fatty Acid Distillates (PFAD), which is classified as a byproduct of the palm oil production with its origin in Malaysia and Indonesia. 88 % of the HVO is waste or byproducts which has an 80 to 90 % reduction in GHG emissions and only 3.8 % of the raw material (GWh/GWh) originates from Sweden.

Table 2.4: Raw material for HVO production 2016 [27].

Rapeed	Tall oil	Corn	PFAD	Vegetable and animal waste oil	Waste from slaughter house	Other
8 %	7%	4 %	23 %	38 %	19 %	1 %

Table 2.3 shows the emission from electricity according to the Swedish Energy Agency but in this thesis the software tool called Network for Transport Measures (NTM) was used. The software uses other key data for GHG emissions which can be found in Table 2.5. The GHG emission used for Swedish electricity is 0.0185 g CO_2eq/kWh which excludes the emission from infrastructure. The emissions of European mixed electricity (EU mix) used by the software are constructed by the European Commission in 2002 [31]. In a report written by the Swedish Energy Agency emissions for electricity as a fuel is the electricity 34.5 gCO_2eq/MJ [27].

Table 2.5: Electricity emissions from NTM software program, WTW perspective [32].

Origin	gCO_2eq/kWh	gCO_2eq/MJ
Swedish electricity	0.0185	0.0051
Swedish electricity with infrastructure	8.4	2.33

2.3.1.2 Emissions/classifications for HCT vehicles

The European Union has a classification system for the trucks in the European Union, the emission limits for an EURO VI truck is displayed in Table 2.6. To lower the nitrogen oxide (NO_x) emissions even further, AdBlue which is an urea additive, is dispensed into the flue gases before entering the catalyst [33].

Table 2.6: Emission regulations for EURO VI at WHTC (World Harmonized Transient Cycle) test for compression ignition engines [34].

CO [mg/kWh]	Hydro Carbons (HC) [mg/kWh]	NO_x [mg/kWh]	NH_3 [ppm]	PM mass [mg/kWh]	PM content [#/kWh]
4000	160	460	10	10	$6 \cdot 10^{11}$

2.3.1.3 Terminal emissions

Combi terminals are used to load the units used between the rail and road transport. Reach stackers are the most common machine used for this task in small and medium-sized terminals. Reach stackers are able to handle the containers or trailer frames quick and easy, it takes less time for a container (2-4 min) to be lifted from one vehicle to another than it takes for a trailer (3-6 min) and this machine is usually fueled with diesel. Apart from the actual lift, there are other actions involved in the procedure of lifting (idle running and running without a container or trailer). If these actions are included in the procedure of handling a container the time is 4-7 min and trailer 4-12 min. The lifetime of a reach stacker is around 5-6 years, after that, it either has to be fully refurbished (change of engine etc) or a new one is bought [35].

The energy savings by increased efficiency in the diesel engines is instead consumed by the new features installed in a newer model of the reach stackers.Figure 2.3 shows a reach stacker lifting a swapbody at a terminal. The reach stackers in Kalmars Harbour had a medium energy consumption of 21 l/h 2008. Shorter transports had a higher energy consumption of 25 l/km and idle running consumed 12 l/h[35]. Table 2.7 shows the average emissions for on and off loading's at a Swedish combi terminal per unit loaded, one unit loaded is for example a container.

Table 2.7: Emissions from terminal handling [35]. Emissions from terminal handling and shunting are on a TTW perspective.

Terminal Size	Big	Average
CO_2 total [g/unit loaded]	8 286	6 163
CO_2 fossil [g/unit loaded]	7 882	5 863
NO_x [g/unit loaded]	76	61
HC [g/unit loaded]	25	23
CH_4 [g/unit loaded]	0	0
CO [g/unit loaded]	47	39
PM [g/unit loaded]	3.8	2.8
SO_2 [g/unit loaded]	0.000027	0.00002
Renewable Energy [MJ/ unit loaded]	5	4
Fossil Energy [MJ/ unit loaded]	109	81

Figure 2.3: Reachstacker lifting a swap body [36].

Since an electric train locomotive is powered by overhead lines it cannot be used in the terminals, where reach stackers are used to loading on and off the units. Instead, diesel powered locomotives are used. T44 is the most common diesel locomotive used. Examples of parameters which also affects the emissions from shunting, length between the railyard and terminal, if the train has to be moved during the loading or if the wagons are coupled or not. The data provided by [35] is a standard/template data during shunting. These values can be found in Table 2.8.

Table 2.8: Emissions of shunting per unit Twenty-foot Equivalent Unit (TEU) [35]. Emissions from terminal handling and shunting are on a TTW perspective.

CO_2total [g/unit loaded]	2 082
CO_2 fossil [g/unit loaded]	1 985
NO_x [g/unit loaded]	40.1
HC [g/unit loaded]	0.451
CH_4 [g/unit loaded]	0
CO [g/unit loaded]	9.3
PM [g/unit loaded]	0.85
SO_2 [g/unit loaded]	0.00671
Renewable Energy [MJ/unit loaded]	1.4
Fossil Energy [MJ/unit loaded]	27.4

2.3.1.4 Safety

270 persons were killed in road traffic-related accidents in 2016 and 2 347 were injured (excluding suicides) [37]. A report mentions that the average risk of an ac-

cident is decreasing or at least remain the same with HCT trucks in comparison to normal trucks, but those accidents which occur is more dangerous in comparison to normal trucks [38]. However, accidents with HCT trucks may be more dangerous, since they are both heavier and longer.

The railway had in 2016 1228 safety-related deviations, 11 people was injured badly and 13 died because of accidents excluding suicides[39].

2.3.1.5 Driving rules for personnel

Rules for truck drivers are regulated by law in Sweden. The daily driving time cannot exceed nine hours, except two times a week this could be exceeded to 10 hours a day. The maximum driving hours per week is 54 hours and during two weeks it cannot exceed 90 hours. There must be a break for 45 min after 4 hours and 30 min. This break can be split into two separate breaks of 15 and 20 min, where the longest break has to be the last break. The driver is not allowed to do any work related task during this break [40]. Within 24 hours from the last daily rest there has to be a new daily rest. The daily rest is minimum 11 hours but can be split into separate breaks, one with at least 3 hours and one with 9 hours. The longest break has to be at the end of the working shift. A weekly break is a break of 45 hours at latest after six 24 hour periods. There can be a reduced daily rest of 9 hours, but as there is a maximum of 3 reduced daily rests in between two weekly breaks[40].

Driving and resting rules for locomotive drivers are not regulated by law but by a labour agreement. The central labor agreement for Seko Swedish Union for Service and Communications Employees states that the working hours cannot exceed nine hours per working day and the working period cannot exceed 10 hours. The breaks should be placed so the employee does not have to work more than five hours in a row, the employee is not obligated to stay at the workplace during break hours. During special occasion the break can be replaced by a "meal break" and the time for this will be included in the working hours [41].

2.3.2 Function, reliability and service

This aspect of sustainable transportation is an important aspect for the transport buyers and an error could change their willingness to buy from the same transport supplier again. When transporting certain gods, some companies try to follow the Just In Time (JIT) method. The goods should be delivered just in time for it to be used. This way the companies can reduce their stock and labor cost, because there are no buffers in the JIT methods there will be cuts in the production/service. Therefore, the reliability and total transport time are important for companies which have adopted the JIT approach. Transport buying companies have their own approach to logistics and what they are expecting from the transport supplier. It is, therefore, important to understand that there may be transport choices that are are not perfect for all transport buyers

2.3.2.1 Lead time

The lead time is the period between start and stop of an activity [42], such as the start of transporting goods until it is delivered at the delivering point. For long distance cargo transport, a method which in Sweden is called ”spetsbyten” is often used by the haulage contractors. An example of spetsbyte can be seen in Figure 2.4, a truck is traveling from point A to point B. Another truck is at the same time traveling from point C to point B. The trucks are switching trailers at point B and drives back to the starting point. This way will the cargo be at constant travel and the truck drivers will get home after a workday.

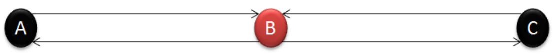

Figure 2.4: An example of ”spetsbyten” where two drivers, and two trucks, are used for a long distance transport where the trailer is switched at point B.

The time elasticity is the percentage decrease of demand for a certain transport choice when the transport time increases with 1 % unit. The time elasticity for road and rail transport is relatively the same and is shown in Table 2.9

Table 2.9: Time elasticity for rail and road transport [43].

Transport choice	Road	Rail
Share [%]	-0.5 to 0	-0.5 to -0.1

2.3.2.2 Capacity

As mentioned in the introduction it is important for the economic growth and for companies to have a functional transporting network in Sweden, where the cargo can be easily transported. The capacity on the road is generally considered good, some roads that have less capacity is the one in the major cities and commuting roads during rush hours [17].

The rail network in Sweden strained and some of the paths are congested [44]. The greatest traffic intensity for rail transport was on the south and west main line in 2012. One way to increase the capacity of the railway is to increase the length of the train [45]. Rail cargo transport had in 2015 increased with 11 % the last 25 years and it is expected to continue growing [46].

2.3.2.3 Delivery on time

Reliability is an important aspect when it comes to logistics to be able to optimize the overall logistic network. Reliability can be defined as the consistency of delivering on time or as the relative variation of the transit time [47]. Table 2.10 shows the delays for the Cargo train between Gothenburg and Umeå [48].

Table 2.10: Percentage of cargo train between Gothenburg and Umeå arriving at latest X min after scedualed arrival [48].

	share [%]
Of which arrived at latest 5 min after schedule	65
Of which arrived at latest 15 min after schedule	72
Of which arrived at latest 30 min after schedule	79
Of which arrived at latest 60 min after schedule	87

Figure 2.5 shows the delivery on time percentage for all cargo rail transport in Sweden between 2012 and 2016.

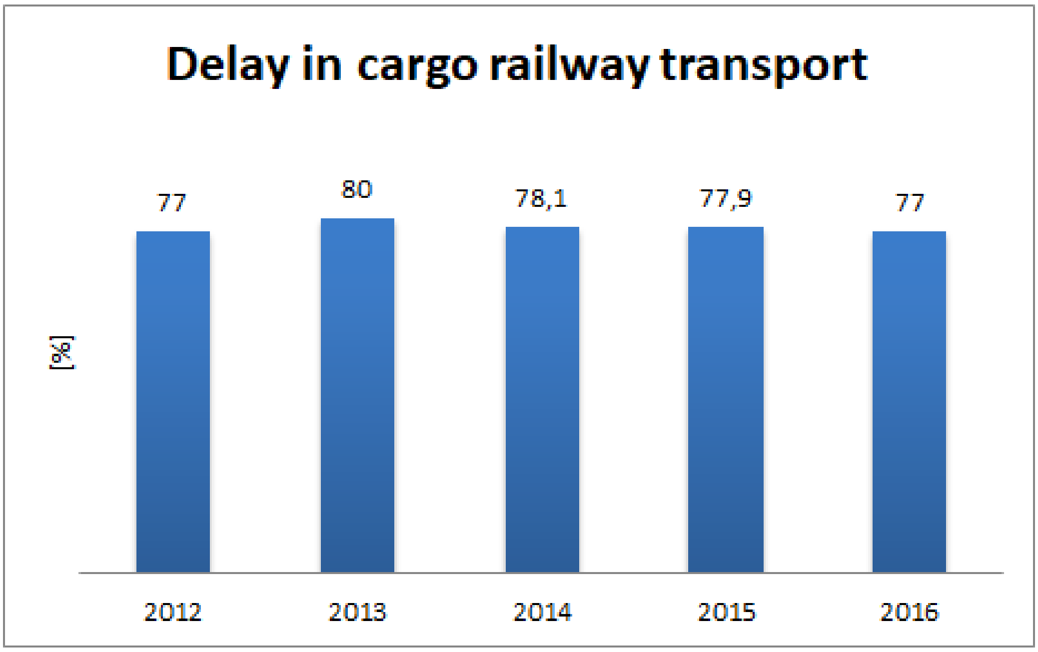

Figure 2.5: Percentage of all cargo trains arriving at time + 5 min for the years 2012-2016 [49].

The delays for passenger trains can be seen in Figure 2.6, 2.7 and 2.8. Figure 2.6 shows the average delay minutes and STM (STM sammanvägt tillförlitlighetsmått is the weighted reliability measure) for the years 2013 to 2016.

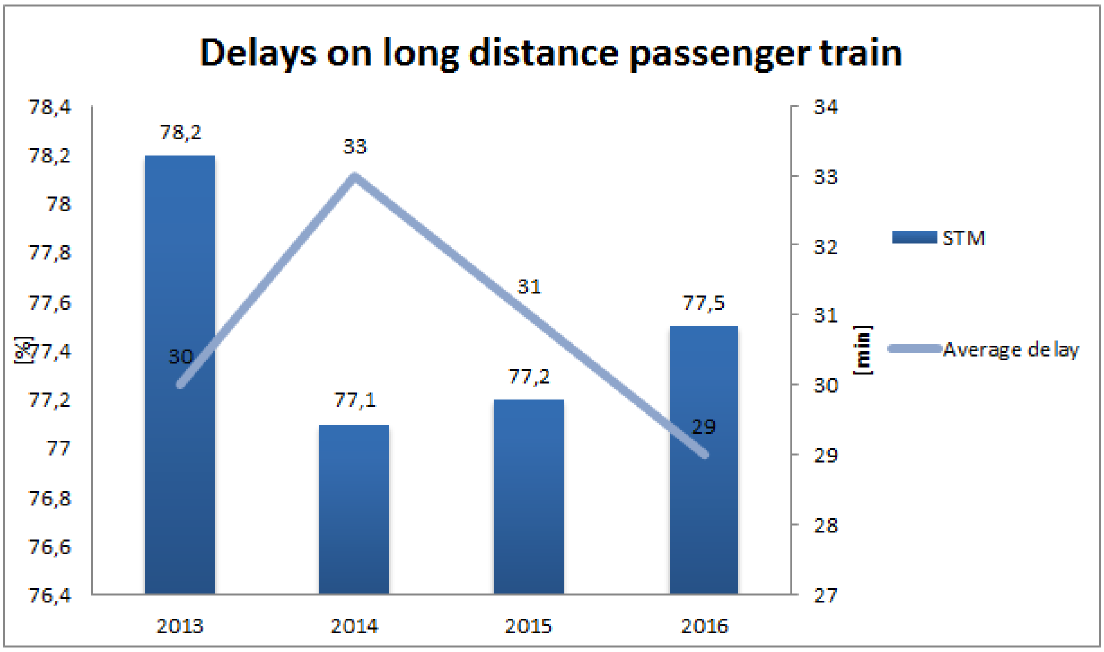

Figure 2.6: Percentage of long-distance trains arriving at time + 5 min for the years 2012-2016 and long distance passenger trains average delay for the years 2012-2016 [50].

Figure 2.7 shows the percentage of long-distance passenger trains which arrives at certain minutes after expected arrival.

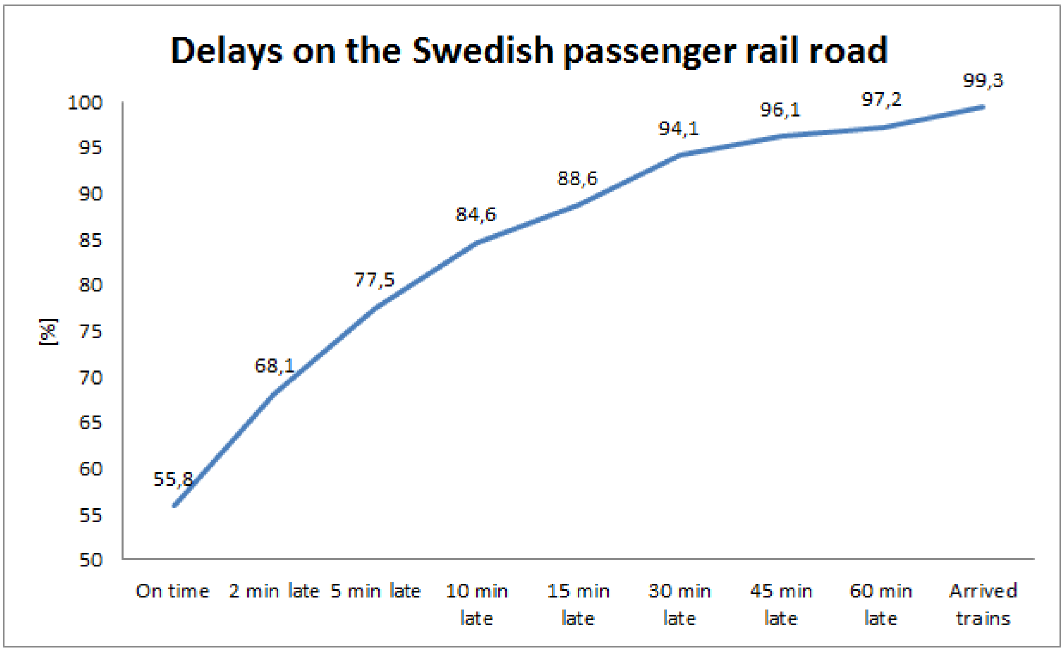

Figure 2.7: Percentage of long-distance passenger trains which has arrived after X min after schedule arrival in 2016 [50].

Figure 2.8 shows the monthly changes of arrival for long-distance passenger trains.

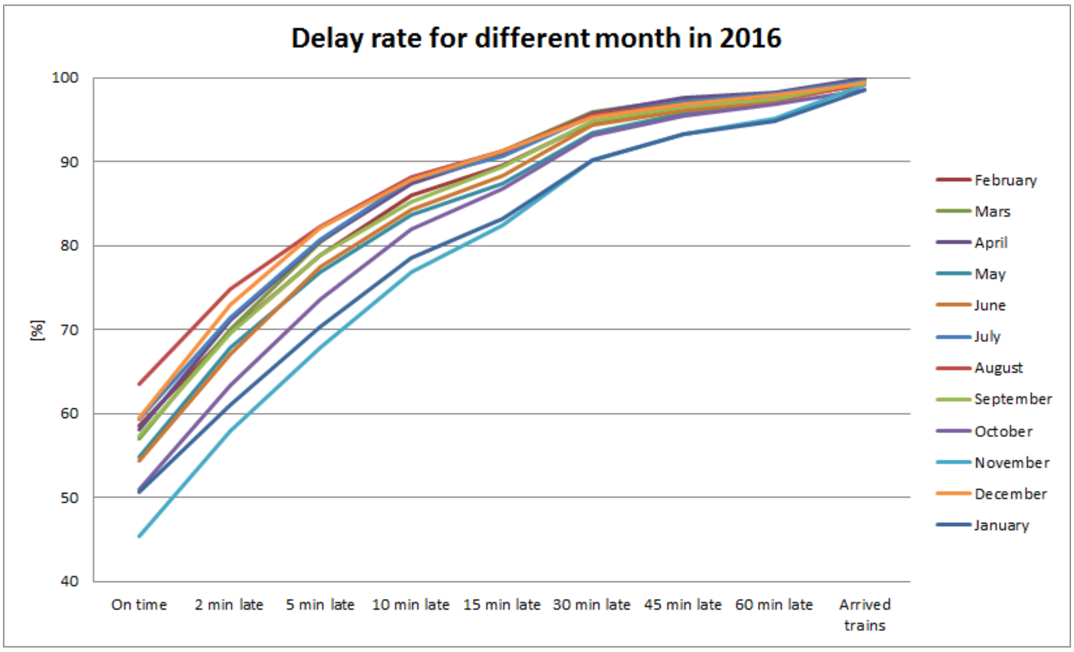

Figure 2.8: Percentage of long-distance passenger trains which has arrived after X min after schedule arrival for different months in 2016 [50].

70-80 % of the scheduled trains were actually carried out in 2012 [45]. 95 % of the planned long-distance passenger train which were planned at the start of the year in 2016 was on the train schedule the day before its departure. Of the total number of trains planned at the annual train schedule was 94 % actually carried out in 2016 [50].

The reliability elasticity for road and rail transport are both -0.3, meaning that these transport choices are reduced with 0.3 % if the delay time increased with 1 % [43].

2.3.2.4 Right place and conditions

The risk of damage is the probability for a certain shipment to be damaged is during a transport, in studies the risk of damage measured as the amount of damage or lost goods per the total amount of transported goods at the same route during a certain time period. When goods are damaged/lost does the company not only loose the value of the damaged/lost goods but also the cost of the administration for the damage/lost goods. Multimodal transport is considered to have a higher risk of damage due to the higher frequency of on and off loadings. Some companies also claim that the damage cost is higher for multimodal transport than for pure road transport. This is due to a higher administration time for investigation of responsibility and reason for damage [43].

2.3.2.5 Flexibility

Flexibility for transport choice is defined as the easiness of a change in the transport, this could be factors such as the ability to change lead-time, faster transport time or ability to change loads [51]. A reason for transport buyers not to choose multi-modal transport is the nonflexibility in shipment size. The rail companies shipment size is bigger than the size of the warehouse [43].

One factor that influences the flexibility is the transport frequency. The transport frequency indicates the number of transport that takes place per time unit. It is easier for companies to adapt to sudden changes if the transport frequency is high. The elasticity for frequency is defined as the increase of transport choice if the transport frequency is increased with 1 %, Table 2.11 shows the elasticity for frequency for road and rail transport [43].

Table 2.11: Frequency elasticity for rail and road transport [43].

Transport mode	Road	Rail
Share [%]	0.1 to 0.2	0.2

2.3.3 Transport logistic cost

Transport logistic cost is the cost to transport the goods from the starting point to the endpoint. A shorter lead time would result in a shorter transport time which decreases the cost for the vehicle and driver but also reduces the cost for the transport buyer which will have a lower cost for stock and capital which is locked in [43]. Value of time (VOT) has been defined as the marginal utility or cost reduction that is generated in the reduction in time needed to transport the goods. Most of the VOT models only take the travel time for the goodsinto account [47].

If the price of a certain transport choice is increased with 1 % (for the price per tonne-km) the demand for that transport choice will increase with a certain elasticity. The price elasticity for road and rail transport is shown in Table 2.12. One reason for the low elasticity of road transport is due to that the road transports advantages is big so the increase in price would not affect the choice of transport.

Table 2.12: Price elasticity for rail and road transport [43].

Transport mode	Road	Rail
Share [%]	-0.6 to 0	-1.0 to -0.1

2.3.3.1 Road transport cost

The monthly salary after four years of experience as a truck driver is 25 886 SEK and the add-on for night hours are approximately 49 SEK/hour [52].

The analysis for the HCT truck is investigating both MK1 and HVO100, the price for MK1 is was in September 2017 12.45 SEK/l including VAT and taxes and HVO100 12.27 SEK/l excluding VAT [53]. Since HVO is a renewable fuel it is excluded from the fuel tax [27].

Some investigations indicate that the transport cost reduction with implementation of HCT vehicle will lead to a modal shift and more road transport. The cost reduction for HCT vehicle is 23 % per tonne-km in comparison with a normal 60-tonne vehicle. An efficiency increase is noted due to that less traffic is needed in order to get the same result. It is also noted that some driving shift has been canceled due to a nonexisting need [38].

2.3.3.2 Combi transport costs

A part of the railway logistics is when the train is moved from the terminal where there are no over headlines to the main line where the electric locomotive can operate. Since there are no over headlines the electric locomotive cannot be used and diesel locomotive is used for the shunting instead. A rough estimation of the time it takes for the shunting is approximately 30 min to enter and 30 min to exit, this would equal a shunting time of 0.625 to 1.58 minutes per load unit. The shunting cost can be calculated by the operating costs and the personal cost. The line haul engine driver has the same salary as the train driver and the shunting engine driver is assumed to have 80 % of the line haul engine driver [54].

When the train is docked to the terminal the cargo will get unloaded, machines such as reach stackers, cranes and other equipment are used for the on and off loadings. A full train takes about 3-4 hours to unload, depending on the train size and numbers of reach stackers. For a trailer/swap body is the handling time 3-6 minutes to on load and 4-12 minutes to unload. The cost for loadings will depend on the size of the terminal, equipment used and type of load unit. 50 % of the units handled on the terminal will be lifted twice [54]. According to Flodén [54] will the costs for on and off loading's will be dependent on the size of the terminal. A small medium and large terminal will handle 25 000, 50 000 and 100 000 TEU respectively per year.

The average cost of electricity in 2016 was 0.5435 SEK/kWh [55]. Electricity consumed on the railway network is excluded from taxes [56].

3
Method

This chapter will focus on how the analysis was done for the three different aspects; (1) social and environmental care, (2) function, reliability and service and (3) transport logistic cost. The system boundary for the calculations is set to from when the cargo is picked up at the starting point until it reaches its final destination at the terminal.

3.1 Social and environmental care

The environmental calculations were done differently on the rail and the road transport. For the rail transport a software program developed by Network for Transport Measures (NTM) was used, the program and its application is described more in detail Section 3.1.2.1. The calculations on the high capacity road transport was done with help from the data provided by Volvo's trials, also described more in detailed Section 3.1.3.

3.1.1 Limitations and boundaries

The different cargo carrier had different load carriers, which made it more difficult to compare the two different transport choices. The HCT vehicles will have a specially designed semitrailer installed on the trailer, this trailer will have a total volume of 97 m^3. A 40-foot container (which is equal to 2 TEUs) will be used for the combitransport, the volume for the 40-foot container is 76 m^3 and the maximum load 26 tonne. It is assumed that the limiting factor was volume, hence the load carrier will always be full in volume rather than mass. It is well known that high-density cargo such as iron ore and timber will favor train transport due to its energy efficiency. The analysis was done on several different densities to see how the result changed. Different densities on the cargo and a maximum volume will give different cargo mass. The load factor is the share of maximum load utilized and was calculated on a mass basis. All results are calculated for one tonne of transported cargo to compare the transport modes.

3.1.2 Combi transport

The distance for the study is set to Gothenburg and Umeå, with the starting point of Transportvägen 11 and end point of Lagervägen 17. The railway cargo has to be delivered to and from the terminal. Jernhuset has a cargo terminal in the middle of Gothenburg at Partihandelsgatan 4 and is chosen as the terminal in Gothenburg even though this terminal is shutting down in December 2017. This is because NTM (see details under Section 3.1.2.1) is limited to the railway for passenger trains, which is explained more in detail below. The combi terminal in Umeå is set to Sandahls goods and Percel AB, at Bangårdsvägen 1, and the final destination is at Lagervägen 15.

Since none of the Schenker terminals are connected to a railway it was assumed that the cargo first was transported by road transport from the terminal in Gothenburg to the combi terminal at Gullbergsvassen. From there it will go by rail up to Umeå and from the combi terminal in Umeå (Bangårdsvägen 1) to Schenker's terminal with road transport. The road transport between the combi terminal was assumed to be carried out by a rigid truck 20 - 26 tonne which was run on diesel MK1 with 7 % renewable fuels.

The route which the rail cargo is transported between Gothenburg to Umeå is illustrated in Figure 3.1. The index for the passenger train changes can be ignored.

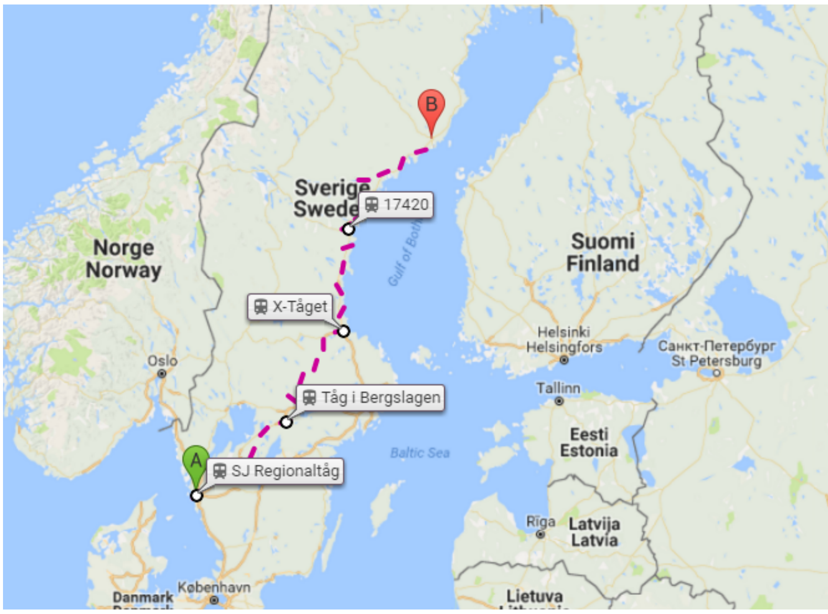

Figure 3.1: The train transport follows the route in the figure [57].

Due to some limitations in the software program routes for train transport can only be created from public transport. The end and start point will, therefore, be set at the passenger terminal at Gothenburg and Umeå. As can be seen in Figure 3.2 and 3.3 the distance between the combi and passenger terminal is not far and its errors can, therefore, be neglected.

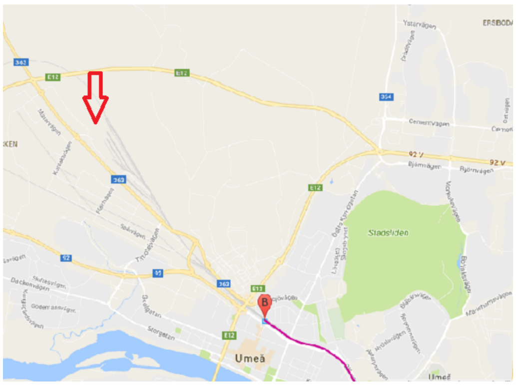

Figure 3.2: The B in the picture is the passenger terminal in Umeå, the red arrow indicates the combi terminal location [57].

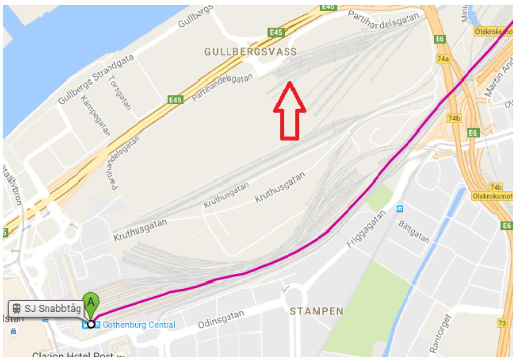

Figure 3.3: The A in the picture is the passenger terminal in Gothenburg, the red arrow indicates the combi terminal location [57].

The distances transported with road transport beetween Schenker's terminals and the combitransport in Gotenburg and Umeå are illustrated in Figure 3.4 and 3.5.

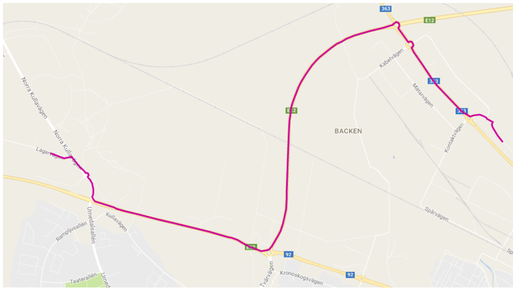

Figure 3.4: The road for the combi terminal in Umeå to Schenkers terminal at Lagervägen 17.

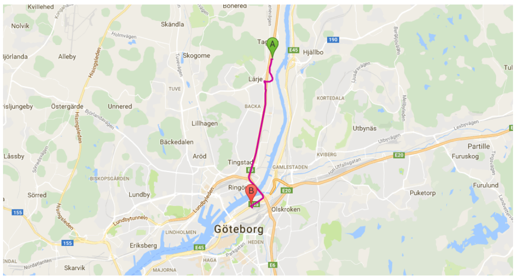

Figure 3.5: The road from Schenkers terminal at Transportvägen 11 to the combi terminal.

It is assumed that the combi terminal handled the load carriers two times in Gothenburg and one time at the terminal in Umeå. The emissions and energy consumption for the reacstackers is calculated by key data and are on a TTW perspective. The WTW energy consumption is calculated by multiplying the energy consumption of production mentioned in Section 2.3.1.1 in the theory.

3.1.2.1 Network for transport measure

The calculations of emissions from rail and road transport for the combi transport choice was calculated with help from the software program developed by NTM [57]. Key parameters for train/road transport: The shipment size is the size of the shipment that is subjected to the transport, cargo carrying capacity is the maximum capacity of the vehicle. Cargo load factor is the portion of the vehicles cargo carrying capacity that is actually utilized. To calculate the emissions emitted by transporting the shipment, the allocation factor is multiplied by the gross emission by the vehicle.

The results reported by NTM can be seen in Table 3.1.

Table 3.1: Resulting measures after a simulation in NTM.

Factor	Measure	Explanation
CO	kg	Carbon oxide
$CO_{2,fossile}$	kg	Carbon dioxide from fossil origin
$CO_{2,biogen}$	kg	Carbon dioxide from non fossil origin
$CO_{2,total}$	kg	Carbon dioxide total
$CO_{2,e}$	kg	Total Greenhouse Gases (GHG) measured in CO_2 equivalents, includes fossil carbon dioxide, methane, nitrous oxide
SO_2	g	Sulfur dioxide
NO_x	g	Nitrogen oxides
N_2O	g	Nitrous oxides
CH_4	g	Methane gas
HC	g	Hydrocarbons
PM	g	Particular matter
Energy use	MJ	

3.1.3 High Capacity Transport vehicle transport

The data for the HCT vehicle is provided by Volvo trucks and is a part of the DUO 2 project and has been collected during summer 2017. The truck is a 13 liter engine with 540 hourse powers called XKT 045.

The topography on the road between Gothenburg and Umeå is assumed to be approximately the same as the one between Gothenburg and Malmö. Another thing affecting the fuel consumption is the road classification, E6 is a highway the entire way from Gothenburg to Malmö which means that it will be a more steady flow of traffic. Since data from the DUO2-project, between Malmö and Gothenburg, is used it has been assumed that the road classification and topography is similar to the road between Gothenburg and Umeå.
The roads between Gothenburg and Umeå is not highway the entire way, some parts are only single lane and with exit/entrances, this will affect the consumption of the fuel to some extent but it is assumed to be negligible. The total distance between the terminal in Gothenburg and Umeå is 993 km, the extra distance for stops/breaks is assumed to be negligible in the bigger picture.

Diesel MK1 and HVO100 were used as different types of fuels and the trucks were assumed to be EURO VI. The energy consumption from the transport was calculated with the fuel consumption for a certain density times the distance. The emissions were calculated assuming the transport will be EURO VI and that the emission from the truck will be at the limit of what is allowed to be emitted. It is also assumed that the fuel consumption will be same for HVO100 and Diesel MK1 as the heating values are about the same. This can be seen in the information sheets about HVO 100 [58] and diesel MK1 [29] from Preem. The emissions regulated for EURO VI are carbon monoxide, Hydro Carbons, nitrogen oxide, ammonia and particulate matter. The results for the HCT transport will, therefore, be different than the results from the NTM software, the results from the CO_2eq emissions are not correlated with the EURO VI and does only depend on the type of fuel.

In Umeå, there are no such project running today, so the roads and bridges have to be prepared for the 74-tonne vehicles. Umeå has a central terminal for combitransport, placed in the middle of Umeå (Bangårdvägen 1) and a road network for 74-tonne vehicles would include a way to this terminal. As can be seen in Figure 3.6 and 3.7 there are two different ways to Lagervägen 17 (final destination) or Bangårdsvägen 1 (combi terminal, indicated with a red arrow). In Figure 3.6 the road crosses a bridge on the E12 which by Trafikverket [17] is not included to be rebuilt for the new BK4 classification, although this way is the shortest one to the combi terminal and may be apart of the rebuilding because of that. All streets which are maintained by Umeå municipal has classification BK1 [59] which allows vehicles to have a brutto weight of 60-tonne [17]. Both bridges in Figure 3.6 and Figure 3.7 is today classified with BK1 [59].

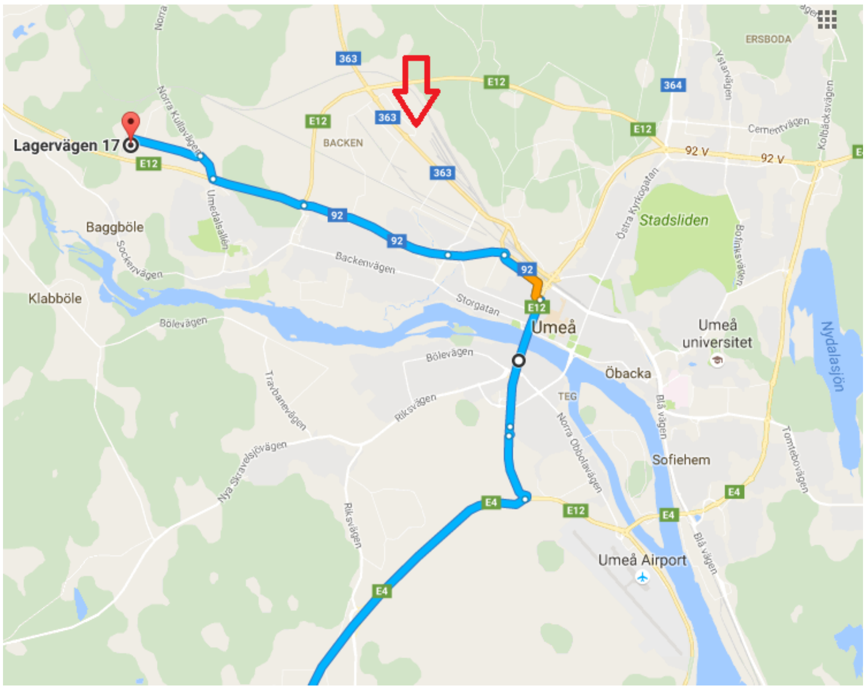

Figure 3.6: One way which the HCT vehicle could drive in Umeå crossing the bridge at E12, the red arrow indicates the combi terminal in Umeå.

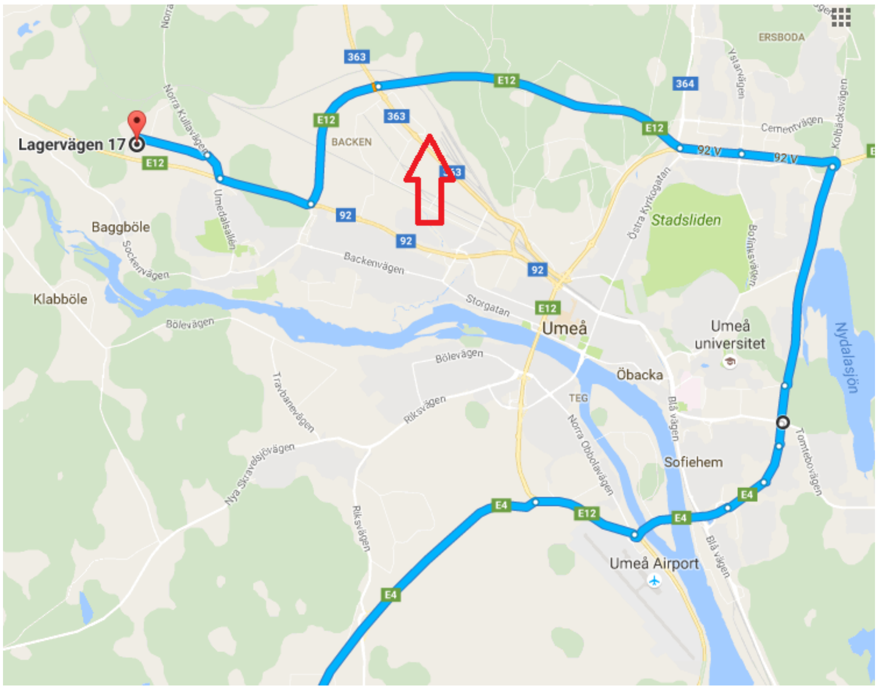

Figure 3.7: One way which the HCT vehicle could drive in Umeå crossing the bridge at E4, the red awwor indicates the combi terminal in Umeå.

3.1.4 Social

The social aspect has not been in focus in this report and will only cover a small discussion about driving regulations and accidents.

3.2 Function, reliability and service

Data for this analysis was hard to find therefore will the focus be on a discussion about modal choice.

3.2.1 Lead time

The lead time in this case is the time period between when the cargo being shipped from Schenker's terminal at Transportgatan 9 to when it arrives at Schenker's terminal at Lagervägen 17 in Umeå. The lead time for the combi transport is calculated with help from information provided by Sandahls bolaget, which is a logistic company. Estimations and the lead time for the HCT transport is calculated with a mean velocity of 70 km/h and with breaks according to the law described in the theory. It is assumed that the truck should deliver the cargo at approximately the same time as the combi transport.

3.2.2 Delivery on time

Trafikverket provided some information about delays on the Swedish railway. This together with information provided by Green Cargo and Kinnarp AB be will be discussed.

3.3 Transport cost logistics

The cost calculations for the two different transport will be calculated on a unit basis. The DUO 2 project's HCT vehicles have specially designed semitrailers which are installed on the truck and trailer chassis. For the Combi transport, it is assumed that the load carrier is a 40-foot container.

The system boundary for the transport cost calculation will be from when the driver check in at the starting terminal until when the cargo has arrived at the final destination and the driver has checked out. The handling of the cargo when at starting and ending terminal is not included, thus the cost is assumed to be the same. The driver's salary when not driving is also included.

The price for the fuel exclude VAT but included taxes, the companies of interest are assumed to be able to deduct the VAT. Electricity which is used on the railway and for rail-bound vehicles is excluded taxes.

3.3.1 Cost calculations for road transport

The cost calculations for the road transport was done with help by a software tool called SåCalc which is developed by AB Åkerikonsult. The key data for the calculations was collected from stakeholders, some data was also given by Lars Aspholmer [52].
The factors which influence the transport cost for the road transport are:

- Vehicle investment cost
- Fuel cost
- Vehicle and road taxes
- Insurances
- Cost for tires
- Service and reparation
- Other fixed cost
- Personnel cost

3.3.2 Cost calculations for combi transport

The transport cost for the combi transport is divided into four different categories; cost for railway transport, road transport, shunting and terminal handling. Cost calculations for trains are difficult due to large differences in cost for different rail operators. The result presented is only a rough estimation to compare with the cost calculations for the HCT transport. The key data was found in the report

”Rail freight costs - some basic cost estimations for intermodal transport” written by Jonas Flodén. The report also explains and calculates the cost of shunting and terminal handling cost [54].As mentioned in Section 2.3.3.2 in the theory, 50 % of the units handled on the terminal will be lifted twice.

The same program used for the HCT vehicle cost calculations was also used for the combi truck cost calculations.
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4
Results and discussion

This chapter contains the result from the calculations as well as a discussion about the results.

4.1 Social and Environmental care

The environmental and social care results for each transport choice can be found in the sections below, the focus has been on the environmental care but with a small discussion about the social aspects for each transport choice.

The results of transporting one tonne of cargo between Gothenburg and Umeå with different types of fuels are shown in Table 4.1, and as can be seen the emission are the highest for diesel HCT truck and lowest with Swedish electricity powered combi transport.

Table 4.1: CO_2eq [kg] emissions comparing rail/combi transports with HCT transports for different density of the transported goods.

	Combi transport		HCT transport	
Density [kg/m^3]	EU mix	SWE mix	Diesel MK1	HVO
50	95.81	12.52	-	-
70	72.49	9.16	86.00	14.15
100	51.49	6.45	59.10	9.72
150	35.52	4.38	43.48	7.15
200	27.82	3.36	34.63	5.70
221	25.57	3.07	32.82	5.40

The emission data used by NTM for Swedish cargo is 0.0185 gCO_2eq/kWh while the Swedish Energy Agency assumes 124 gCO_2eq/kWh (assuming 1 kWh = 3.6 MJ). For a density of 150 kg/m^3 would this results in a total emission of 7.8 kgCO_2eq/tonne just for the rail transport, which is more than the total CO_2eqv. emissions seen in Table 4.1. It is therefore important to look at the emissions for an European electricity mix and use that as an upper limit of what the emitted emissions for railway transport could be.

The average density on cargo is about 150 kg/m^3 and rail transport has the capacity to carry heavier cargo than road transport. This report focus on studying transport of cargo with limitations by the volume and only one way. The empty position factor is assumed to be zero, hence the truck is assumed to always be full. Table 4.2 shows the energy consumption (WTW) for each transport mode.

Table 4.2: Energy consumption [MJ] comparing rail/combi transports with truck/HCT transports for different density of the transported goods.

Density [kg/m^3]	Combi SWE mix [MJ/tonne]	Combi EU mix [MJ/tonne]	HCT transport [MJ/tonne]
50	774	1 900	-
70	583	1 440	1166
100	414	1 023	801
150	285	706	589
200	223	553	469
221	204	509	445

It is assumed that the high energy consumption for an European electricity mix in comparison to SWE mix electricity is due to the fact that the Swedish electricity is assumed to be generated by hydropower only while the European electricity mix probably is generated with a mixture of combustion power generation (eg coal condense power). Hydropower has a high efficiency while coal condensing power plants have a lower efficiency.

4.1.1 Combi transport

The combi transport was divided into different categories; road transport Gothenburg, rail transport, road transport Umeå, shunting (in both Gothenburg and Umeå) and terminal handling (in both Gothenburg and Umeå). The emissions are displayed in a WTW perspective and includes the emissions for production, except for shunting and terminal handling where the energy is only on a TTW perspective.

For the rail transport NTM was used, to get as accurate key data as possible Sandahlsbolagen was contacted. All key and input data for the railway transport can be found in Appendix A.1 and the rail emissions can be seen in Table 4.3.

Table 4.3: Results for rail transport emission contribution to the combi transport.

		EU mix		SWE mix	
Density [kg/m^3]	Cargo load factor [%]	CO_2 ekv. [kg/tonne]	Energy [MJ/-tonne]	CO_2 ekv. [kg/tonne]	Energy [MJ/-tonne]
50	15	84.85	1733	1.29	607
63	20	64.31	1318	0.98	461
100	29	45.73	937	0.70	328
150	44	31.62	648	0.48	227
200	58	24.84	509	0.38	178
221	64	22.85	468	0.35	164

For the road transport between Schenker's terminal and the combi terminal, two different types of vehicles were used. Gothenburg is, as described earlier, as an environmental area and only EURO V vehicles are allowed inside that zone, but it is assumed that the truck is an EURO VI. In Umeå there are no restrictions and it is therefore assumed that it is an EURO V. All key and input data can be found in Appendix A.1. The amount of CO_2eq and energy use for the road transport can be found in Table 4.4, the results for the road transport in Gothenburg and Umeå are shown together in the table.

Table 4.4: Results for road transport emission contribution to the combi transport.

Density [kg/m^3]	CO_2 ekv. [kg/tonne]	Energy [MJ/tonne]
50	2.53	35.22
63	1.94	26.85
100	1.41	20.35
150	1.00	15.44
200	0.81	12.98
221	0.75	12.19

At both terminals, the unit will be loaded and unloaded from the carrier. It is assumed that the unit will be lifted twice at the terminal in Gothenburg and once at the terminal in Umeå. The emissions of CO_2 equivalents and energy use for one tonne of cargo can be found in Table 4.5.

Table 4.5: Results for terminal handling emission contribution to the combi transport.

Density [kg/m^3]	CO_2 ekv. [kg/tonne]	Energy [MJ/tonne]
50	5.98	89.78
63	4.29	64.31
100	2.99	44.89
150	1.99	29.93
200	1.50	22.45
221	1.36	20.34

The shunting of the train will be done by a diesel locomotive and the emissions will, therefore, be relevant for the results. The results for the emissions and energy are shown in table 4.6.

Table 4.6: Results for shunting emission contribution to the combi transport.

Density [kg/m^3]	CO_2 ekv. [kg/tonne]	Energy [MJ/tonne]
50	2.72	40.90
63	1.95	29.30
100	1.36	20.45
150	0.91	13.63
200	0.68	10.23
221	0.62	9.27

The emissions from terminal handling and shunting are on a TTW perspective while the energy consumption are on a WTW perspective. Although there will be a difference in the results, this results can be seen as a lower limit of the CO_2eq emissions.

Figure 4.1 and 4.2 shows the share of factor contributing to CO_2eq emissions when transporting cargo with combi transport between Gothenburg and Umeå. As can be seen the largest factor for CO_2eq emissions are, for European electricity, the railway transport, but for Swedish electricity the load carrier handling and shunting are the most contributing factor to the emissions. The emissions for Swedish electricity from railway is negligibly small in comparison to the other factors, this is due to the extremely low value used by NTM and the result would not look the same if the value 124 g CO_2eq/kWh provided by the Swedish Energy Agency [27] was used.

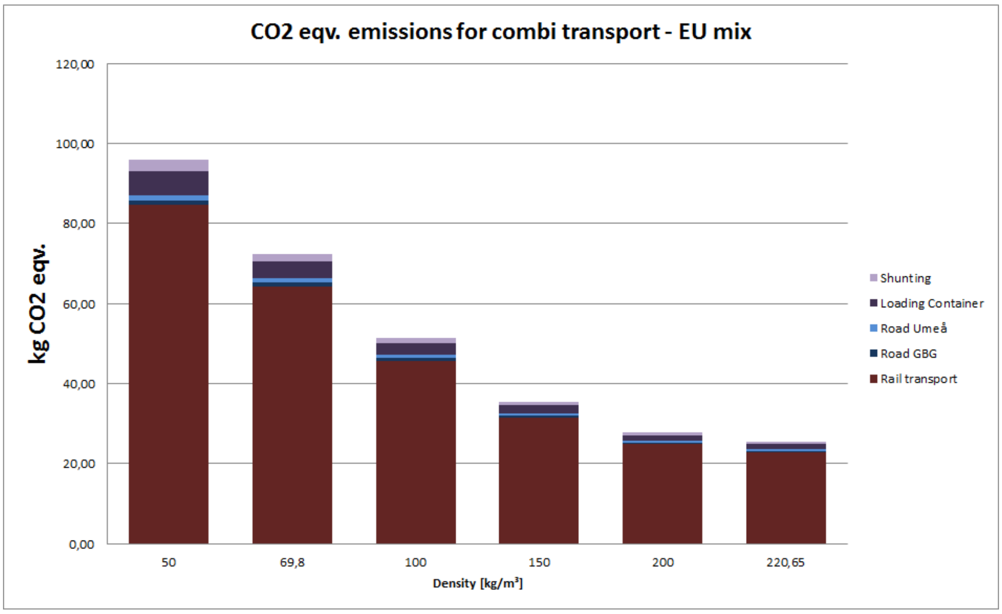

Figure 4.1: CO_2eq emissions for combi transport with European electricity.

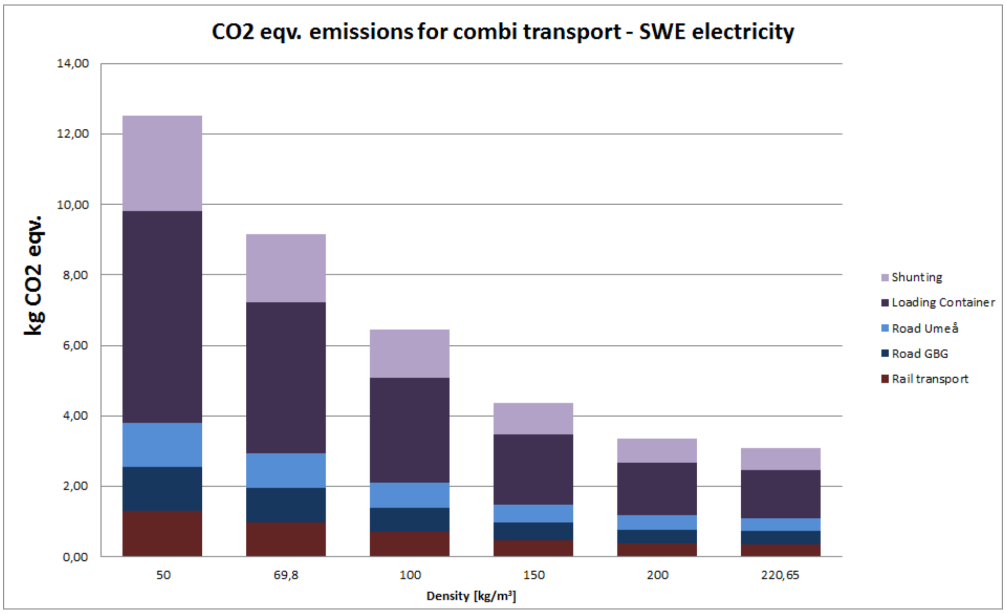

Figure 4.2: CO_2eq emissions for combi transport with Swedish electricity.

Figure 4.3 and 4.4 shows the share of each factor contributing to the energy consumption when transporting cargo with combo transport between Gothenburg and Umeå.

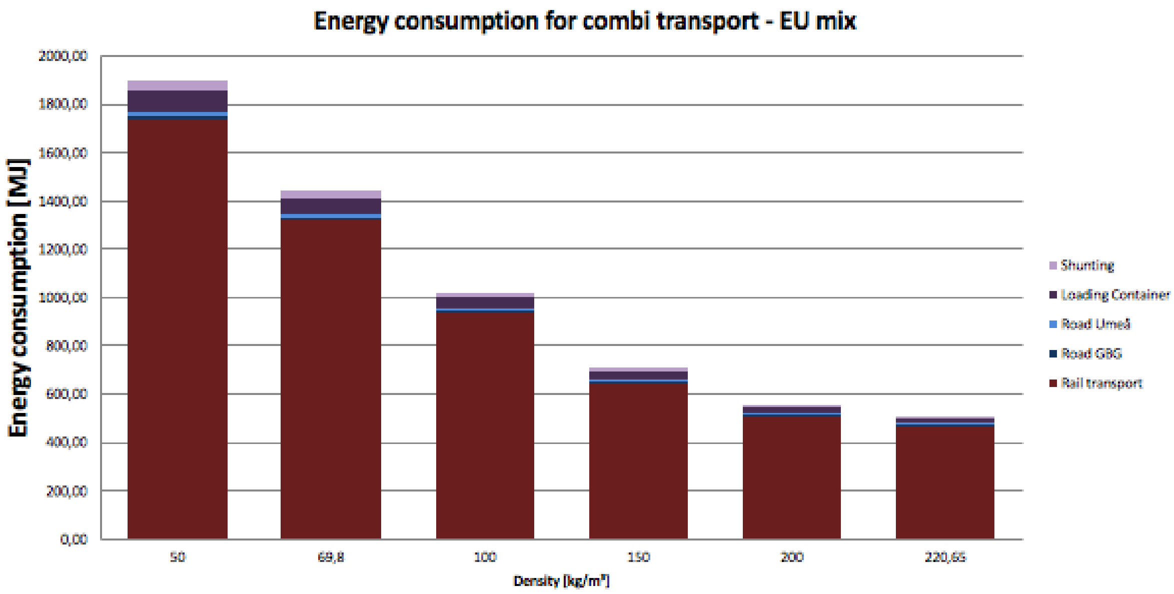

Figure 4.3: Energy consumption for combi transport with European electricity.

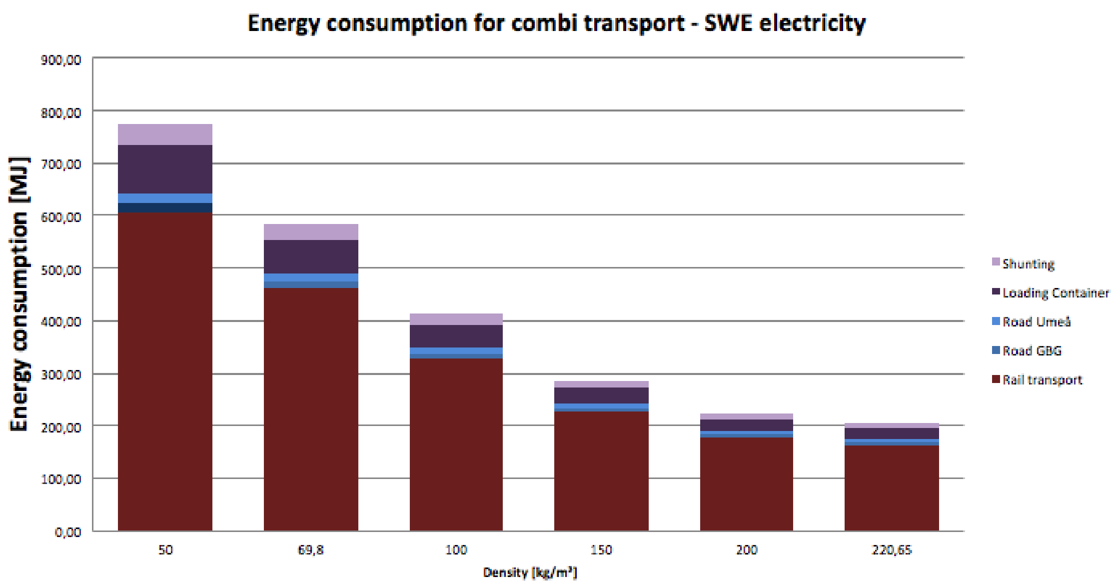

Figure 4.4: Energy consumption for combi transport with Swedish electricity.

More detailed results can be found in Appendix A.2.

4.1.2 HCT transport

The road transport for HCT vehicles has been analyzed for HVO 100 and MK1. The results can be seen in Figure 4.5 or in the Table 4.7 below, the results for the density of 50 kg/m^3 is excluded, this is because of the limited data from Volvo. The emissions of CO_2eq are on a WTW perspective but the energy consumption is on a TTW perspective.

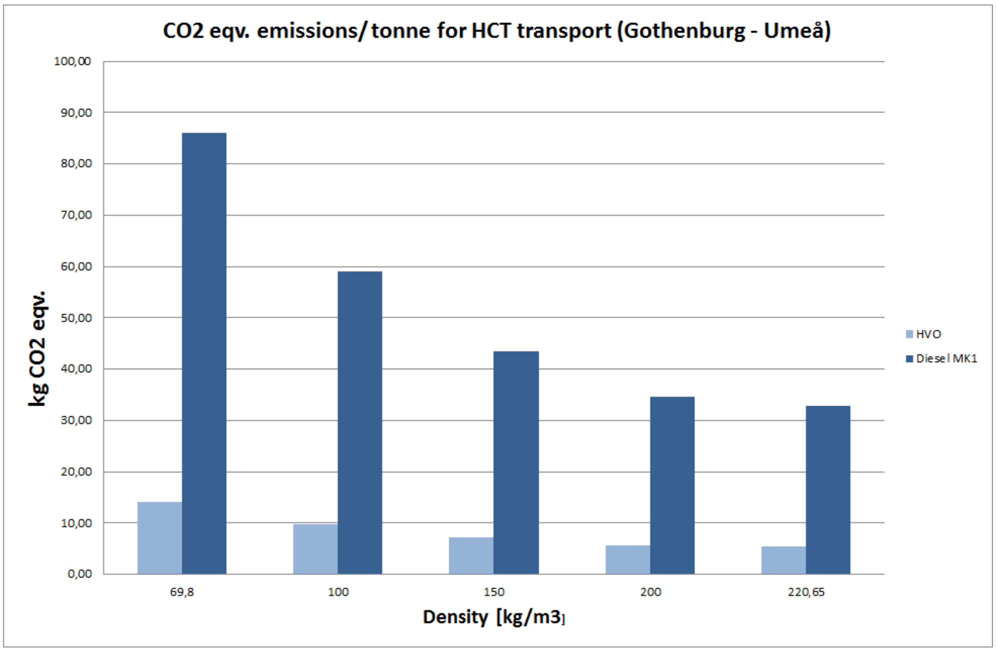

Figure 4.5: Emissions for the HCT transport with HVO or MK1 as fuel.

Table 4.7: Results for HCT road transport.

		MK1	HVO
Density [kg/m^3]	Cargo load factor [%]	CO_2eq [kg/tonne]	CO_2eq [kg/tonne]
50	19	-	-
70	27	86.00	14.15
100	39	59.10	9.72
150	58	43.48	7.15
200	78	34.63	5.70
221	86	32.82	5.40

Table 4.8 shows the fuel and energy consumption for each density, more detailed data and results can be found in Appendix A.3. The fuel consumption is, as mentioned in the method, real values from a trial between Gothenburg and Malmö. The topography might be slightly higher between Gothenburg and Umeå, so the values might be a bit too low. The data from the test trails are also limited, hence the consumption of 100 kg/m^3 is lower than of 70 kg /m^3. This may be due to different weather condition or other sources which may differ between the journeys. The results are the same for both fuels with the assumption of same calorific value.

Table 4.8: Fuel consumption for HCT transport [60].

Density [kg/m^3]	Fuel consumption [ml/km]	Fuel consumption [ml/tonnekm]
50	-	-
70	402.9	29.75
100	396.7	20.45
150	437.8	15.05
200	464.9	11.98
221	486.1	11.36

The energy consumption for the HCT transport is shown in Table 4.9, where the energy consumption is calculated with a TTW perspective.

Table 4.9: Energy consumption TTW for HCT transport with MK1 having a calorific value of 10.06 kWh/l [29].

Density [kg/m^3]	Energy consumption [MJ/tonne]
50	-
70	1 070
100	735.1
150	540.9
200	430.7
221	408.2

4.1.3 Social aspects for both combi and HCT transport

The resting hours for truck drivers are regulated by law in Sweden, as mentioned in the theory. For train drivers the resting hours are not regulated by law but by the labor agreement. A local labor agreement between the labour and the employer could be in the favor to a law since it can be regulated to suits both the driver and employer in a more beneficial way[41].

The accident statistics are higher for road transport since it includes other types of vehicles (cars, motorcycles etc) and not only trucks.

The accident statistics are higher for road transport, compared to rail transport. It is however difficult to identify the amount of accidents that is connected to long-distance trucks. It is, therefore, difficult to judge if any of the transport choices are better than the other from a safety perspective.

4.2 Function, reliability and service

This section will not cover specific results but more discuss the reasons behind different modal choices. The choice of transport mode depends highly on factors such as lead time, delivery on time and right place and right condition aswell as the ”aim” of the transport. This report focus on cargo with volume limitations and the results from this analysis will therefore depend highly on the focus of the transport buyer.

4.2.1 Lead time

The lead time for the train would be from when the goods starts to move from its origin until when it arrives. The transport company Sandahlsbolaget want the cargo received 19.30 (Mon-Fri) and it can be picked up in Umeå 11.00 (Tue-Fri) and 9.00 (Sun). The total transporting time for the rail transport is 15 h and 30 min. The road transport from Schenker’s terminal to Gullbergsvassen is assumed to take 45 min and the road transport in Umeå is also assumed to take 45 min. The total lead time for the combi transport is 17 h.

The driving rules for truck drivers are stated in the theory Section 2.3.1.4. In Figure 4.6 the route and changing scheme for the HCT truck is displayed. The truck is assumed to drive 70 km/h and three changes are therefore needed for the cargo to be delivered to Umeå. It is assumed that every truck driver takes a 45 min break at the change and that the change takes 5 min to execute. The total lead time for the HCT truck was calculated to 16 h and 42 min. This would result in a lead time 20 min faster than for the combi transport. It is assumed that the transport will be delivered at approximately the same time as for the combi transport. The HCT vehicle and its cargo will be leaving Schenker’s terminal in Gothenburg at 17:00 and deliver the cargo in Umeå at 9:47.

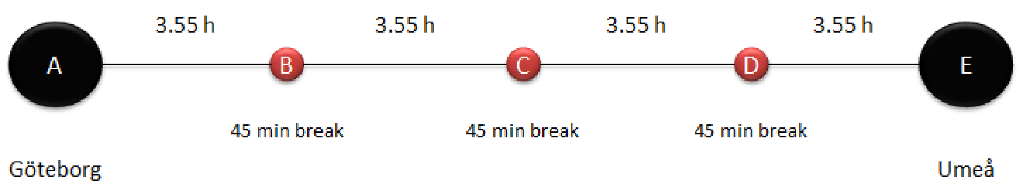

Figure 4.6: Truck changing for the HCT truck.

The lead time calculated is the ideal lead time for both transport choices and when talking to Susan Johansson at Kinnarp AB, she explained that the lead time for combi transport between Kinnarp and Umeå is much longer, due to the uncertainties on the Swedish railway. To guarantee that the cargo will be at the right place on Monday is the cargo sent on Wednesday down to Gothenburg combi terminal. This is more than two extra days, which is two extra days of production cost, the cost of load carrier parking and personnel cost.

4.2.2 Capacity

Real Rail is as mentioned the company in charge of the rail traffic analysed between Gothenburg and Umeå, the capacity is as mentioned in the introduction limited on the railway and the train between Gothenburg and Umeå is almost full according to Real Rail. HCT trucks are increasing the capacity of the road transport (higher cargo volume/weight per vehicle) and the capacity is not seen as a limiting factor as long as the truck is not driving through urban areas during rush hours. This is not the case in this study since the truck is leaving Gothenburg during the evening and arriving before noon.

4.2.3 Delivery on time

The delivery on time is, as mentioned in the theory, an important aspect for the transport buyers. The information provided by Trafikverket [48] for cargo transport between Gothenburg and Umeå are inadequate on several parameters. There are no information on how many trains which was supposed to depart, which actually departured and how many of the trains actually arrived at the final destination. For passenger trains these data is provided and it can be assumed that the passenger traffic in most cases will be prioritized over the cargo traffic, the data would, therefore, be the best possible if applied on the cargo traffic. These data also indicate the delays of the train and not the delay time for the cargo. Data for delays of cargo has been hard to find since most companies refers to company information/secret, probably because it may affect the companies image negatively. Anders Wingmalm who is manager at Green Cargos Terminal in Gothenburg says that if a train is late, the terminal can not guarantee that it will be handled when it arrives [61] . The late train will be handled when there is a time in the schedule. This is not a problem for smaller terminals which may only have one or two trains per day, but maybe a bigger problem if the terminal is bigger.

When talking to Kinnarp it was stated that there was a lot of problems with delays in their transport between Gothenburg and Umeå/Luleå. The lead time for the cargo is increased two days and there was not the same problem for the transport with road transport [62].

Also for the road it has been hard to find data. If the two transport modes are to be compared can it only be out of the knowledge provided by Kinnarp. The analysis would be that the reliability for delivery on time is higher for road transport than for rail transport.

4.2.4 Right place and right condition

There is no tracking system on the load carriers which complicates the searching if a carrier gets lost. According to Anders Wingmalm there are less than five cases per year where the load carrier is delivered to the wrong terminal. The load carrier is usually found after some hours and can thereafter be delivered to the right destination. Some terminals have a tracking system within the terminal so the transport customer/buyer can track the handling of their unit [61].

There is a greater risk for damage of gods/cargo when transporting with multimodal transport, due to the terminal handling. According to Anders Wingmalm the share of damaged load carriers is relative small in comparison to the numbers of carriers handled at the terminal in Gothenburg [61].

In order to detect the damages on the cargo, a visual inspection is done when the load carrier arrives at the terminal, when it is loaded on to the train and when it reaches the terminal at the destination. When the load carrier is retrieved at the terminal it is up to the driver to visual inspect the load carrier in order to discover if new damages have occurred during the transport [61]. For HCT trucks this will be easier to manage since only one company will be responsible for the cargo the entire way.

4.2.5 Flexibility

A possible change in the transport are the numbers of units transported and there is a limiting factor in both transport modes. The HCT truck is limited to two units and the combi transport has a low flexibility in the railway where almost all trains between Gothenburg and Umeå has a 100 % utilization. The flexibility for road transport is quite high and if the company owning the cargo also owns the trucks it will be easy to change the transport characteristic, such as volume of cargo, route etc. If a haulage contractor is involved the capacity may be higher (more trucks etc.) but another party has to be involved.

The road transport has a flexibility advantage, it can easily change the route if there is a problem, although HCT vehicles will be limited depending on road classification.

4.3 Transport logistic cost

The transport cost for both transport choice is assumed not to depend on the density and degree of filling. The volume of transported cargo is 97 m^3 for the HCT vehicle and only 76 m^3 for a 40-foot container. Table 4.10 shows both the total transport cost per unit and per volume unit [m^3] for both transport modes. The table only shows the cost and not the price of the transport, it can be assumed that the price for combi transport will be higher since more than one part will involve and have a margin on the work. More details about the cost will be described in Section 4.3.1 and 4.3.2.

Table 4.10: Transport cost logistic provider for both transport modes transporting from Gothenburg to Umeå.

Transport mode	Total cost [SEK]	Cost per m^3 [SEK]	Total distance [km]
Combi transport	3 088	41	1047
HCT transport	6 907	69	993

Both transport modes is assumed to have an investment intrestrate of 6 %.

4.3.1 Transport cost for road transport

It is assumed that the cost for HVO 100 and MK1 are approximately the same and that the truck drives 3 000 hours and 250 000 km per year. The interest rate for the truck is 6 % and the truck is assumed to be operating 45 weeks per year, the investment cost is annualised.

The road transport cost calculations are divided into investment cost, fuel cost, taxes, insurances, cost for tires, service and reparation cost and other fixed cost.

4.3.1.1 Investment cost

The investment cost for the HCT truck is 3 346 200 SEK and the costs are displayed in Table 4.11. The tire cost is calculated separately and is therefore neglected from the trucks investment cost. The lifetime of the truck is assumed to be six years and the resale value of the truck after those six years can be seen in Table 4.12. The depreciation is assumed to be affected only by the distance made by the truck.

Table 4.11: Investment cost for a HCT truck for the buyer.

Part of truck	Cost [SEK]
Distribution truck chassi	1 300 000
Dolly	230 000 [63]
Trailer	1 000 000 [64]
Chassi to trailer	900 000 [63]
Tire cost	-83 800
Total investment cost	3 346 200

Table 4.12: Resale value for parts for the HCT vehicle.

Resale value	Price [SEK]
Truck	50 000
Dolly	40 000
Trailer and chassi	200 000
Total resale value	290 000

4.3.1.2 Fuel cost

The fuel consumption for the truck is 438 ml/km for both HVO100 and MK1, assuming a transporting cargo with a density of 150 kg/m^3. The selling price for diesel in September 2017 was 12.45 SEK/l, 4.49 SEK/l was taxes and 2.49 SEK/l was VAT. As mentioned in theory and method will the VAT be excluded from the calculations so the diesel price is assumed to be 9.96 SEK/l [53] An average price for HVO from Preem was in 2017 14.09 SEK/l, including VAT[65] and 11.27 SEK/l excluding VAT. HVO is not taxed, due to it is renewable [53].
According to Lars Aspholmer, it is reasonable to assume that 5 % of AdBlue per liter of diesel is needed and the price for it is 3 SEK/liter excl. VAT. so the total fuel consumption cost is 44,28 SEK/10 km for the MK1 option. Adblue is also needed when HVO100 is used as fuel, in this cost calculation is it assumed that the HVO100 price is the same as for MK1 and the results for the two alternatives would, therefore, be the same.

4.3.1.3 Vehicle and road taxes

There are two different taxes for the truck. The tractor pays a tax of 500 SEK/year and the Dolly pays a tax of 11 450 SEK/year. The vehicle also pays a road administration tax and a supervision fee for inspection of the vehicle. The total cost for fees and taxes are 24 441 SEK per year.

Table 4.13: Taxes and fees for 2017 for the HCT vehicle [52] [66].

Type of tax	Cost [SEK/yr]
Vehicle tax	500
Road administration tax	11 991
Vehicle tax for Dolly	11 450
Super vision fee	500
Total fees and taxes	24 441

4.3.1.4 Insurances

The cost for insurances is assumed to be 50 000 SEK/year with deductible of 6 500 SEK/year, the total cost for insurances per year are therefore 56 500 SEK/year [52].

4.3.1.5 Cost of tires

The total amount of tires on the vehicle is 26. There are different types of tires and the cost for those is displayed in Table 4.14. The life time for the new and retreaded are assumed and can also be found in Table 4.14. The total cost for tires is 12.35 SEK/10 km.

Table 4.14: Estimated tire cost for the HCT vehicle, tire cost was provided by Goodyear [67].

Shaft/tire	**No of tires**	**Cost for one tire [SEK]**	**Retreaded cost [SEK]**	**Lift time new tire [10 km]**	**Lifetime re-treaded [10 km]**
Steer shaft	2	5 100	-	6 000	-
Shaft	8	5 600	2 200	9 000	9 000
Semi trailer 1	6	4 800	2 000	12 000	12 000
Dolly	4	5 400	2 200	9 000	12 000
Semi trailer 2	6	5 100	-	12 000	-

The calculated tire cost is 12.35 SEK/ 10 km for the HCT vehicle.

4.3.1.6 Service and reperation cost

The assumed service and reparation cost is 5.47 SEK/10 km which include one big service á 4 500 SEK/year, a service fee of 2 SEK/10 km and an assumed reparation cost of 82 210 SEK/year.

4.3.1.7 Other fixed costs

This parameter will cover the cost of parking, IT/mobile in the truck, service and operation cost for IT and truck washing. The total cost for the fixed cost is 27 500 SEK/year. The total cost and cost for each factor can be found in Table 4.15.

Table 4.15: Other fixed costs for a HCT truck [52].

Factor	cost [SEK/year]
Parking cost	6 000
Mobile phone / IT in the truck	6 000
Service and operational cost for IT	3 000
Car wash	12 500
Total	27 500

4.3.1.8 Salary for driver

The cargo will be transported from Gothenburg to Umeå with "spetsbyten", the logistic scheme can be seen in Appendix A.4. Four drivers will take a shift to drive the cargo and the total work hours for the delivery is 32 hours. This will be divided into two separate cargo loads, hence the driver will switch cargo and carry something in the opposite direction. So the work hours for driving the cargo from Gothenburg to Umeå will be 16 hours, of those will approximately 26 hours be between 18:00 and 06:00 in the night and will cost 49.17 SEK/h for inconvenient working hours.

4.3.1.9 Results cost calculation

With these assumptions and calculations the cost is 82.47 SEK per 10 km and is 4 834 SEK per week. The distance between Gothenburg and Umeå is 993 km and it is assumed that five transports (i.e. ten including returns) like this one would be carried out per week, so the share of the weekly cost for the truck would be 10 % for the cargo which is transported. It is also assumed that there will be no overtime for the driver.

The total transport cost for the shipping company would therefore be 13 543 SEK with a HCT vehicle from Gothenburg to Umeå. The HCT vehicle can transport two semitrailers and the cost can, therefore, be divided by two, the cost per trailer would be 6 772 SEK. As can be seen in Figure 4.7 the variable cost is be the greatest share (60 %) of the total cost for the transport. The personnel cost will account for 36 % of the total cost and the fixed cost will only account for 4 % of the total cost.

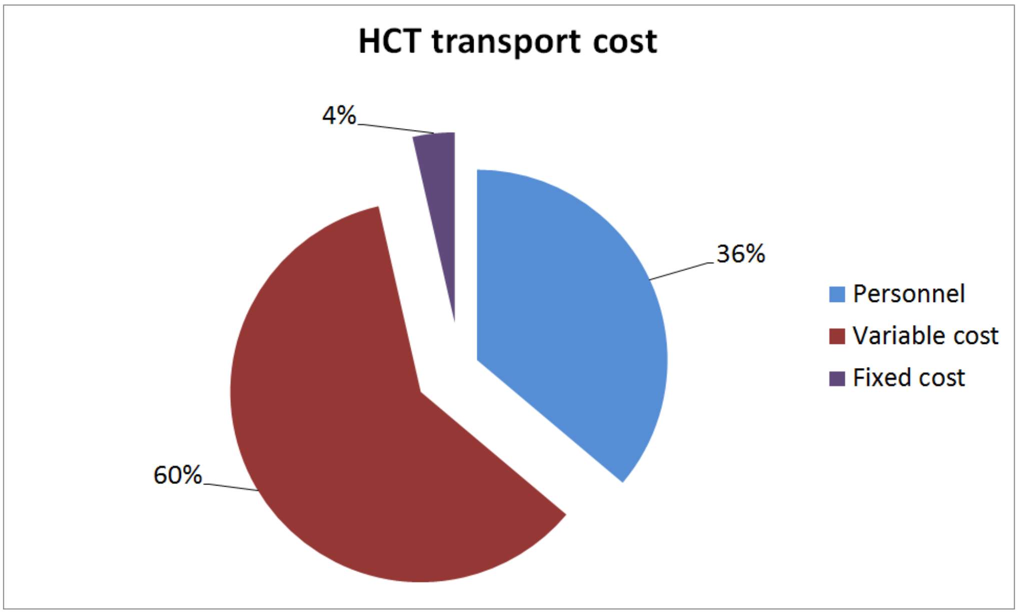

Figure 4.7: Factors that influenced the total cost for the HCT transport.

The variable cost will greatly influence the total cost, Figure 4.8 shows that 54 % of the variable cost comes from the fuel.

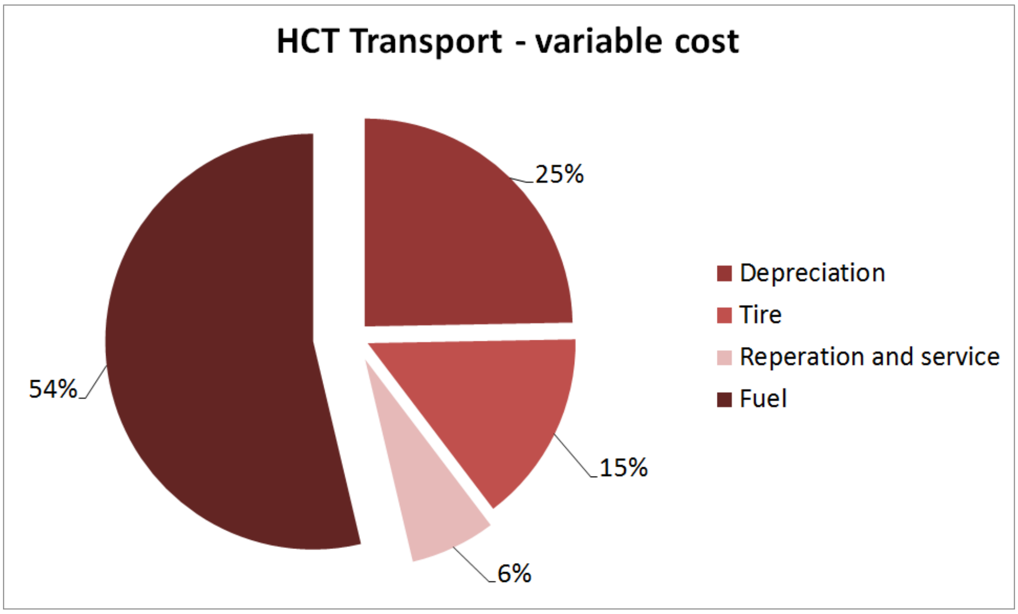

Figure 4.8: Factor which influences the variable cost.

The interest cost has the greatest share (50 %) of the fixed cost. Since the variable cost only accounts for 4 % of the total transport cost this is almost negligible in comparison to the personnel and fuel cost.

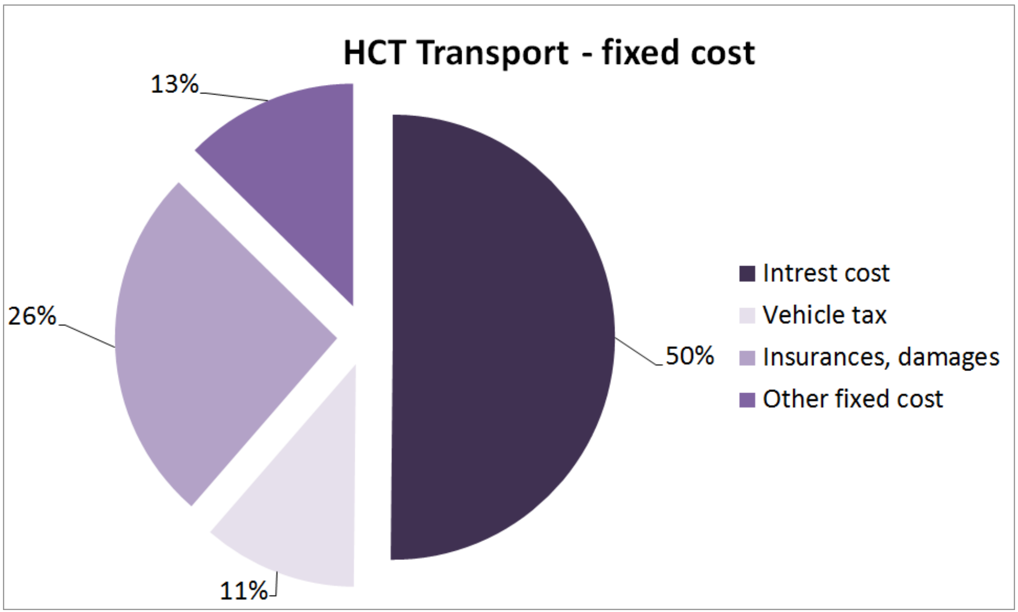

Figure 4.9: Factors which influences the fixed cost.

4.3.2 Transport cost for combi transport

The transport cost for the combi transport is divided into three different categories; cost for railway transport, road transport, and terminal handling.

It is assumed that the train will be a medium cost alternative train, the train has modern equipment and the utilization is medium [54]. Real Rail is running the train between Gothenburg and Umeå, its departures are explained in Section 4.2.1 it runs five times a week [68].

The key data and calculations for the combi transport can be found Appendix A.4. Some of the key data has been changed and some are assumed to have changed negligibly since Jonas Flodén wrote the report in 2010 [54].

To get an as realistic case as possible the calculations are based on one of the transport which took place last year. The input data is shown in Table 4.16. The loaded weight is assumed to be 31 tonnes on each carrige.

Table 4.16: Input data from Real Rail.

Number of wagons	31
Length of one wagon [m]	18.34
Engine weight [ton]	92

The total cost of transporting on the railway between Gothenburg and Umeå is 82 198 SEK (with the assumption that 70 % of the driving will occur during the night). It is also assumed that the load factor of the rail is 100 %. In Table 4.17 more detailed cost for the transport are shown.

Table 4.17: Transport cost for rail transport.

Total cost per... [SEK]	
trainkm	79.5
grosstonnekm	0.05
nettonnekm	0.08
per TEUkm	0.85

The prices for terminal handling and shunting are found in Table 4.18 and can be compared with the calculated cost for shunting and terminal handling.

Table 4.18: Price for shunting and terminal handling at Umeå terminal [69].

Service	price excl. VAT
Lift of container/trailer [SEK/lift]	250
Docking fee [SEK /train]	2950

Fuel cost for the truck delivering to and from the combi-terminals in calculated assuming the selling price for diesel in September 2017 was 12.45 SEK/l, 4.49 SEK/l was taxes and 2.49 SEK/l was VAT [53]. As mentioned in the theory will the VAT excluded from the calculations so the diesel price is assumed to be 9.96 SEK/l. The shunting engine cost for the medium and large size terminal was calculated to 1 324 and 1 345 SEK per hour.

Table 4.19: Shunting and terminal handling cost per load unit.

Terminal size	Medium	Large
Average shunting cost [SEK]	24.34	28.26
Cost per lift excl. shunting [SEK]	182	166

50 % of the units will be lifted twice. The unit will be handled in Gothenburg where it will be loaded off a truck and loaded on a train. When it arrives in Umeå it will be unloaded the train and on loaded to a truck. The assumed number of lifts will be three, since there is a different cost for the terminal in Gothenburg and in Umeå, and it is assumed that the unit will be handled twice in Gothenburg. Gothenburg is assumed to be a large terminal while Umeå is assumed to be a medium size terminal. The calculated cost of terminal handling can be seen in Table 4.19 The total cost of lifting will then become, 514 SEK per container unit.

It is assumed that four transports back and forth to the combi terminal can be made per day, this would equal 20 trips per week and a one-way trip would therefore account for 2.5 % of the total weekly cost for the truck. It is also assumed that the transport lead time is one hour per transport way. The key data and assumptions can be seen in Table 4.20. The truck driving between the terminals is assumed to be a rigid truck and most parameters are the same as for the HCT truck and are displayed in Appendix A.5. The variable cost is 65.01 SEK/10 km and the fixed cost is 3 610 SEK/week.

Table 4.20: Key road data for combi transport.

Factor	Göteborg	Umeå
Time [h]	1	1
Distance [km]	6.3	6.4

The total transport cost for combi transport and the shares for each different factors can be seen in Table 4.21.

Table 4.21: Total cost for combi transport between Gothenburg and Umeå, for one unit (40 foot container).

Factor	Cost [SEK]
Train	1 768
Shunting	53
Terminal handling	514
Road transport Gothenburg	379
Road transport Umeå	375
Total transport cost	3088

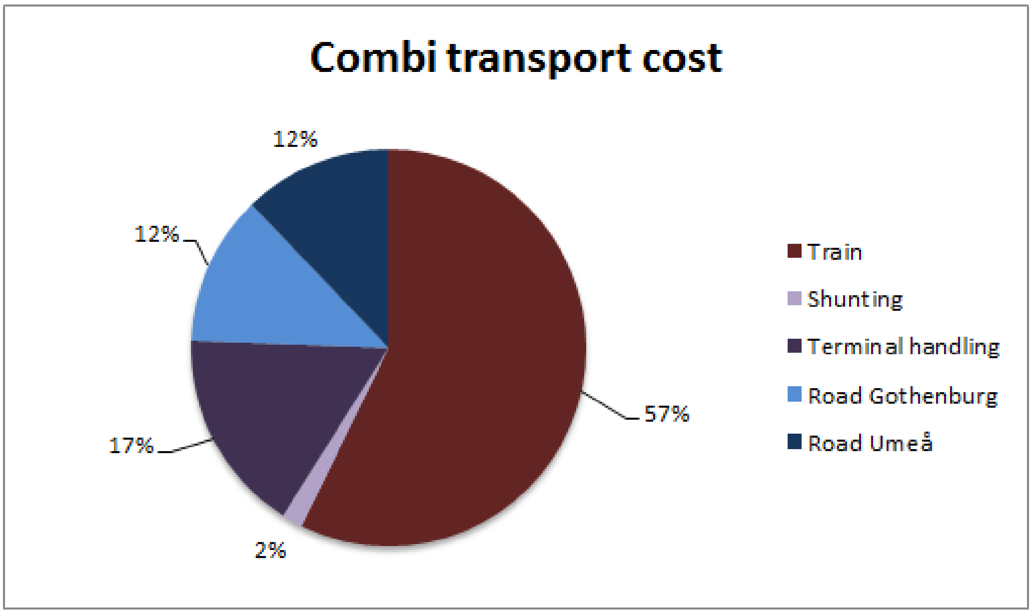

Figure 4.10: Factors which influences the total transport cost for combi transport.

Table 4.21 shows the total cost for the combitransport, according to a large logistics service provider is the price for transporting a container between Gothenburg and Umeå between 7 000 and 8 000 SEK. The cost of the train transport is more than 3 times smaller than the price to the consumer. The transport price with a train price of 7 000 SEK would be 102 SEK/m^3 or 7 754 SEK/container (excluding marginals for road combi transport and assuming shunting and terminal handling is included in the train transport price).

5

Conclusions

One conclusion is that the most cost and emission effective choice is combi transport. It should, however, be noted that this conclusion refers to the costs and not the price for the transport buyer. The emissions from combi transport with Swedish electricity is less than half of the HCT transport with HVO 100. Important to point out is that the emission for Swedish electricity used in NTM is a lot lower than what the Swedish Energy Agency is using in a report from 2017. Shunting and reach stackers contributes the most to the emissions for the combitransport with Swedish electricity.

The cost of transport is less than the half per square meter for combi transport in comparison to HCT transport. If the company wants to be in charge of their own transport chain would HCT trucks be a more cost-effective solution, since the price of combi transport between Gothenburg and Umeå is three times the calculated cost of the combi transport. Both the Swedish electricity-powered rail transport and HVO fueled truck is sensitive to tax reform since the fuels are excluded from tax today.

The ideal lead time for both transport modes are the same but the reliability of the train transport is not as high and this effects many of the transport buyers when calculating their lead time. The reliability of both transport modes has been hard to evaluate due to the difficulty of finding data. One conclusion is that the reliability of the train is low and 87 % of the trains between Gothenburg and Umeå arrives at latest 60 min after schedule. If the train is late the terminals cannot guarantee that the train will be handled directly when it arrives and the cargo has to wait until a free spot arrives, the cargo can, therefore, be late. Another aspect is the capacity and flexibility of the transport modes, the trains between Gothenburg and Umeå are usually 100 % loaded and the capacity limitations on the railway for the moment are high.

All conclusions are summarized as a share in Figure 5.1.

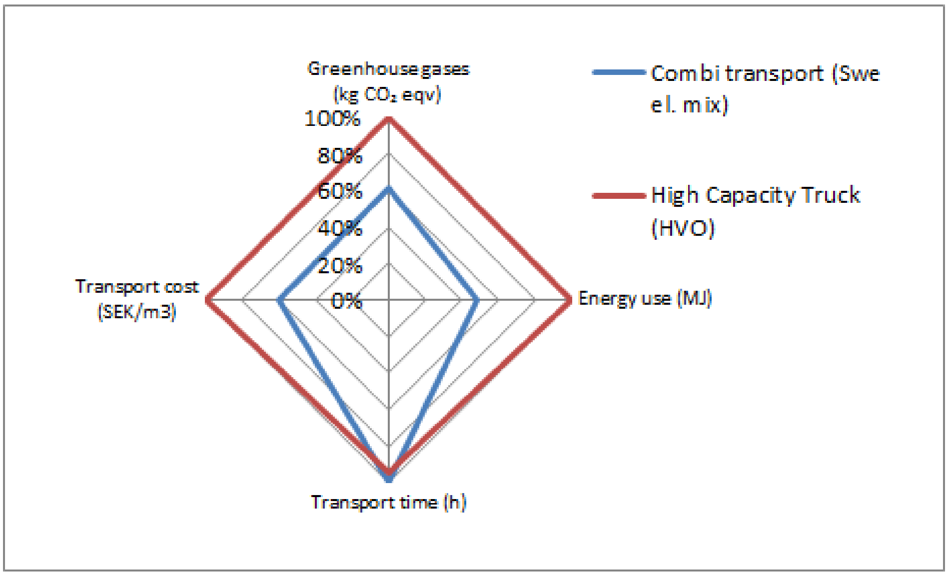

Figure 5.1: The diagram shows the share of GHG, energy use, transport time and transport cost for each transport mode.

Figure 5.2 shows the comparison between HCT transport with HVO100 as fuel and Combi transport fueled with Swedish electricity with emission according to the Swedish Energy Agency. The transport cost for HCT transport is the cost with a marginal of 5 % and the combi transport cost is with the price of train transport described in the result. The large difference between cost and price for the train depends on the scope of the cost calculations. Administration costs are not included and there might also be some extra cost due to delays which are not included.

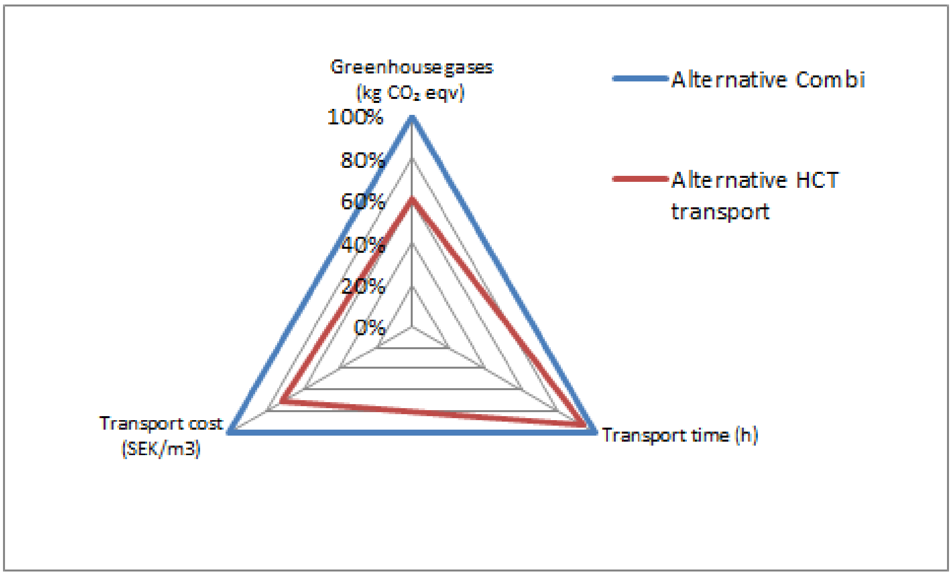

Figure 5.2: The diagram shows the share of GHG, transport time and transport cost for each transport mode with electricity's greenhouse gas emissions from Swedish Energy Agency, the price of the train transport set to 7 000 SEK and a 5 % transport cost marginal for the HCT transport.

HCT vehicles might in the future be a transport mode choice for transports which is highly dependent on the time reliability of the delivery. HCT vehicles using HVO fuel show good results on the greenhouse gas criteria. It should, however, be noted that one drawback for the HCT option is that HVO, produced in a sustainable way, will be a limited fuel alternative.

The main conclusions can be summarized as:

- The most cost-effective choice is combi transport - the price for transport buyers is uncertain since it was difficult to compare but assumptions indicate that HCT transport would be a more feasible solution when comparing the price.
- The emissions are lower from the combi transport, compared to the HCT transport run on MK1 diesel, also when assuming European electricity mix.
- The emission from HCT transport can be lower if assuming HVO100 and European electricity mix or electricity emission data from the Swedish Energy Agency.
- The transport time is ideally the same for both transport options.
- The reliability of delivering on time for the combi transport is lower than for the HCT transport.

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A
Appendix

A.1 Key data for combi transport

Table A.1: Basic parameters for railway transportation

Lable	Electric Cargo train
Vehicle type	Electric cargo train
Calculation model	Shipment transport weight
Cargo type	Average
Train type	Medium
Shipment weight [tonne]	1
Distance [km]	1034.44

Table A.2: Additional data for railway data

Topography	Hilly
Electric source	EU 27 Mix/Swedish railway mix
Cargo Load factor - weight [%]	*Depending on cargo density*
Empty positioning factor	0
Max payload: Gross Weight ratio [%]	54.6
Train weight [tonne]	Depends on the cargo load
Transmission losses	0.15
Brake regeneration	0

Table A.3: Basic parameters for road transportation

Lable	Rigid truck 20-26 t
Vehicle type	Rigid truck 20-26 t
Calculation model	Shipment transport weight
Shipment weight [tonne]	1
Distance [km]	6.26 / 6.39

Table A.4: Additional data for road transport

Fuel	Diesel B5 - SWE
Road type	Urban
Euro class	Euro 5 [1] & 6 [2]
Road gradient [%]	2
Cargo Load factor - weight [%]	*Depending on cargo density*
Cargo carrier capacity - weight [tonne]	26
Fuel consumption	*Calculated*

A.2 Result for Combitransport

	Density [kg/m3]	CO2 total [kg]	CO2 fossil [kg]	CO2 biogen [kg]	CO2e [kg]	SO2 [g]	CO [g]	HC [g]	CH4 [g]	NOx [g]	N2O [g]	PM [g]	Energy (WTW) [MJ]	Electricity[kWh] / Diesel [l]	Abba [ml/tonnekm]	ABBA [kJ/tonne km]	gCO2e emissions / km tonne
Rail transport	50	80,69	80,69	0,00	84,58	464,60	32,09	0,57	155,90	151,30	0,00	1,83	1733,00	152,80	0,00	1675,30	81,76
	69,8	61,35	61,35	0,00	64,31	353,20	24,40	0,43	118,50	115,00	0,00	1,39	1318,00	116,20	0,00	1274,12	62,17
	100	43,62	43,62	0,00	45,73	251,20	17,35	0,31	84,27	81,79	0,00	0,99	936,90	82,62	0,00	905,71	44,21
	150	30,16	30,16	0,00	31,62	173,60	12,00	0,21	58,26	56,55	0,00	0,69	647,70	57,12	0,00	626,14	30,57
	200	23,70	23,70	0,00	24,84	136,40	9,43	0,17	45,78	44,43	0,00	0,54	509,00	44,88	0,00	492,05	24,01
	220,65	21,80	21,80	0,00	22,85	125,50	8,67	0,15	42,11	40,87	0,00	0,50	468,20	41,29	0,00	452,61	22,09
Road GBG	50	1,30	1,22	0,08	1,26	0,30	0,36	0,98	0,54	1,79	0,09	0,02	18,16	0,47	75,13	2900,96	57,89
	69,8	1,00	0,94	0,06	0,97	0,23	0,27	0,76	0,41	1,31	0,06	0,02	13,99	0,36	57,89	2234,82	43,45
	100	0,73	0,68	0,05	0,70	0,17	0,19	0,55	0,30	0,86	0,05	0,01	10,13	0,26	41,92	1618,21	29,95
	150	0,51	0,48	0,03	0,50	0,12	0,12	0,39	0,21	0,51	0,03	0,01	7,18	0,19	29,71	1147,44	19,46
	200	0,41	0,39	0,03	0,40	0,09	0,09	0,31	0,17	0,36	0,02	0,01	5,77	0,15	23,87	921,73	14,67
	220,65	0,39	0,36	0,02	0,38	0,09	0,08	0,29	0,16	0,33	0,02	0,01	5,43	0,14	22,48	867,73	13,54
Road Umeå	50	1,31	1,23	0,08	1,27	0,30	2,97	0,98	0,54	7,88	0,09	0,10	18,28	0,47	74,10	2860,72	464,63
	69,8	1,01	0,95	0,06	0,98	0,23	2,28	0,76	0,42	5,88	0,07	0,07	14,09	0,37	57,12	2205,01	356,96
	100	0,73	0,68	0,05	0,70	0,17	1,64	0,55	0,30	4,00	0,05	0,05	10,18	0,26	41,25	1593,11	256,34
	150	0,52	0,48	0,03	0,50	0,12	1,15	0,39	0,21	2,54	0,03	0,04	7,23	0,19	29,28	1130,67	180,28
	200	0,42	0,40	0,03	0,41	0,10	0,92	0,31	0,17	1,92	0,02	0,03	5,89	0,15	23,87	921,75	143,68
	220,65	0,39	0,37	0,02	0,38	0,09	0,84	0,29	0,16	1,75	0,02	0,03	5,47	0,14	22,18	856,18	131,60
Loading Container	50	5,98	5,69	0,00	5,98	0,00	35,00	19,21	0,00	56,05	0,00	2,74	89,78	24,94			
	69,8	4,29	4,08	0,00	4,29	0,00	25,07	13,76	0,00	40,15	0,00	1,96	64,31	17,86			
	100	2,99	2,85	0,00	2,99	0,00	17,50	9,61	0,00	28,03	0,00	1,37	44,89	12,47			
	150	1,99	1,90	0,00	1,99	0,00	11,67	6,40	0,00	18,68	0,00	0,91	29,93	8,31			
	200	1,50	1,42	0,00	1,50	0,00	8,75	4,80	0,00	14,01	0,00	0,68	22,45	6,23			
	220,65	1,36	1,29	0,00	1,36	0,00	7,93	4,35	0,00	12,70	0,00	0,62	20,34	5,65			
Shunting	50	2,72	2,59	0,00	2,72	0,00	15,16	6,29	0,00	37,16	0,00	1,18	40,90	11,36			
	69,8	1,95	1,85	0,00	1,95	0,00	10,86	4,51	0,00	26,62	0,00	0,85	29,30	8,14			
	100	1,36	1,29	0,00	1,36	0,00	7,58	3,15	0,00	18,58	0,00	0,59	20,45	5,68			
	150	0,91	0,86	0,00	0,91	0,00	5,05	2,10	0,00	12,39	0,00	0,39	13,63	3,79			
	200	0,68	0,65	0,00	0,68	0,00	3,79	1,57	0,00	9,29	0,00	0,30	10,23	2,84			
	220,65	0,62	0,59	0,00	0,62	0,00	3,43	1,43	0,00	8,42	0,00	0,27	9,27	2,57			
Total	50	92,00	91,41	0,17	95,81	465,20	85,58	28,03	156,98	254,18	0,17	5,88	1900,13	190,05		1815,44	91,54
	69,8	69,59	69,17	0,13	72,49	353,66	62,88	20,21	119,33	188,96	0,13	4,30	1439,69	142,93		1375,53	69,26
	100	49,43	49,12	0,09	51,49	251,53	44,25	14,15	84,87	133,26	0,09	3,02	1022,55	101,30		976,98	49,19
	150	34,09	33,89	0,07	35,52	173,84	29,99	9,48	58,69	90,67	0,06	2,04	705,67	69,59		674,22	33,93
	200	26,71	26,55	0,05	27,82	136,59	22,98	7,17	46,12	70,02	0,05	1,56	553,33	54,26		528,67	26,58
	220,65	24,55	24,41	0,05	25,57	125,68	20,96	6,51	42,43	64,07	0,04	1,42	508,72	49,80		486,04	24,43

Figure A.1: Emissions transporting 1 tonne of cargo between Gothenburg and Umeå with EU electricity mix

	Density [kg/m3]	CO_2 total [kg]	CO_2 fossil [kg]	CO_2 biogen [kg]	CO_2e [kg]	SO_2 [g]	CO [g]	HC [g]	CH_4 [g]	NOx [g]	N_2O [g]	PM [g]	Energy (WTW) [MJ]	Electricity[kWh] / Diesel [l]	Abba [ml/tonne km]	ABBA [kJ/tonne km]	gCO_2e emissions / tonne km
Rail transport	50	1,32	1,28	0,04	1,29	0,38	1,33	0,02	0,09	0,64	0,01	0,15	606,70	152,80		586,75	1,25
	69,8	1,00	0,98	0,03	0,98	0,29	1,01	0,02	0,07	0,49	0,01	0,11	461,30	116,20		586,75	0,95
	100	0,71	0,69	0,02	0,70	0,21	0,72	0,01	0,05	0,35	0,01	0,08	328,00	82,62		317,21	0,67
	150	0,49	0,48	0,01	0,48	0,14	0,50	0,01	0,03	0,24	0,00	0,06	226,80	57,12		219,34	0,47
	200	0,39	0,38	0,01	0,38	0,11	0,39	0,01	0,03	0,19	0,00	0,04	178,20	44,88		172,34	0,37
	220,65	0,36	0,35	0,01	0,35	0,10	0,36	0,01	0,02	0,17	0,00	0,04	163,90	41,29		586,75	0,34
Road GBG	50	1,30	1,22	0,08	1,26	0,30	0,36	0,98	0,54	1,79	0,09	0,02	18,16	0,47	75,13	2900,96	57,89
	69,8	1,00	0,94	0,06	0,97	0,23	0,27	0,76	0,41	1,31	0,06	0,02	13,99	0,36	57,89	2234,82	43,45
	100	0,73	0,68	0,05	0,70	0,17	0,19	0,55	0,30	0,86	0,05	0,01	10,13	0,26	41,92	1618,21	29,95
	150	0,51	0,48	0,03	0,50	0,12	0,12	0,39	0,21	0,51	0,03	0,01	7,18	0,19	29,71	1147,44	19,46
	200	0,41	0,39	0,03	0,40	0,09	0,09	0,31	0,17	0,36	0,02	0,01	5,77	0,15	23,87	921,73	14,67
	220,65	0,39	0,36	0,02	0,38	0,09	0,08	0,29	0,16	0,33	0,02	0,01	5,43	0,14	22,48	867,73	13,54
Road Umeå	50	1,31	1,23	0,08	1,27	0,30	2,97	0,98	0,54	7,88	0,09	0,10	18,28	0,47	74,10	2860,72	464,63
	69,8	1,01	0,95	0,06	0,98	0,23	2,28	0,76	0,42	5,88	0,07	0,07	14,09	0,37	57,12	2205,01	356,96
	100	0,73	0,68	0,05	0,70	0,17	1,64	0,55	0,30	4,00	0,05	0,05	10,18	0,26	41,25	1593,11	256,34
	150	0,52	0,48	0,03	0,50	0,12	1,15	0,39	0,21	2,54	0,03	0,04	7,23	0,19	29,28	1130,67	180,28
	200	0,42	0,40	0,03	0,41	0,10	0,92	0,31	0,17	1,92	0,02	0,03	5,89	0,15	23,87	921,75	143,68
	220,65	0,39	0,37	0,02	0,38	0,09	0,84	0,29	0,16	1,75	0,02	0,03	5,47	0,14	22,18	856,18	131,60
Loading Container	50	5,98	5,69	0,00	5,98	0,00	35,00	19,21	0,00	56,05	0,00	2,74	89,78	24,94			
	69,8	4,29	4,08	0,00	4,29	0,00	25,07	13,76	0,00	40,15	0,00	1,96	64,31	17,86			
	100	2,99	2,85	0,00	2,99	0,00	17,50	9,61	0,00	28,03	0,00	1,37	44,89	12,47			
	150	1,99	1,90	0,00	1,99	0,00	11,67	6,40	0,00	18,68	0,00	0,91	29,93	8,31			
	200	1,50	1,42	0,00	1,50	0,00	8,75	4,80	0,00	14,01	0,00	0,68	22,45	6,23			
	220,65	1,36	1,29	0,00	1,36	0,00	7,93	4,35	0,00	12,70	0,00	0,62	20,34	5,65			
Shunting	50	2,72	2,59	0,00	2,72	0,00	15,16	6,29	0,00	37,16	0,00	1,18	40,90	11,36			
	69,8	1,95	1,85	0,00	1,95	0,00	10,86	4,51	0,00	26,62	0,00	0,85	29,30	8,14			
	100	1,36	1,29	0,00	1,36	0,00	7,58	3,15	0,00	18,58	0,00	0,59	20,45	5,68			
	150	0,91	0,86	0,00	0,91	0,00	5,05	2,10	0,00	12,39	0,00	0,39	13,63	3,79			
	200	0,68	0,65	0,00	0,68	0,00	3,79	1,57	0,00	9,29	0,00	0,30	10,23	2,84			
	220,65	0,62	0,59	0,00	0,62	0,00	3,43	1,43	0,00	8,42	0,00	0,27	9,27	2,57			
Total	50	12,632	12,009	0,202	12,515	0,981	54,819	27,488	1,163	103,522	0,186	4,192	773,825	190,045		739,335	11,957
	69,8	9,248	8,791	0,155	9,158	0,752	39,494	19,797	0,895	74,452	0,140	3,015	582,994	142,931		557,010	8,749
	100	6,519	6,196	0,112	6,453	0,540	27,623	13,854	0,647	51,814	0,098	2,107	413,653	101,297		395,216	6,165
	150	4,426	4,207	0,079	4,378	0,380	18,490	9,280	0,458	34,363	0,066	1,409	284,770	69,594		272,077	4,183
	200	3,398	3,229	0,064	3,359	0,304	13,940	7,005	0,370	25,774	0,051	1,060	222,531	54,257		212,613	3,209
	220,65	3,110	2,955	0,059	3,073	0,282	12,651	6,367	0,345	23,371	0,047	0,962	204,417	49,798		195,306	2,936

Figure A.2: Emissions transporting 1 tonne of cargo between Gothenburg and Umeå with SWE electricity

A.3 Result HCT emission

Table A.5: Key data for HCT transport calculations

Density [kg/m^3]	Load factor [%]	Fuel consumption [l/100km]	Fuel consumption [l/100 km tonne]
50	19	0	0
70	27	40.29	2.98
100	39	39.67	2.04
150	58	43.78	1.5
200	78	46.49	1.20
221	86	48.61	1.14
250	97	59.95	1.24

Cargo loadfactor [%]	Density [kg/m3]	Fuel type	Emissions per tonne and way								
			Emission [kgCO2e]	CO [g]	NMCH [g]	Nox [g]	PM [g]	PN [1]*10^12	TTW Energy [MJ]	WTW Energy [MJ]	Energy [kWh]
19%	50	HVO	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
		Diesel MK1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
27%	70	HVO	14,15	1122,78	44,91	129,12	2,81	168,42	1004,59	1095,00	279,05
		Diesel MK1	86,00	1188,44	47,54	136,67	2,97	178,27	1069,59	1165,86	297,11
39%	100	HVO	9,72	771,67	30,87	88,74	1,93	115,75	690,44	752,58	191,79
		Diesel MK1	59,10	816,79	32,67	93,93	2,04	122,52	735,11	801,27	204,20
58%	150	HVO	7,15	567,75	22,71	65,29	1,42	85,16	507,98	553,70	141,11
		Diesel MK1	43,48	600,95	24,04	69,11	1,50	90,14	540,85	589,53	150,24
78%	200	HVO	5,70	452,09	18,08	51,99	1,13	67,81	404,50	440,91	112,36
		Diesel MK1	34,63	478,53	19,14	55,03	1,20	71,78	430,68	469,44	119,63
86%	221	HVO	5,40	428,48	17,14	49,27	1,07	64,27	383,37	417,88	106,49
		Diesel MK1	32,82	453,53	18,14	52,16	1,13	68,03	408,18	444,92	113,38

Figure A.3: Emissions transporting 1 tonne of cargo between Gothenburg and Umeå with HCT vehicle

A.4 Drivers schedule for HCT vehicle

Comment	Start	Clock in/ preperations	Change cargo	Drive from A to B	Change cargo	Break	Drive back	Change cargo	Clock out	Lead time	Unpaid break	End of shift	Worked hours
Driver 1		00:04:30	00:05:00	03:33:00	00:05:00	00:45:00	03:33:00	00:05:00	00:04:30	04:23:00			
Work time	16:50:30	16:55:00	17:00:00	20:33:00	20:38:00	21:23:00	00:56:00	01:01:00	01:05:30		00:15:00	01:05:30	08:00:00

Comment	Start	Clock in/ preperations	Change cargo	Kör från C till B	Change cargo	Break	Drive back	Change cargo	Clock out	Lead time	Unpaid break	End of shift	Worked hours
Driver 2		00:04:30	00:05:00	03:33:00	00:05:00	00:45:00	03:33:00	00:05:00	00:04:30	03:38:00			
Work time	16:50:30	16:55:00	17:00:00	20:33:00	20:38:00	21:23:00	00:56:00	01:01:00	01:05:30		00:15:00	01:05:30	08:00:00

Comment	Start	Clock in/ preperations	Change cargo	Drive form C to D	Change cargo	Break	Drive back	Change cargo	Clock ut	Lead time	Unpaid break	End of shift	Worked hours
Driver 3		00:04:30	00:05:00	03:33:00	00:05:00	00:45:00	03:33:00	00:05:00	00:04:30	04:23:00			
Work time	21:13:30	21:18:00	21:23:00	00:56:00	01:01:00	01:46:00	05:19:00	05:24:00	05:28:30		00:15:00	05:28:30	08:00:00

Comment	Start	Clock in/ preperations	Change cargo	Drive from E to D	Change cargo	Break	Drive back	Change cargo	Clock out	Lead time	Unpaid break	End of shift	Worked hours
Driver 4		00:04:30	00:05:00	03:33:00	00:05:00	00:45:00	03:33:00	00:05:00	00:04:30	04:18:00			
Work time	01:36:30	01:41:00	01:46:00	05:19:00	05:24:00	06:09:00	09:42:00	09:47:00	09:51:30		00:15:00	09:51:30	08:00:00

Start	16:50:30
End	09:51:30
Lead time cargo	16:42:00
Worked hours in total	32,00
Worked hours per transported cargo	16

Change cargo	00:05:00
Clock in/ preperations	00:04:30
Drive	03:33:00
Break	00:45:00

Figure A.4: Schedule for truck drivers

A.5 Cost calculations for combitransport

A.5.1 Railway tranport

Table A.6: Key data for railway engine [54]

Purchase price [kr]	700 000
Life time [yr]	50
Tara weight [tonnes]	20
TEU per wagon	3
Running distance per year [km]	220 000
Time in traffic per year [h]	3143
Maintenance cost per km [kr]	0.15

Table A.7: Key data for wagon [54]

Purchase price [kr]	35 000 000
Life time [yr]	35
Weight [tonnes]	83
Electricity consumption [kWh/grosstonkm]	0.0212
Running distance per year [km]	220 000
Time in traffic per year [h]	3143
Maintenance cost per km [kr]	6

Table A.8: Train transport calculated result per year

Factor	Cost per km [kr]	Cost per hour [kr]
Engine (fixed cost)	10.40	727.72
Engine (variable cost)	14.04	-
Engine, total	24.24	-
Empty wagon (fixed cost)	0.19	13.45
Empty wagon (variable cost)	0.61	-
Empty wagon, total	0.81	-
Loaded wagon (fixed cost)	0	-
Loaded wagon (variable cost)	0.69	-
Loaded wagon, total	0.69	-
Personnel (salary)	-	347.60
Personnel wagon (Other cost/ train hour)	-	69.52
Personnel wagon, total	-	532.98

Table A.9: Key data for shunting machinery [54]

Size of terminal	Medium	Large
Purchase price [kr]	20 000 000	10 000 000
Life time [yr]	50	15
Utilization per year [h] 2 900	3 300	
Diesel consumptiom [l/h]	29	37
Maintenance cost per hour [kr]	130	130

Table A.10: Shunting cost, calculated result

Factor	Medium	Large
Shunting (fixed cost) [kr/hour]	416.38	345.58
Shunting (variable cost) [kr/hour]	481.67	573.30
Shunting (total cost) [kr/hour]	898.05	918.88
Personnel cost [kr/hour]	959.37	959.37
Total cost [kr/hour]	1 324.43	1 345.27

A.5.2 Road transport

- Investment cost

Table A.11: Investment cost of truck for combi transport

Part of truck	Price [kr]
Distribution truck chassi	1 300 00
Trailer	780 00
Tire cost	-32 800
Total investment cost	2 047 200

Table A.12: Resale value for parts for the combi road vehilce

Resale value	Price [kr]
Truck	50 000
Trailer and chassi	100 000
Total resale value	150 000

- Fuel cost
  The fuel consumption for the truck is 3,4 l/ 10 km, this is equal to the fuel consumption of transporting cargo with a density of 150 kg/m^3, the total fuel cost with AdBlue is 35.54 kr/ 10 km.
- Vehicle and road taxes
  The total cost for fee and taxes are 12 991 kr per year.

Table A.13: Taxes and fees for 2017 and for the combi road vehicle.

Type of tax	Cost [kr]
Vehicle tax	500
Road administration fee	11 991
Super vision fee	500
Total fees and taxes	12 991

- Insurances
  Same as for the HCT truck.
- Cost for tires
  The total cost for tires is 4.92 kr / 10 km.

Table A.14: Tire cost for the combi truck.

Shaft/tire	**Nr of tires**	**Cost for one tire [kr]**	**Retreaded cost [kr]**	**Lift time new tire [10 km]**	**Lifetime re-treaded [10 km]**
Steer shaft	2	4 300	-	6 000	-
Shaft 2	4	4 100	2 200	9 000	9 000
Shaft 3	6	3 900	2 000	12 000	12 000

- Service and reperation
  Same as for HCT truck.
- Other fixed cost
  Same as for HCT truck.
- Salary for driver
  Same salary as for HCT truck.