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LNG in the Rail Freight Industry: The case of the Nordland Line

Viktorija Ditmonaite

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The Author

Viktorija Ditmonaite
(Molde, 26th of May 2015)

Summary

The following thesis is written in collaboration with Nordland County Council and Jernbaneverket and can be taken as the input to Norwegian national transport planning process (NTP). One of the currently escalated questions by Jernbaneverket is related with the future of non-electrified railway tracks in Norway. The decision has to be made whether to leave the diesel fleet or adopt alternative fuel, which would increase the environmental performance of Norwegian railway industry. One of the main fuel options is liquefied natural gas (LNG). It is safe, environmentally friendly fuel and may offer a cost advantage compared with oil-based fuels.

The aim of the thesis research is to analyse the potential of LNG in the Norwegian rail freight industry from economic perspective, and provide the recommendations towards fuel implementation for Jernbaneverket. The selected case study is the Nordland Line connecting Bodø and Trondheim by a 729 km railway line.

SWOT analysis was made in order to explore LNG as a transportation fuel's advantages, disadvantages, opportunities and threats of being implemented in Norwegian railroading. It showed that even though there are crucial advantages about LNG (e.g. price competitiveness, environmental effectiveness, abundant resources, etc.), still a considerable number of disadvantages and risks limit the attractiveness and progress of the LNG technology. For instance, lower energy density, not existing regulatory environment supporting a switch to LNG fuels, higher upfront costs and not fully developed downstream refuelling infrastructure act as a strong brake for implementation of LNG fuel in rail transportation.

The empirical research was based on two different methodological tools: production cost analysis (from rail operator's perspective) and cost-benefit analysis (from society's perspective). PCA revealed that with current price levels in the fuel market operating costs for LNG locomotive would be slightly higher than for diesel locomotive. CBA results showed a very marginal LNG benefit over diesel fuel for society; however taking into account all disadvantages and risks of LNG fuel it is believed that the price gap of fuels should be higher in order to justify the investments.

Finally, the situation is very sensitive to the change of fuel prices. A small increase of diesel price can increase LNG attractiveness considerably. Therefore, LNG fuel should not be underestimated in the long term when engine technology will mature, refueling infrastructure will be fully developed and the price differential will become high enough to invest into new generation locomotives.

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List of Abbreviations

Abbreviation	Meaning
LNG	Liquefied Natural Gas
US	United States
CO_2	Carbon dioxide
NO_x	Nitric Oxide
SO_x	Sulphur Oxide
CO	Carbon Monoxide
PM	Particulate Matter
GHG	Greenhouse Gas Emissions (CO_2, CH_4, N_2O)
HFOs	Heavy Fuel Oils
SWOT Analysis	Analysis of strengths weaknesses opportunities threats
Btu	British Thermal Units
MMBtu	Million British Thermal Units
EIA	U.S. Energy Information Administration
BP	British Petroleum
IGU	International Gas Union
IEA	International Energy Agency
ECA	Emission Control Areas
SECA	Sulphur Emission Control Area (Europe: North Sea, English Channel, Baltic Sea)
CEDIGAZ	International Association for Natural Gas
CNG	Compressed Natural Gas
NGV	Natural Gas Vehicle
SSLNG	Small-Scale LNG
Tcf	Trillion Cubic Feet
Dry natural gas	Finished, ready for sale gas
NBP	National Balancing Point
NPV	Net Present Value
ERR	Economic Rate of Return
Jernbaneverket	Norwegian Railway Authority
Cost per unit	CPU
TEU	Twenty Foot Equivalent Unit

1.0 INTRODUCTION

1.1 General overview

There is a growing interest in using Liquefied Natural Gas (LNG) as a transportation fuel for freight rail both in academic and business society. For instance, Class 1 railroads[1] are already considering and analysing about switching from diesel to LNG fuel for railway locomotives (IRJ 2013). Also, according to Oscar Munoz (2013, quoted in Strømhaug 2014, 1), executive vice president and chief operating officer in CSX Corporation: “LNG technology has the potential to offer one of the most significant developments in railroading since the transition from steam to diesel in the 1950s. That change took many years to complete and began with a lot of unknowns, and this one is no different”.

There are mainly two reasons of this possible historic change – potential for significant cost savings and environmental effectiveness compared with diesel fuel that is commonly used to run locomotives if the mainline is not electrified. The fuel costs for Class 1 railroads is the important element influencing the final service price since they represent 23% of total operating expenses (EIA 2014a). According to EIA (2014a), the North Sea Brent spot price for crude oil was about seven times higher than Henry Hub spot price for natural gas on energy equivalent basis in 2012. Even though the oil-to-gas price ratio is forecasted to narrow in the future, still a significant gap is expected to continue (crude oil prices 3.2 times higher than natural gas price per MMBtu by 2040). Moreover, according to Garry Hart (quoted in Fuel Fix 2014), CEO of engineering and consulting company Black &Veatch, the switch of 200 locomotives to LNG fuel could cut railroad’s annual fuel costs by approximately 60-80 million dollars per year. Therefore, given that railway companies use considerable volumes of diesel fuel every year and the big price differential after the shale gas revolution in US, there is no surprise that Class 1 railroads are extensively developing the first prototypes of LNG-fuelled locomotives and their standardized tenders. It is estimated that the growth of LNG supply should reach about 35 per cent of total freight rail by 2040 in US (Chase 2014). However, the latter rate of adoption strongly depends on the LNG technology commercialization rate and the development of regulatory framework.

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[1]Class 1 railroads – major US railroads, are defined as line-haul freight railroads that account for 94% of total rail freight revenue. The companies are: BNSF, Union Pacific, Canadian National Railway, CSX Corp., and other.

From environmental point of view LNG is claimed to be the cleanest fuel compared to conventional gasoline and diesel fuelled vehicles (Kumar et al. 2011, Ou and Zhang 2013, Arteconi et al. 2010). The researchers Ou and Zhang (2013) concluded that thanks to a lower carbon content of LNG compared with petroleum, CNG- and LNG-powered vehicles emit 10-20% and 5-10% less GHGs than gasoline- and diesel-fuelled vehicles, respectively.

The current status on the use of LNG to power railway locomotives is (Strømhaug 2014):

- LNG as a fuel for railway locomotives has been tested out over some years, and is becoming more and more common in USA, Canada and Australia. Results so far have shown very positive indication regarding reduced emission and economy. New locomotives have been built, but so far most locomotives are converted from diesel to LNG (Dual fuel).
- LNG is extensively used as a transportation fuel in all forms of transport in India, and also Bolivia, Peru and other LNG producing countries in South America.
- In spite of quite long experience with LNG in ships and road transport, there seems to be no experience in Europe on use of LNG in railway operations.
- There is relatively low competence on the issue in academia and public administration in Europe.

Overall, even though there is a very little knowledge about LNG potential to power the railway locomotives, it is believed that for the main-haul freight trains on lines that are not electrified due to high cost and low traffic, LNG might be a better solution than diesel fuel (Strømhaug 2014).

1.2 Definition of LNG

According to Kumar et al. (2011), natural gas is a mixture of paraffinic hydrocarbons such as methane, ethane, propane and butane, etc.; and it can be used either as compressed natural gas (CNG), liquefied natural gas (LNG) or blended with hydrogen. LNG is the cleanest form of natural gas and contains more than 98% methane. Also, LNG is a clear, odourless, non-toxic, non-corrosive, cryogenic liquid at atmospheric pressure (Kumar et al. 2011). LNG can be get by cooling it down to -162 °C at which it becomes a liquid and easy to transport since this process reduces LNG volume by a factor of more than 600 (Kumar et al. 2011). Also, the author claims that other advantages of LNG over CNG and

LPG are related with easier transportation, storage and better density as well as higher flexibility compared to compressed natural gas.

1.3 Relevance of the topic

During InnoTrans[2] 2014 exhibition in Berlin, the commercial companies presenting exclusively the railway engine technologies (MTU, Vis Systems) stated that they are already making feasibility studies about LNG as well as intensively working on developing the first LNG-engine prototypes. However, the exhibitors mention that it might take several decades until we see the commercial production of LNG engines designed for rail locomotives.

Moreover, overviewing the existing scientific literature about LNG it was found that there is plenty of information about the general aspects of LNG; however, very little information exists about LNG as a freight locomotive fuel. Therefore, it is believed that this research would bring new insights about the potential of LNG in railroading and in this way would reduce the high existing academic knowledge gap.

Finally, there is a growing interest in Norway on this issue as well. Nordland County Council and Jernbaneverket asked for studies related to use of LNG as a fuel for the 729 km long railway line (Nordlands – banen) between Trondheim and Bodø as the input to Norwegian national transport planning process (NTP). If the research would show positive results, the next step would be to implement a project on full-scale testing on LNG locomotives in a Norwegian setting. This research is intended to reveal economic prospects of the LNG technology; therefore, it could contribute to the main project later in case of its implementation. Agreements with Nordland County Council and Jernbaneverket have been signed for collaboration regarding this Master's thesis.

1.4 The structure of the paper

The idea of research is to analyse the potential of the LNG technology to power railway locomotives in terms of financial and social benefits compared to its respective costs. Currently, LNG use in railroading is the new phenomenon with a lot of challenges and unclear outcomes; however, it is generally believed that LNG might become a new source of energy not only in the road and shipping sector but also in the rail industry.

The paper is structured as follows:

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[2]InnoTrans 2014 – International Trade Fair for Transport Technology. It focuses mainly on Railway technology.

Section two gives a reader a broader picture about natural gas and LNG importance globally and in Norway. Also, the current application of LNG in transport sector, its value chain and pricing systems are overviewed.

The research methodology for the thesis as well as research problem and research objective is determined in section three.

Section four elaborates the theoretical aspects of LNG as a fuel potential in transportation. It covers the current findings of LNG usage in road and short sea shipping as well as explores the possible challenges for implementing LNG technology in Norwegian railroading. The final outcome of the section four is the SWOT matrix of LNG as an alternative fuel option in the Norwegian rail freight industry.

Section five describes the concrete case study together with its alternative project and analyses the best methodological approach to investigate the economic advantage of LNG fuel in railroading.

In section six the technical framework for analysis is provided.

The results of empirical case study analysis are discussed and recommendations are given in the section seven.

Finally, section eight presents the conclusions of the research.

2.0 BACKGROUND: THE LNG INDUSTRY

The aim of this section is to overview the LNG industry both from global and Norwegian perspective. Also, to investigate what is the current utilization of LNG as a vehicle fuel both on the global scale and Norway. The collected background information is important since it gives a reader a broad picture about the current trends of LNG in the market and the reasons of it becoming a favourable fuel option in transportation.

2.1 Worldwide

2.1.1 Overview

Global energy demand is increasing continuously by 2.3% in 2013, an acceleration over 2012 (+1.8%) (BP 2014). The average worldwide energy demand growth for the 10 years was 2.5% annually (BP 2014) mainly due to emerging economies that require the biggest share of energy import. Oil is the world's leading fuel, constituting 32.9% of global energy consumption in 2013; however, its share is gradually declining from 1990 (BP 2014). Natural gas is, after coal, the third most important energy source making up 23,7% of global energy consumption in 2013. The trade of natural gas is also gradually increasing – in 2013 it increased by 1.8% (BP 2014).

One of the negative aspects of increasing demand of energy is CO_2 emission that countries find very hard to mitigate. According to Kumar et al. (2011), global CO_2 emissions are forecasted to grow by close to 30% from 2005 to 2030, despite improved energy efficiency and growth in nuclear and renewable energies.

As a result, more and more countries are searching for alternative fuels that would be cheap to produce and deliver, and the most importantly, with a minimal environmental impact. Natural gas is one of the main preferable option since it is widely available and renewable (if produced from bio-gas and bio-methane), emits lower amounts of GHG emissions compared with traditional fuels (Kumar et al. 2011).

Within gas markets, LNG has potential as an energy source for power plants, heating and engines as well. LNG share in global gas trade was 31.4% in 2013, over the past three years constituting about 240 MT (IGU 2014a) (figure 1). From 1990 to 2013 the trade in LNG evolved from 55 million tones per annum (mtpa) to 240 mtpa representing an annual growth rate about 7.5% (Wood 2012). The reasons behind this growth are not only related with increasing energy demands, and development of LNG production and delivery technology but, also, due to increased spot trade and greater flexibility in the terms and conditions of long-term gas contracts which are the central in LNG trade industry (LNG

Industry 2014a). However, it is difficult to forecast trade development for LNG due to volatile regional LNG market conditions, competition from other sources of natural gas, emergence of new technologies, late development and start-up of some planned projects (Wood 2012). IEA organization (2013) predicts that global LNG trade is expected to grow by 31% during the mid-term time period 2012-2018 even though in 2012-2015 LNG market has been tight due to supply shortages and low utilization rate of regasification capacity.

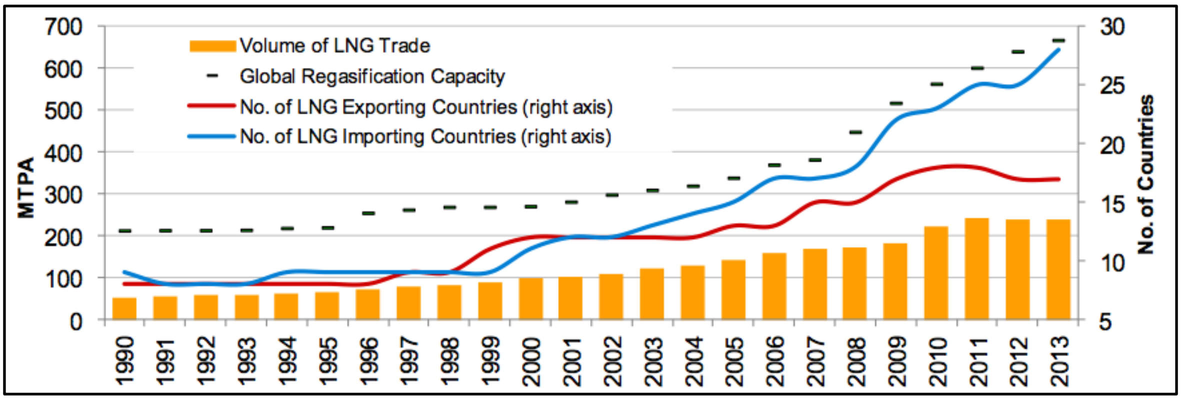

Figure 1: LNG Trade Volumes, 1990-2013 (Source: IGU 2014a, 7)

Since 2008 the number of new importing countries increased by eleven; making up in total 29 countries spread across the world. Japan is the world's largest LNG consumer followed by South Korea and China. IEA (2013) states that 70% of global LNG imports belong to Asia. This region clearly dominates in LNG trading operations.

On the LNG supply side, currently there are 17 exporting countries with the main regions such as Asia Pacific (Brunei, Indonesia, Malaysia and Australia) (30% of total supply) and Middle East (Qatar – the world's largest LNG supplier) (42% respectively) (IGU 2014a).

Even though LNG market seems a very concentrated one, it won't last a long time since the two big players are entering the game. Firstly, US is going to provide the world its low-cost and stable supplies of LNG after discovering abundant resources of shale gas. For example, in 2012 unconventional gas production reached 18% of global gas production with majority of these resources coming from North America (IEA 2013). Secondly, Australia is also planning to become a serious supplier of LNG after 2015. These processes will make the LNG market more geographically diversified and liquid, with substantially increased spot trade and market competition.

Traditionally natural gas is used in power (40% of global gas demand), industrial (24%) and commercial sectors (22%) (IEA 2013). One of the recent trends in gas market is the increasing share of demand for transportation sector. However, the use is very marginal – only 1.4% of total gas consumption in 2012 belonged to the transport sector. The consumption is expected to continue and reach 2.5% in 2018 (IEA 2013).

Overall, it can be stated that natural gas is strongly increasing its role in global energy mix due to its environmental effectiveness, competitive price and abundant worldwide resources. One of its forms – LNG – is rapidly increasing its importance as well especially in transportation. The further section describes this trend in more detail.

2.1.2 LNG in transportation

The dominant fuel in transportation is oil and oil products: in road transport – diesel and gasoline; in marine sector – fuel oil; and in rail transport – diesel (if the line is not electrified). Meanwhile the use of LNG as a transportation fuel currently is marginal; nevertheless, it is believed to have good prospects in shipping and heavy trucking, and even in rail industry in some countries. The main reason is LNG price-competitiveness over oil based fuels, especially in US where the shale gas revolution has pushed down gas prices to record lows (Cedigaz 2014). Other drivers of LNG attractiveness are (IGU 2013):

- Macroeconomics and trade. Increasing global trade stimulates the higher need for transportation, especially for shipping (90% of cargo delivered by ships). As a result, the need for green and cheap bunker fuel is vital leaving a huge opportunity for LNG.
- Sulphur Emission Regulations restricting sulphur content in fuel to 0.1% from 2015 in North America and North Europe. Here, the advantage of LNG is that it has almost no sulphur in its content and produces lower NO_X emissions compared with fuel oil and marine diesel oil.
- Government support. In Europe, the European Commission issued a new draft Directive in 2013 supporting a new infrastructure for alternative fuels (IGU 2013). LNG is highlighted as a preferable fuel for marine and heavy-duty vehicles and requires European ports to be able to provide LNG bunker services.
- Floating LNG technologies: both liquefaction and regasification (more indirect driver). These technologies substantially reduce the costs of the LNG value chain compared with building the long pipelines to the shore in certain regions (EIA 2014b).

In addition, LNG can provide energy diversification advantage in countries that are fully dependent on oil imports.

Le Fevre (2014) states that globally natural gas accounted for around 2% of road transport fuel in 2012 and BP (2014) forecasts that this share might increase to 2.3% by 2018. Together with marine sector the total gas demand should fluctuate around 2.5% by 2018 and 4% by 2035 (BP 2014). China will contribute mostly to more than a half of this additional demand (IEA 2013). However, currently there is no global statistics indicating the exact share of LNG amount used in trucking and shipping sectors; just for natural gas in general.

Analysing the growth of NGVs[3] in the global market (figure 2), it can be seen that the number of NGVs was constantly growing from 1.3 million in 2000 to 16.2 million in 2012 (IEA 2013).

However, as IEA (2013) notes that gas is still a niche market in the road transport sector, as NGVs constitute only 1.5% of the total number of vehicles. Cedigaz (2014) adds that use of LNG will be largely limited to heavy-duty vehicles (not economical for light-duty vehicles) and mainly will be driven by the difference between the price of diesel and that of LNG.

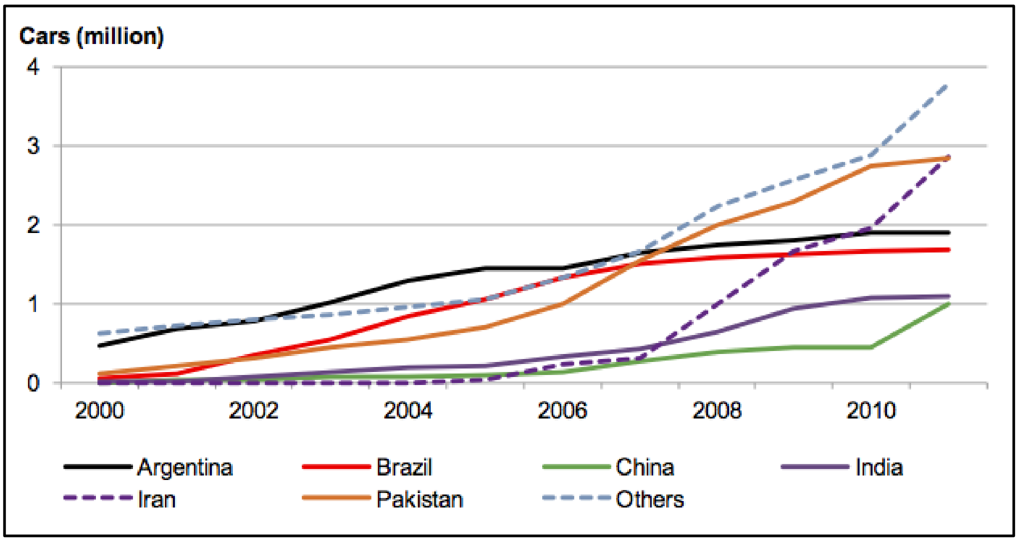

Figure 2: Evolution of the numbers of NGVs, 2000-2012 (Source: IEA 2013, 50)

Also, the above graph illustrates that the growth of NGVs was very region-specific. Pakistan, Iran, Argentina and Brazil – four countries - represented 61% of the total NGVs (9.8 million). While in Europe the share of NGVs is even smaller (just over 10% of total) and concentrated basically in two countries: Italy and Ukraine (Le Fevre 2014).

[3]Natural gas vehicles in road transport.

Speaking about marine sector and LNG, Europe is the leader in running LNG-fuelled ships (IGU 2013). LNG bunkering business is especially noticeable in Norway and to a lower degree in Sweden. Also, countries such as Netherlands, Belgium, United Kingdom and France are also showing increasing interest in developing LNG fuelling capacity in their ports. Cedigaz (2014, 1) notes that the main trigger of this process is environmental legislation: "Compliance with the new emission limits will require either: to switch to cleaner but more expensive oil-based fuels, to implement costly exhaust gas treatment technologies, or to switch to LNG. Economic analysis taking into account all relevant factors shows LNG to be a very attractive solution when compared to other compliance solutions". Since currently there are no SECAs in Asia, the incentives to switch to LNG fuelled ships are very low (IGU 2013).

Finally, LNG application in rail industry is only on locomotives' testing stage. Cedigaz (2014) claims that the potential for LNG will be restricted only to several countries with high levels of long haul freight and low level of penetration of electric powered traction in the freight sector.

To sum up, currently the use of LNG in the transport sector is minimal. However, this also indicates the big growth potential as a fuel in both road transport (heavy-duty vehicles) and shipping (due to strict environmental regulations). Regarding the rail industry, it depends on many favourable external conditions such as developed long haul freight and minimal level of electrified lines. Finally, LNG technology development faces a number of challenges in every sector such as classical chicken and egg problem or too weak government support that slow down the progress of LNG fuel adoption.

2.1.3 The LNG value chain

Natural gas can be delivered either by pipelines or in liquid form on LNG carriers. The last transportation method requires natural gas to be cooled down to -162 °C reducing its volume by a factor of more than 600 in order to transport it overseas. Also, this delivery method is both efficient and safe since there is no probability of LNG spills on water. From LNG commercial start in 1960s there were already 50,000 shipments made on LNG carriers all over the world with no case of accident (Linde Group 2014). According to U.S. Department of Energy (2005), high delivery reliability, technology improvements in liquefaction efficiency and decrease of the LNG supply chain costs – opened a new business segment in natural gas industry.

The LNG value chain is constructed of the four main stages before the delivery it to the end-user (figure 3). Each stage is briefly described (Gas in Focus 2013):

1. Exploration and production. In this stage specialists identify the potential areas of resources to start drilling operation. If the well is viable, it can go into production.
2. Liquefaction. Before the conversion from gas to liquid, the extracted natural gas is filtered and purified (from water and other substances like carbon dioxide) in order to avoid damaging liquefying equipment. During liquefaction the natural gas is cooled to -162°C in the heat exchangers to produce LNG. Later it is kept in insulated tanks until it is ready to be loading on LNG carriers. Liquefaction costs are the major cost component in the whole supply chain. Today, Qatar is the largest liquefaction capacity holder (27% of the global total (IGU 2014)). The worldwide liquefaction capacity is expected to grow by 36% 2013-2018 period to reach 397 mtpa (in 2013 - 290 mtpa) (IGU 2014).
3. Shipping. At the end of 2012, 378 LNG tankers were operating in maritime sector with the coming new ones – 78 LNG tankers till 2016 (IEA 2013). The average transportation distance is expected to increase when the U.S. will start exporting LNG to Asia (IEA 2013).
4. Storage & Regasification. The received LNG is unloaded into cryogenic storage tanks until regasification process. It is done under high pressures in order to return LNG into its gaseous form. In the final delivery step, the gas is transported by pipelines to customers for providing energy for heating houses, powering plants and other uses. Today, liquefaction plants and regasification terminals both can provide LNG bunkering facilities as well as ability to load LNG into specially designed trucks, rail cars for further transportation till the end point. According to IGU (2014), the global regasification capacity is expanding (currently: 688 mtpa in 2013) every year. Japan is the largest holder of import terminals, followed by US.

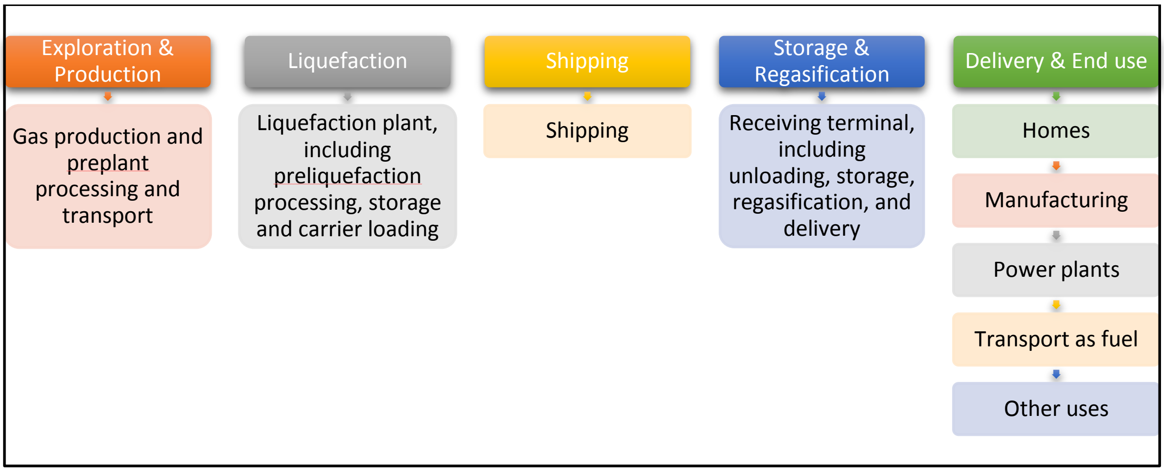

Figure 3: LNG Value Chain (Source: author adapted by U.S. Department of Energy 2005, 8)

In the LNG transportation chain context, it is necessary to distinguish the small-scale LNG (SSLNG) business. Recently the SSLNG value chain is expanding all over the world covering the small-scale liquefaction and regasification facilities as plants with a capacity under 1 mtpa (IGU 2014). SSLNG is principally the same as before described conventional LNG value chain with one difference – the amounts of LNG transported are much smaller compared with the usual chain. There are two basic categories of SSLNG – wholesale and retail.

Retail LNG is the small-scale consumption of LNG in end-user applications, such as power generation or transport activities (IGU 2014a). This kind of chains is usually oriented to end-user needs. With the growing role of LNG as a vehicle fuel, the liquefaction plants in SSLNG value chains are getting increasing attention primarily in China and US. According to IGU (2014a), Norway has both liquefaction and regasification terminals. The need for SSLNG in Norway is mainly driven by a lack of pipe gas infrastructure in areas with difficult terrain; and due to government support (NO_x funds) for LNG investments in shipping.

To sum up, each stage in LNG transportation chain requires capital-intensive projects, time and a lot of investments into infrastructure. Therefore, investors must be sure about positive ROI of the particular project. As a result, long-term contracts where the risk is allocated among the participants (sellers and buyers) in the supply chain are dominant in LNG markets. Such contracts reduce the flexibility of the market but at the same time it helps for it to move on. In fact, growing capacity of liquefaction and regasification terminals as well as increasing order book of LNG carriers in the world demonstrates the positive market expectations towards liberalizing LNG industry.

2.1.4 LNG measurement and pricing systems

Natural gas is sold by energy content and not per unit of volume and globally is expressed and measured in British Thermal Units (Btu) (Baumgart and Olsen 2010). Btu measures the heat energy, which is released when a unit volume of gas is burned (Baumgart and Olsen 2010).

Regarding LNG, the standard method of measurement is, also, based on the form of energy transferred e.g. from production facilities into LNG carrier (Helminski 2014).

As previously was mentioned, the gas markets are not liquid (shortage of supplies) and are largely based on the long-term contracts in which the agreed amounts of natural gas are sold for fixed prices. However, rapidly increasing supplies of natural gas and relatively low prices compared with crude oil might strongly influence the growing liberalization of the gas market (an increasing share of short term contracts). As a result, the changing LNG industry will require new business models and commercial arrangements to be executed in order successfully compete with traditional fuels (Norton Rose Fulbright 2014).

There are mainly two types of natural gas pricing systems in the international markets: oil-indexed pricing and gas-on-gas based pricing (EIA 2014b). Under the first pricing system, natural gas prices are linked with oil market spot prices which change in response to oil supply and demand (EIA 2014b). Under gas-on-gas pricing framework, the price of natural gas is indexed to competitively determined gas market spot prices, which change in response to natural gas supply and demand (EIA 2014b).

United States use gas-on-gas based pricing (Henry-Hub system) while in Europe the dominant is oil-indexed pricing. However, as EIA (2014b) notes the gas-on-gas system is expanding in Europe as well: from 6% of trades in 2005 to 33% of trades in 2010. The main reference system for spot price in Europe is Heren Index (British National Balancing Point, NBP). In the Asia-Pacific region, the dominant pricing system is oil-indexation (Japan/Korea Spot (JKS)).

The price for natural gas can differ very much depending on a region: from low prices due to present oversupply in US market, to a fluctuating market in Europe and higher prices in the Asian markets due to a scarcer supply of LNG (Norton Rose Fulbright 2014).

A more detail attention to current and future natural gas prices is provided in literature review part.

2.2 Norway

2.2.1 Overview

Norway is the biggest producer of crude oil in Europe, the world's 3rd largest natural gas exporter after Russia and Qatar and an important supplier of both oil and natural gas in European market (EIA 2014c). Also, Norway has the largest proven natural gas reserves in Europe (74 Tcf in 2014) (EIA 2014c).

The country exports almost all natural gas it produces per year. For instance, in 2013 Norway produced 3.97 Tcf of dry natural gas while exported 3.8 Tcf (96% of total production) to European markets (United Kingdom, Germany, France, the Netherlands and other countries) mainly through pipelines and a small share via LNG tankers (figure 4) (EIA 2014c).

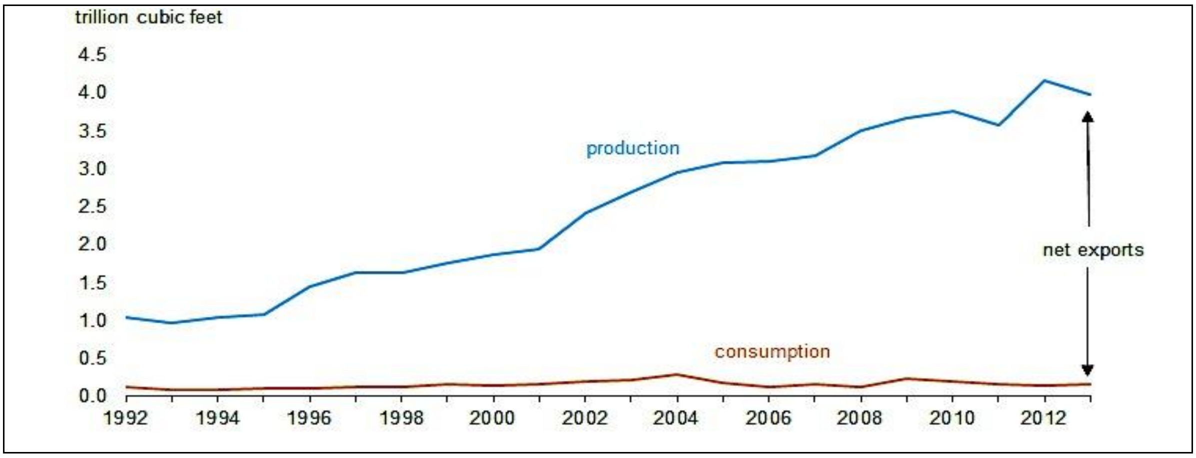

Figure 4: Norway dry natural gas production and consumption, 1992-2013 (Source: EIA 2014c)

According to Norwegian Statistics Database (2014), 73% of total domestic use of natural gas belonged to petroleum and natural gas production industries, primarily offshore, while only 9% (or 506 million Sm3) of natural gas was used for net domestic consumption (fishing and agriculture, household, services, and manufacturing sectors) in 2013. Even though, the importance of natural gas as a fuel alternative has increased in Norway, still the total share of net domestic consumption of natural gas as a motor fuel constituted only 25% (121 million Sm3 – mainly water transport in LNG form) in 2013 based on the estimates of Norwegian Statistics Database (2014). Having in mind that Norway has the biggest natural gas reserves in Europe, the domestic use of natural gas for transportation is very low.

Regarding LNG production, Norway started producing and exporting it in 2007 when the commercial production of Snøhvit gas field was opened. Norway possess the Melkøya facility (close to Hammerfest), the first-large scale LNG export terminal in Europe, which is connected by pipeline with the Snøhvit gas field (EIA 2014c).

Within Norwegian natural gas markets the LNG production is very limited – the share of total gas production was only 4.0% in 2013 and practically all produced LNG was exported (4.0%) to European and Eurasian markets (Norwegian Petroleum Directorate 2014) leaving a small share for the domestic fuelling of manufacturing and water transport sectors. From another point of view, this indicates that Norway has a big potential in developing LNG industry inside the country and, especially, exploiting the possibility to use its own produced LNG in the transport sector.

2.2.2 LNG in transportation

As previously mentioned, Norway is the pioneer and current leader in using LNG to power ships (e.g. ferries, offshore vessels). Meantime road and rail transport are still waiting for their turn to be assessed whether it is worth investing into LNG-technology or not.

Today Norway owns 42 fully operating LNG vessels. Globally plus 39 ships are confirmed to be brought into the market by 2017 where around 20 are Norwegian owned (Graugaard 2013). In general, the Norwegian experience in using LNG fuel for ships is successful: significantly reduced emissions and bunker price. Therefore, no wonder that with additional government support (through NO_X fund) LNG demand in Norwegian shipping market has increased.

Regarding the road sector, a situation is different. Currently there are no LNG fuelling stations for trucks, and only CNG is used for some vehicles like public busses in Trondheim, Bergen, Oslo and Haugesund. Also, Norway's government is supporting much more hybrid and electric passenger vehicles than natural gas fuelled automobiles. In heavy-duty trucks' market use of natural gas, especially LNG is at the stage zero. According to Velazquez (2014), suppliers of heavy duty-trucks such as Trucknor and Scania stated that they are not too much interested in LNG technology because of the lack of motivation from customers' side, non-existent supply infrastructure and higher focus on CNG and biogas but not on LNG.

Finally, the future of LNG in the Norwegian rail sector is also not clear. Most of the lines are already electrified, and regarding the possibility switching from diesel to LNG on non-electrified lines requires a deep research assessing the economic and social benefits of the project in order to move into testing stage of LNG-locomotives.

Overall, even though the natural gas in LNG or CNG form currently is used in very limited amounts in Norwegian transport market, still the expectations of GasNor to increase the competitiveness on natural gas (as well as LNG) are optimistic. Velazquez (2014) states that it is expected that the Norwegian government will follow the proposed EU directive, Clean Power for Transport, seeking to promote use of alternative fuels and decrease the dependency of oil in transport sector. If Norway signs the directive, the government will be obliged to provide the infrastructure that can supply ships and heavy-duty trucks with LNG and/or CNG along the main traffic corridors in country. GasNor[4] (quoted in Velazquez 2014, 33) is especially promoting use of natural gas due to these reasons:

- Cost competitive fuel which can lower operation costs;
- Clean burning fuel which can lower maintenance costs;
- Proven and reliable LNG-technology and availability improvement;
- Natural gas meets present and future environmental regulations.

Therefore, it can be stated, that even though the development of LNG as a fuel in the Norwegian transportation is just in the beginning stage, the idea itself has already received a lot of interest from country's government and related companies from transport sector (e.g. Jernbaneverket). Given the positive results of carried studies about LNG fuel economy and a big support from government and transport sector's companies willing to invest into new generation transport vehicles, it can be expected that the development of the LNG industry would accelerate much faster making Norway the European leader in using LNG in transportation. This would strengthen the country's reputation in the international markets even more as well as would give further push for other European countries to develop LNG infrastructure in their countries by purchasing fuel, equipment and expertise from Norway.

To sum up the background about both natural gas and LNG importance in global energy mix, it can be stated that the value of these energy sources is expected to grow in the close future both worldwide and in Norway. In terms of LNG application as a vehicle fuel, the use is very marginal since still a lot of constraints exist slowing down the development of the LNG industry in the global transport market (e.g. lack of supplying infrastructure, governmental regulations and support). Currently, LNG has been successfully tried in road and shipping sectors. LNG application in road sector is the most extended in Asia, while LNG in shipping sector is the most developed in Norway. Regarding the rail sector, LNG

[4]GasNor – it is Norway's leading downstream natural gas company, with an extensive pipeline network, some CNG distribution and LNG distribution from three separate production plants

is expected to increase the share in the global fuel mix as well; however with a very minimal impact on the worldwide energy structure. Also, LNG is expected to be much more competitive in the road and shipping sector compared with the rail sector due to various reasons. For instance, its development must satisfy a lot of criteria with the main one: a big distance and not electrified long-haul railway lines in the region. According to Cedigaz (2014) this condition was found just in several countries (e.g. USA, India).

3.0 RESEARCH FRAMEWORK

3.1 Research problem

The research area of the thesis is LNG as a freight locomotive fuel in Norway. Currently most of the railway lines are electrified; however, there still exist several lines in which trains are run by diesel. In such lines LNG is considered as a potential alternative to diesel that might be successfully implemented as it was done in Norwegian shipping sector. The main drawback is that there is little knowledge about the LNG technology in the rail sector (no profound studies have been carried out) both in scientific literature or business sector; therefore, the process is just in the idea stage leading to a lot of unknown factors about this technology.

Currently, some companies (e.g. MTU, Vis Systems) can already come with the technical solutions for dual fuel engines for new generation locomotives; however, it is not enough to speed the LNG implementation process. It can be assumed that the expected problem in the market is that freight companies would invest into new locomotives only with two conditions: (1) the stable LNG supply has to be assured meaning both enough supplies of LNG and the existing infrastructure; (2) a regulatory environment supporting a switch to LNG fuels has to be built. In turn, another company would invest more into LNG supply infrastructure only if it would be sure that freight companies would purchase LNG-fuelled locomotives. The most critical issue for both sides is favourable LNG price compared with diesel as it strongly influences the project's repayment ratio. In addition, the government's commitment in establishing supportive regulatory environment and incentives programs is necessary in order to make the project work both from legal and economical perspective. EU financial support is also vital since the total investments into refuelling infrastructure and locomotives might be upfront and huge.

As a result, every player (rail operator and fuel distributor) in the game contains a high risk about their return on investments as well as a high level of uncertainty about a lot of issues surrounding the LNG technology (its economy, environmental performance, technology aspects, and etc.). However, this information failure existing in the current Norwegian rail market could be minimized by implementing the *right* governmental policy that would incentivize market to move toward more environmentally friendly transport fuel if the research would show positive results. The current situation regarding the LNG technology is depicted in the appendix 1.

Overall, the research problem of the thesis can be formulated in the following way:

1. There is a low competence about LNG technology in the rail industry both in academic and business society.
2. There is no clear indication about the economic advantage of using LNG for rail transport compared to diesel.

Subsequently, the research problem reveals the main aim of the research:

1. To investigate the economic advantage of using LNG as a fuel to power the railway locomotives.
2. To provide recommendations for Norwegian Railway Authority and Nordland County Council regarding the feasibility of switching to LNG-fuelled locomotives on the Nordland Line based on the findings of scientific literature and empirical analysis.

To fulfil the purpose of research the following research questions can be formulated:

RQ1. Why is LNG considered as a possible fuel alternative in the rail transportation industry?

RQ1.1. What are the LNG advantages and disadvantages over other forms of fuel used in transportation based on existing LNG use practises?

RQ1.2. What are the main incentives to switch to LNG in the Norwegian rail freight industry?

RQ1.3. What are the possible drawbacks of using LNG in Norwegian rail freight?

Answering the above questions would help to clarify the LNG potential and the main obstacles of being implemented in Norwegian railroading. Also, a big attention would be delivered to economical and environmental efficiency of using LNG in all transport segments.

The next logical step would be to evaluate LNG from a financial point of view in a Norwegian rail setting. To explore this, the following research questions could be formulated:

RQ2. Are there any financial advantages related to the use of LNG fuel compared with diesel fuel in Norwegian rail freight?

RQ2.1. What is the logistics scenario of supplying LNG to freight trains on the Nordland Line?

RQ2.2. What is the difference between transportation cost per unit using diesel or LNG fuel?

To include impacts on society, monetized environmental impacts of the two fuel alternatives should be evaluated. This is done through the next set of research questions:

RQ3. Could a switch towards LNG as a fuel on non-electrified railways in Norway be justified:

RQ3.1. Which are the relevant environmental impacts of diesel and LNG locomotives?

RQ3.2. What is the difference in Net Present Values of diesel and LNG propulsion on the Nordland Line?

It is important to notice that the answers given will be preliminary ones, since it is impossible to assess the values precisely in future market price. Therefore, a sensitivity analysis will be performed in order to analyse the different possible scenarios for implementing LNG in trains.

RQ4. What are the final recommendations for Jernbaneverket and Nordland County Council regarding the feasibility of switching to LNG-powered locomotives on the Nordland Line?

Recommendations will be based on a synthesis of findings in the scientific literature and results of an empirical analysis.

Finally, the unit of analysis in research is LNG as a fuel for freight rail transport in Norway.

3.2 Research Methodology

3.2.1 Case study as a research method

The defined research aim and questions naturally direct to the research design option. According to Yin (2014): "In the most elementary sense, the design is the logical sequence that connects the empirical data to a study's initial research questions and, ultimately, to its conclusions". In this thesis the logic connecting research questions with collected empirical evidence is a single case study method. The reasons for choosing this method are explained below.

According to Yin (2014) the case study as a research method is the most suitable under these conditions: (1) when the main research questions are "how" and "why"; (2) a researcher has little or no control over behavioural events; (3) the focus of study is contemporary phenomenon; (4) the boundaries between phenomenon and context are not strongly distinct. According to Ellram (1996, 98): "In exploratory research, the issue could be how or why is something being done? A case study methodology would be desirable in those circumstances because it provides depth and insight into a little known phenomenon." LNG in the rail freight industry is the new and complex phenomenon not only in Norway but also in the global rail industry with no clear outcomes. Also, this phenomenon could not be analysed without the context that helps significantly understand the little known issue. Therefore, a single case study method is selected with the main purpose to investigate the economic advantage of the LNG technology and provide recommendations for Norwegian Railway Authority and Nordland County Council.

Another important issue is to emphasize what kind of data is used: qualitative or quantitative. According to Cooper and Schindler (2008, quoted in Beermann 2014, 6), the quantitative research method is the most suitable for testing the theories, trying to find out what and how often the research object is occurring. The statistical data is usually used in this type of analysis. In contrast, qualitative research is based not on quantitative data but on qualitative (scientists' research, experts' opinions, surveys, direct monitoring, etc.) information. Here, the researcher seeks to understand the situation, the motives, the relationships or social interactions of the analysed object (Ellram 1996). According to Cooper and Schindler (2008, quoted in Beermann 2014, 6), qualitative research allows for an in-depth understanding of a situation and based on the findings to guide for the right recommendations. The research performed in this thesis could be regarded more as a qualitative than quantitative research as it explores LNG intervention into rail freight industry in Norway not only describing the context, possible opportunities and threats but also aims to give the recommendations for the company. However, in order to better understand the situation about the LNG technology in railroading the numerical data is used as well. This tactic should strengthen the quality of recommendations as the issue is observed from different perspectives (findings in scientific literature/reports) and empirical calculations about the economy of LNG.

Finally, it is necessary to mention two things: (1) the role of the theory (section 4) is to support or contrast the findings resulted from empirical part but not to help in generalizing from case study to theory; (2) the *analytic generalization*[5] is not performed in the research since all empirical findings from such a case study have limited validity within the case study only.

The case study itself is described in section five as well as its best chosen technique for empirical data analysis and the criteria helping to decide about the potential of LNG as a freight locomotive fuel in Norway. Also, it is important to overview these issues before

[5]Analytic generalization – concept offered by Yin (2014) when case study findings can be generalized in other situations leading to the theory building from concrete case.

starting the research: structure of the analysis, data collection and validity and reliability of data, in the following sub-sections.

3.2.2 Research process

The analytic research starts with identifying the research area and research problem that needs to be solved. When this is done together with defining research aim, questions, unit of analysis, and research methodology – the plan must be set. It shows the researcher's step-by-step structure of analysis that guides him from the research problem to the final part – recommendations. The research process of the thesis is demonstrated in the following figure:

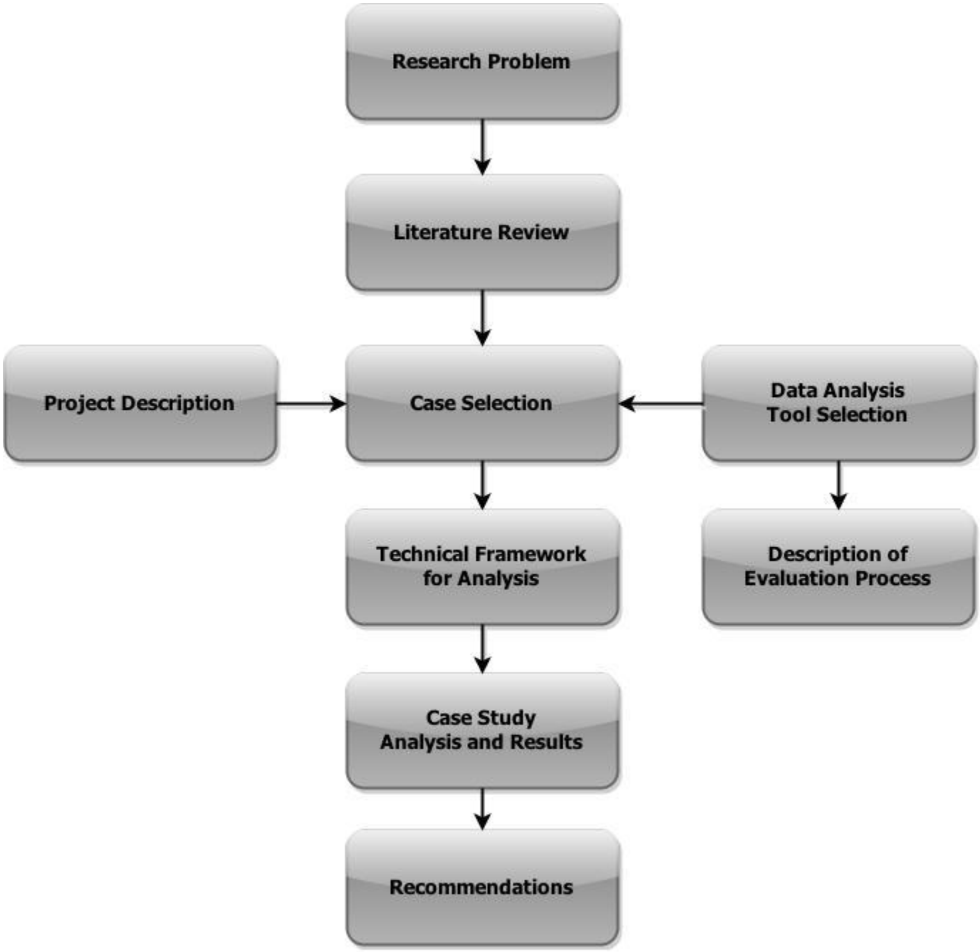

Figure 5: Structure of research (Source: own display)

According to Eisenhardt and Graebner (2007), sound empirical research starts with strong grounding in related literature. Yin (2012) claims that a case study that starts with building relevant theory makes it easier to be implemented, especially if the researcher has little knowledge in the research field. In the thesis, the theoretical ground addresses the first research question (*Why is LNG considered as a possible fuel alternative in the rail transportation industry?)* with intention to understand this phenomenon by analysing the current existing knowledge in academic and business society. Further, the case study is described and the most appropriate empirical research method is chosen. After conducting the case study analysis, the results are presented and discussed. Finally, revising the findings in literature review together with the results of empirical analysis, recommendations are derived for Jernbaneverket and Nordland County Council regarding the LNG technology in Norwegian railroading.

3.2.3 Data collection

Data collection is the vital step for the research determining its quality and information richness on the issue. In the thesis, both type – primary and secondary – data sources are used.

Secondary data sources are used to build the theoretical basis for LNG as an alternative fuel in transport segment. The sources include:

- Scientific literature (databases such as Science Direct and Proquest);
- Reports issued by US and European public organizations;
- Reports issued by private research consultancy (e.g. Energy Aspects Ltd).
- Specialised Rail Journals.
- Other web-pages.

Primary data is necessary for conducting empirical analysis to estimate the LNG potential in railroading. The author received preliminary operating cost structure for diesel locomotives from Jernbaneverket. Hubert, CEO of VIS Systems, gave the possible price for LNG locomotives and fuel tenders in European market. In case of lacking data about LNG locomotives the assumptions as close as possible to reality were made.

3.2.4 Validity and reliability

According to Yin (2012), the case study research should not be based only on one data source since it would be difficult to rely on the case's study findings. The best tactic is to use multiple data sources in order to ensure data validity and reliability. It is called *triangulation* tactic (Yin 2012). In this research several independent data sources are used such as qualitative data: findings in scientific literature and related reports, and direct numerical data from the company. Also, in order to make assumptions about the LNG technology in railroading as close as possible to reality, the consulting with VIS Systems expert is done. The mentioned sources of data should help to ensure the reliability and validity of research.

4.0 LITERATURE REVIEW: LNG AS A FUEL ALTERNATIVE

LNG as an alternative fuel compared with traditional fuels is a new research topic among scientists. There are a number of studies regarding LNG transportation, distribution and storing issues as well as general overview about LNG trade statistics; however, there is little research done on comparing LNG with other fuel options, especially in rail sector, emphasizing its advantages and disadvantages.

LNG fuel can be analysed from different angles. It can be breakdown by perspective such as environmental (Arteconi and Polonara 2013), safety (Siu et al. 1998), physical (Kumar et. al. 2011) or other aspect depending on the purpose of the article; or, the analysis can be done in the concrete transport sector: road, shipping or rail, comparing with other fuel alternatives. Also, several researchers (Kumar et al. 2011; Le Fevre 2014) compare either LNG vs. CNG (if natural gas is decided to be used to fuel the transport vehicle), or natural gas vs. other type of fuel, since there is no such thing as LNG- or CNG- engine; the difference between them is related with the way the fuel is stored and supplied to the engine. At the end, both fuels are changed back to gaseous form in order to power the vehicle (Westport 2013).

In this research LNG as a fuel option is analysed from different perspectives (safety, environmental, and etc.) in some cases discussing the findings in both road and marine transport sectors. Finally, several findings about LNG usage in rail sector as well as related challenges are overviewed followed by summarization in the SWOT matrix in the Norwegian rail freight industry.

4.1 Physical aspects

According to EIA (2013), factors such as energy density, cost, weight and size of on-board energy storing are important when deciding which fuel to choose. Fuels that need large, heavy and expensive storage can reduce the space available to convey people and freight, weigh down a vehicle or make it too costly to operate, even after taking account of cheaper fuels (EIA 2013). The graph below shows that in comparison with diesel and gasoline, other fuel choices may have higher energy content per unit weight, but none have more energy per unit volume (EIA 2013).

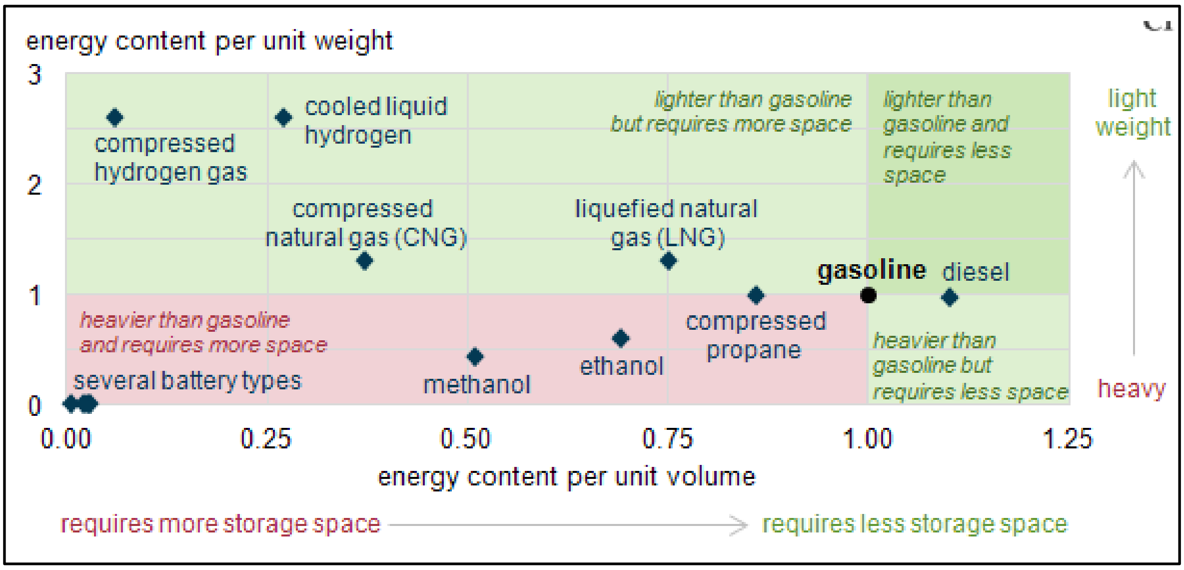

Figure 6: Energy density comparison of several transportation fuels (indexed to gasoline = 1) (Source: EIA 2013)

Natural gas, either CNG or LNG, is lighter than gasoline or diesel but have lower energy content (diesel ≈128,700 Btu/gallon; LNG 75,000 Btu/gallon) leading to the need to have a bigger and heavier storage tank in vehicle in order to go the same distance. Le Fevre (2014) confirms this stating that one litre of diesel fuel has the same energy as 1.7 litres of LNG. Overall, LNG- and CNG- both add weight and space requirements compared to oil-based fuels; however, in general they are considered as much cleaner energy sources than their counterparts (see: environmental aspects).

When comparing CNG and LNG, the matter is more about the type of vehicle analysed, but not the fuel itself since both have their advantages and disadvantages. The main advantage of LNG over CNG is much lower space requirement (LNG is 600 times less than the same amount of natural gas while CNG is only 1% less of its original volume (Kumar et al. 2011)). This gives LNG a cost advantage in transporting it in big volumes and large distances compared with CNG. Another strength of LNG is higher energy density over CNG (435 Kg/m^3 compared with 175 Kg/m^3) meaning that for a given capacity fuel tank, an LNG-fuelled vehicle can travel up to 2.4 times the distance of CNG counterpart, or in other words, LNG-fuelled vehicle needs 2.4 time smaller fuel tank capacity than CNG- vehicle for a given vehicle range (Kumar et al. 2011). Blomerus (2013) states that the LNG refilling speed is the same as diesel fuel since LNG is a fluid that can be pumped with a high fuel flow rate. However, as J.B. Hunt Transport Company (2014) notices, LNG is more expensive than CNG due to the cost to convert and transport the natural gas in a liquid form.

Finally, Westport (2013) states that CNG is a good option for medium duty applications < 300 miles per fill; whereas, LNG is the most suitable for heavy-haul transport with long driving range requirements, especially for the fleet vehicles that are in constant operation and need to be refilled quickly.

4.2 Safety aspects

The first priority in the LNG industry is safety and security in all fuel delivery stages. According to Foss (2012), LNG has been safely handled for many years without any major incidents in the industry. This is related with both fuel characteristics and a high consideration about security and planning in the LNG industry.

Firstly, LNG is a nontoxic, odourless, noncorrosive and no carcinogenic fuel (Kumar et al.2011). It is not stored under pressure and is not explosive. According to Consumer Energy Centre, LNG vapour will only explode in an enclosed space within the flammable range of 5-15%. The Centre also confirms that LNG is not flammable since in the contact with air LNG vaporizes leaving no footprint on the environment. Moreover, there are various safety regulations and procedures under each delivery stage of LNG: for LNG carriers import and export terminals, and final delivery and use for customers' transport vehicles.

According to Siu et al. (1998) report made on qualitative risk assessment for LNG refuelling station, LNG fuel is safer than propane or gasoline; however, its use still contains some risk. LNG is a cryogenic fuel, so there is the risk associated with skin or eye burns on contact. However, during the interviews with refuelling/maintenance facilities, none of them have experienced a major LNG accident. All of them have established special training and procedures for safe practices in order to avoid the accidents. Overall, LNG can be regarded as a much safer fuel compared with other alternatives as long as its production/delivery and use is held under strict standards of safety.

4.3 Commercial aspects

Currently LNG usage for transport is marginal with relatively low developed infrastructure, especially in downstream LNG supply chain (from regasification terminal up to final-end users) in many countries, including Norway. This implies that even though Norway has abundant natural gas resources and LNG production facility, LNG supply and distribution is poorly developed making LNG less attractive than diesel from commercial point of view. According to Johnson (2013), diesel technology is proven technology: durable, safe, with higher fuel economy per diesel gallon equivalent (DGE) than natural gas. Also, there already exists a nationwide diesel fuelling infrastructure and commercial practise. Finally, ultra low sulphur diesel burning engines currently are replacing older diesel engine technology with extended operating range between refuelling (Johnson 2013). However, as author Johnson (2013) mentions in some countries LNG technology might be more preferable choice for heavy trucking than diesel; however, it strongly depends on the development rate of LNG refuelling infrastructure. And the latter factor is significantly influenced by the final demand in the market.

Overall, the diesel technology is more commercially attractive than the LNG technology in terms of existing infrastructure, supply and contracting practise in the market, established regulations and introduced more environmentally friendly diesel engines; therefore, diesel should not be underestimated when considering LNG as a fuel choice.

4.4 Environmental aspects

One of the main advantages of LNG is the environmental effectiveness compared with traditional oil-based fuels. This is important advantage because transport sector represents the biggest share on the global balance of GHG emissions (Arteconi and Polonara 2013). For instance, in EU-27 the GHG emissions due to transport sector constituted around 20% of total emissions in 2009 (Arteconi and Polonara 2013).

In European policies one of the possible measures to reduce the environmental footprint of transport operations is to substitute conventional fuel with cleaner alternative fuels such as natural gas (The European Union's Green Paper 2001, quoted in Arteconi and Polonara 2013). The latter energy source is emphasized due to its availability to use at a competitive price, using technologies already existing in the global market. Yeh (2007) also adds the diversification advantage of natural gas that is highly important for countries dependent on oil imports (China, Japan, South Korea). Finally, Cheenkachorn et al. (2013) see the advantage of LNG in reduction of GHG emissions and its renewability through the biomass production processes.

There is a lot of research done on LNG as a fuel environmental effectiveness in both sectors – road and marine even though LNG has been used a relatively short period of time. In such researches, the environmental impact of LNG is analysed either in the final fuel consumption stage (regarded as *tailpipe* emissions) or taking into account all emissions produced from the beginning – feedstock recovery and transport – till final fuel use by transport vehicle. The latter estimation is done by life cycle analysis that aims to assess potential impacts of a product over its full life cycle (Yan and Crookes 2009).

In this section LNG life cycle emissions (as well as tailpipe emissions) are overviewed in comparison with other competitive fuels in both road and marine sector.

4.4.1 Road transport

According to US Alternative Fuels Data Centre, natural gas is a low-carbon, clean burning fuel allowing a significant reduction of hydrocarbon, carbon monoxide, oxides of nitrogen, and greenhouse gas emissions.

Argonne National Laboratory's based on the GREET model evaluated the life cycle petroleum use and GHG emissions of light duty-vehicles running on CNG and LNG. The result showed natural gas emits 6% to 11% lower levels of GHGs than gasoline throughout the fuel life cycle (quoted in US Alternative Fuels Data Centre). In comparison LNG and CNG, GHG emissions were nearly identical; however, LNG had slightly higher records since the fuel in general requires more petroleum to process than CNG.

Arteconi et al. (2010) studied the GHG emissions throughout the life cycle of the fuels – diesel and LNG – used for heavy-duty vehicles in the European contingent. They focused on two LNG supply scenarios: purchasing it directly from the regasification terminal (LNG-TER) or producing LNG locally with small scale-plants (LNG-SSL). Authors distinguished three main stages over the fuels life cycle in which the GHGs contribution is the biggest:

- Production. It includes fuel extraction, transportation and processing in refinery (diesel) or liquefying in the terminal (LNG);
- Distribution, which includes all processes needed to handle this fuel from the departure from production facility till the consumption by vehicle;
- Combustion stage.

The results are shown in table 1 where the fuel performance is expressed in terms of per-kilometre emissions.

Table 1: Life-cycle emissions, in total and by category of the cycles analysed

	Production	Distribution	Combustion	Diesel pilot	Total emission
	kg CO_2-eq/km_{truck}	kg CO_2-eq/km_{truck}	kg CO_2-eq/km_{truck}	kg CO_2-eq/km_{truck}	kg CO_2-eq/km_{truck}
DIESEL	0.2003	0.0208	1.6353	-	**1.8563**
LNG-TER	0.1600	0.0879	1.4013	0.0150	**1.6642**
LNG-SSL	0.3887	0.0006	1.4013	0.0150	**1.8055**

Source: Arteconi et al. 2010a, p. 2011.

The highest amount of GHGs was produced in the combustion phase for all scenarios. In comparison LNG and diesel, the LNG-TER scenario was superior offering a 10% reduction in GHGs compared with other cases, whereas the emissions resulting from the LNG-SSL scenario were similar to diesel option (Arteconi et al. 2010). The reason is related with lower efficiency of small-scale liquefaction plant that added a higher portion of GHGs compared with diesel. However, as authors mention, improving the liquefaction processes the results of LNG could be much greater and reasonably different compared with current situation.

In another study done by Arteconi and Polonara (2013), authors underlined the positive and negative aspects related to LNG as a motor fuel. Firstly, they identified the biggest bottleneck in the LNG value chain (in road transport) – lack of refuelling infrastructure to enable proper LNG supply and distribution flow at least in Italy. Also, the lack of national regulations and standards in the field stays as a real threat for possible investors willing to invest into LNG-technology. From another side, in authors' opinion, LNG is an environmentally friendly fuel with the highest potential for heavy-duty vehicles due to reduced on-board weight and space requirements. Finally, researchers claim that the most critical part for the introduction of a new fuel is its economy (price difference between LNG and diesel/gasoline) together with developed infrastructure but not environmental aspects. However, this might be true in Italy's road transport but not necessarily in countries that suffer from high levels of pollution in cities (smog problems) such as China, Pakistan or Brazil. Those countries seek to implement LNG for trucks due to both price competitiveness and environmental effectiveness.

The researchers Ou and Zhang (2013) also evaluated life cycle GHG emissions for natural gas based on alternative vehicle fuels in China. The emissions were calculated based on Tsinghua life cycle analysis model – specially designed instrument to analyse vehicle fuels in China. In this study the GHG emissions were expressed on an energy basis (as the mass of emissions per unit of energy – g/MJ). They found that due to a lower carbon content CNG- and LNG-fuelled vehicles emit 10-20% and 5-10% less GHGs than gasoline- and diesel-fuelled vehicles, respectively. Moreover, GHGs' results strongly depended on LNG supply route. It was found that the highest amount of emitted GHG emissions belonged to the scenario where LNG was liquefied locally.

Another profound research on life-cycle emissions of greenhouse gases was done by Beer et al. (2002). They analysed Australian heavy-duty vehicles using alternative fuels such as CNG, LPG, LNG, Ethanol, Biodiesel, Low Sulphur Diesel (LSD) and ultra-low sulphur diesel (ULS). The researchers claim that renewable fuels, biodiesel and ethanol have the lowest *exbodied* GHG emissions (in g/km) while LNG appears to have the highest life-cycle greenhouse gas emissions of all the fuels that were considered. This is because of extra energy required to liquefy and cool LNG. The similar finding was formulated in the report produced by California Air Resources Board (2008, quoted in Arteconi et al. 2010) where the GHGs derived from natural gas versus diesel vehicles were examined in the Californian setting. The study underlined that any reduction of GHGs based on natural gas fuels depends on the way and the processes that the gas undergoes during its life cycle, and the vehicle used itself (light- or heavy-duty vehicle). Only in the scenario where LNG was shipped to California and used directly in its liquid state offered a minimal advantage in terms of GHGs compared with diesel whereas the scenarios with double liquefaction processes had no advantage at all.

Summarizing various findings among researchers, it can be stated that the significant variability of the results of LNG environmental effectiveness exist. The reasons can be various: difference in available data, assumptions, LNG procurement scenarios and etc. Therefore, it is difficult directly to compare the studies. However, in general it can be said that life cycle GHGs strongly depend on its supply scenario (LNG produced locally has higher emissions than LNG shipped and consumed at the place). Also, life cycle GHGs produced by LNG can be lower about 5-10% compared with diesel however not in all cases.

4.4.2 Marine transport

LNG environmental effectiveness was recognized and supported much strongly by academic and business representatives in marine segment than in road sector. Researchers (Acciaro 2014, Burel et al. 2013, Adamchak 2013), private companies (e.g. Det Norske Veritas, Baltic Transport Journal) and European Commission agree that today LNG is the answer to the strict environmental regulations imposed by International Maritime Organization (IMO) at least in the medium term. Ship owners operating in ECA territories have to comply with 0.1% SO_X emission control from 1 January 2015. In addition, the stricter control will be put also on NO_X emissions – the ship builders have to reduce them to 80% by 2016 (this is valid only for Tier III engine standards in ECA zones) (Burel et al. 2013). In 2020, the sulphur will have to be reduced up to 0.5% globally making LNG attractive not only within ECA territories but worldwide as well. According to Semolinos et al. (2013), European Commission has issued a new draft Directive in which LNG is regarded as a preferred fuel for marine and heavy-duty transport and requires all European seaports to be able to provide LNG bunker services. Clearly, the stringent environmental regulations are the main reason of faster LNG penetration in marine market at least within ECA zones compared with other transport sectors.

In order to comply with new ECA regulations there are three main options: to switch to higher-quality fuels, low in sulphur content (referred to as distillates); to use exhaust gas cleaning systems (maritime scrubbers), or to choose LNG (Acciaro 2014). There is much research done on the consideration about each alternative finally coming up with the most favourable option – LNG alternative. Authors (Burel et al. 2013; Acciaro 2014) agree that LNG can offer substantial reduction in NO_X (by 80%-85%), SO_X (100%), PM (100%) and CO_2 (20%-30%) emissions from ships and even decrease the operational costs by 35% compared with conventional fuel (HFOs). According to Baltic Transport Journal (2011), LNG is the most environmentally friendly type of fuel in terms of all main air pollutants (figure 7).

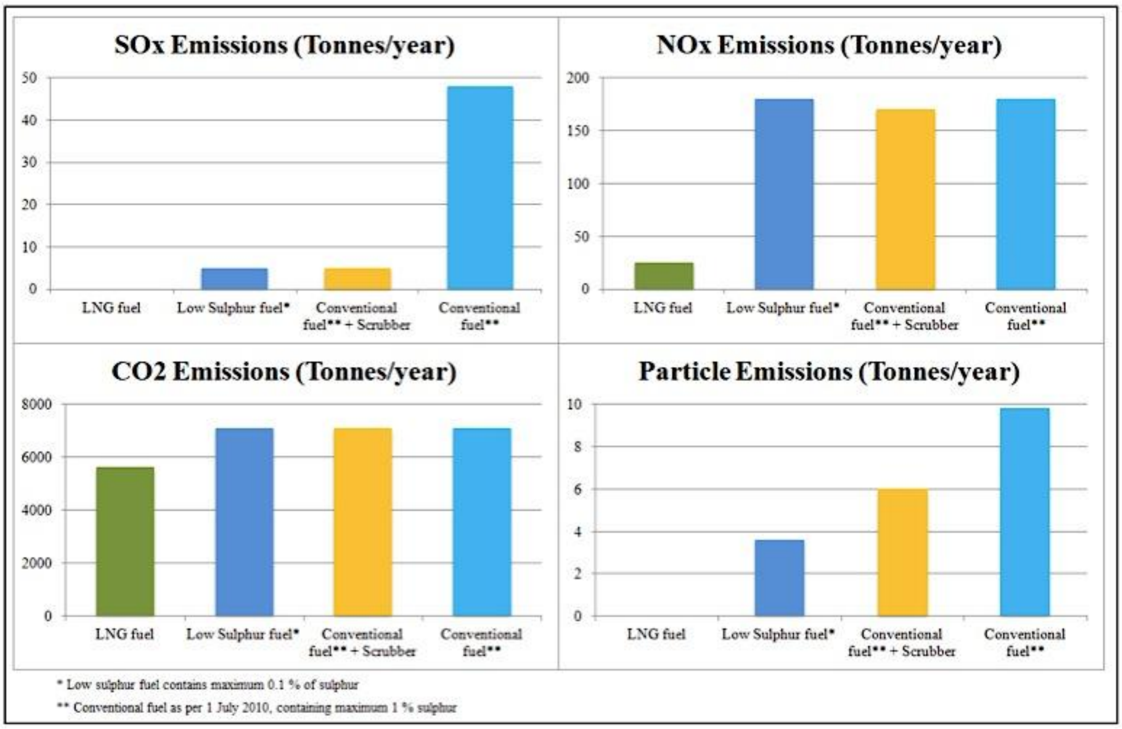

Figure 7: Emission for alternative marine fuel concepts (Source: Baltic Transport Journal 2011, quoted in Beermann 2014, 45)

In terms of LNG life-cycle emissions, the realistic estimations are in the range of 10% lower than diesel fuel chains (Acciaro 2014). However, it is important to notice that in marine sector the business is concerned mostly about the tailpipe emissions (the last consumption stage) rather than life cycle emissions in order to comply with environmental regulations imposed by IMO. Also, apart from meeting these standards, ship-owners value that LNG does not require any cleaning equipment of emissions; therefore, it represents a cheap alternative to distillates (Acciaro 2014). Also, Clean North Sea Shipping organization (2013) adds that the use of LNG results in reliable and quieter engine operations, and lower operating costs.

However, Acciaro (2014) notices that a lot challenges about LNG exist: high upfront costs, a high degree of uncertainty on the differential between the prices of LNG and conventional maritime fuels, availability of LNG and the reliability of its supply chain (sufficient number of bunkering facilities in European ports). Therefore, LNG-fuelled vessels are still the new phenomenon in marine sector. Currently there are 42 fully operating LNG-fuelled ships with 39 in order book. Norway is the pioneer and current leader in launching this type of vessels due to strong government support through NO_X tax fund, strict environmental standards and abundant gas resources. Graugaard (2013) predicts the demand of LNG reaching up to 4-7 million tons for 1000 ships by 2020; this would correspond to 0.2% – 0.3% of global LNG production of 2010. Even though it seems as a small share, it signals the realistic beginning of new-generation vessels where the first movers (Norway) in the marine market will benefit the most.

To sum up the environmental perspective about LNG in marine sector, Baltic Transport Journal (2011) correctly states that LNG is the best choice among other alternatives due to its excellent environmental compliance imposed by IMO. However, still a lot of challenges need to be overcome in order to accelerate the usage of LNG-fuelled vessels.

4.5 Cost aspects

There is no secret that LNG vehicles (truck, locomotive or new generation ship) cost more than the traditional ones. However, the whole LNG “magic” is mainly put on the LNG price competitiveness compared with the relative traditional oil-based fuels. This advantage in business representatives’ opinion should offset the higher upfront costs and lower LNG energy content than that of diesel. Since LNG has been already tried on trucks or ships, it is worth to overview the experience from financial perspective.

4.5.1 Road transport

According to Enerdata Analysts (2014), in 2013 the LNG truck was around 30-40% more expensive than a diesel powered truck. In the presented case by Enerdata (2014), the comparison between the fuels cost per km for an LNG-fuelled truck versus a diesel-powered truck is done. The results are shown in table 2.

Table 2: Fuel cost per km for LNG and diesel vehicles

Fuel type	Consumption per km	Fuel cost	Fuel cost per km
LNG	0.46 m^3/km	RMB 4.5/m^3	2.07 RMB/km
Diesel	0.39 l/km	RMB 7.6/l	3.00 RMB/km

Source: Enerdata Center 2014

According to their calculations, LNG truck is 1 RMB/km ($ 0.16/km) cheaper to operate than a diesel truck. Taking into account the higher upfront costs, the payback period will depend on the average distance travelled per year. Or in other words, the more you travel, the faster invested money comes back to the pocket. Regarding the price changes, Enerdata Analysts claim, that the fuel cost differential is reduced to 28% (from current level 31%) if half of the price increase (0.4 RMB/km) is passed to the end user. If the entire fuel cost rise is passed, then the difference in fuel cost per km is minimized to 25%. Even though the payback period would lengthen in the latter case, still Enerdata Analysts believe that it is economical to switch from diesel to LNG trucks.

According to Argonne National Laboratory (2013), after examination of 18 LNG trucks in 15 months period, came to the firm conclusion – LNG fuel enables a significant reduction of cost and harmful emissions. LNG trucks achieved similar fuel economy on an energy equivalent basis during the study period; therefore, on average LNG fuel costs were around $ 0.36 per mile compared with conventional truck $ 0.69 per mile (around 48% lower). With such cost estimates, the payback period is less than three years.

4.5.2 Marine transport

The researchers Burel et al. (2013) analysed the economic upturn of LNG-fuelled vessels. The results show the 15-20% higher upfront costs, 35% lower operating costs, 25% lower CO_2 emission and the payback period for an LNG system installation about three years. With LNG price increase scenario to HFOs price levels, the payback period would extend to five years; while additional increase of the LNG price to 120% of HFO price would rise the payback time to eight years.

According to Zeus Intelligence (2013) economic analysis of LNG vessel costs in North America, the total savings for four types of vessels: tug, ferry, cargo vessel and offshore supply vessel (OSV), during 10 years period are different. The positive payback period is seen for ferries (+$ 0.27 million) and new build OSV (+$ 10.3 million), meaning the companies should achieve enough future cash flows to offset high initial investment costs. In contrast, the project payback after 10 years for tugs and cargo vessels is negative (-$ 0.28 million and -$ 3.4 million respectively). It is because the tugs require less fuel, and cargo vessels – due to difficulties to repay high enough initial investment costs (+$ 24 million) over 10-years period.

Finally, Germanischer Lloyd (GL) (2013) adds that the benefits of LNG strongly depend not only on the price differential, investment costs but also on its usage. The higher the ECA exposure, the shorter the payback period for different types of cargo vessels.

To sum up various aspects about LNG as a vehicle fuel versus diesel fuel, it can be stated that LNG is a safe and clean burning-fuel and may offer significant fuel cost savings at least in US with the lowest LNG prices in the world. Its recourses are substantial (in US, Canada, Australia, Middle East and Norway) and it has already been successfully tried in road and shipping markets. However, LNG has lower energy density than diesel (weight and space penalties) and its upfront costs are higher compared with conventional oil-fuelled vehicles. Also, in many countries the downstream supply infrastructure as well as distribution network is poorly developed. In addition, no common industry standards (e.g. for LNG equipment, safe handling) exist.

4.6 Rail sector

LNG is getting a high attention from transport companies, investors, and government not only in road and marine sectors but also in rail industry. The major debates about LNG locomotives are taking up in the United States since there the economic and environmental effects after the change could be huge. In 2012, Class 1 railroads consumed around 3.7 billion gallons of diesel that constituted 23% of total operating expenses (EIA 2014a). Having strong environmental consciousness and opportunity to save on the fuel costs in terms of much lower LNG price than diesel, no surprise that Class 1 railroads currently are developing new generation natural gas locomotives.

The main reasons to switch from diesel to LNG locomotives are:

1. Environmental incentives. Canadian Railway Inc. after testing LNG-fuelled locomotives confirmed the emission reduction of NO_X by 70% and CO_2 by 30% compared with the diesel-fuelled locomotives on 482 km distance. NO_X is especially dangerous air pollutant since it is the major source of smog and acid rain. CO_2 significantly contributes to GHGs emissions formation (global warming). Therefore, taking into account previous findings about LNG tailpipe emissions (does not contain SO_X and PM), it can be stated that LNG is cleaner fuel compared with diesel as long as the methane leakage is controlled.

2. <u>Fuel cost savings.</u> Several companies such as Canadian Railway, General Electric, EIA (2014a), IRJ (2013) claim that the biggest advantage of fuel conversion is the potential fuel cost savings. They believe that around $ 200.000/year/locomotive could be saved with natural gas-fuelled locomotive compared with diesel counterpart.

However, even though the above-mentioned incentives are strong enough to start the pilot projects on testing LNG-powered trains, the commercial production can take decades since it requires to overcome three complicated challenges in addition to favourable LNG price differential: engine and fuel tender technology solutions, refuelling infrastructure and a supportive regulatory framework. This leads to the fundamental question of LNG technology defined by Chase (2014): "Whether, and to what extent the railroads can take advantage of this relatively cheap and abundant fuel?".

The same incentives and challenges regarding LNG as a fuel alternative exist in the Norwegian railway industry. Jernbaneverket claims that the only benefit for them of the fuel change would be reduced air pollution, or, in other words, better railway environmental performance. The motivation for railway operators is the potential fuel cost savings and, optimistically, increased operational efficiency compared with diesel-powered locomotives. However, in Norway as in the rest of the world there is no experience of using natural gas fuelled locomotives as well as no profound studies examining the potential of LNG in the Norwegian setting.

In order better understand the issue, it is necessary to overview the possible challenges that could arise with the implementation of LNG technology in the Norwegian railway sector. Regarding the potential benefits, the empirical evidence about the change of operating costs with LNG fuel is provided in the analytical part of thesis.

The considerations about the following obstacles are presented in the next sub-sections:

1. Technology;
2. Infrastructure;
3. Long-term LNG price;
4. Regulations;

4.6.1 LNG Technology

4.6.1.1 Engine

MTU Systems, a production company of engines, confirms that technology solutions of dual-fuel engine are already invented; however, they, probably, would not be cheap since the first engine prototypes are just under the testing stage in the market. According to Hubert, CEO of VIS Systems: “None of European manufacturers has dual-fuel engine approved for our market. In addition, the engines might be available no earlier than 2017/2018 but at much lower power”. Therefore, it can be stated, that dual fuel engine technology is not matured in the rail industry and it has to go still a long way to be commercialised in European market. This acts as a big disadvantage for faster LNG technology adoption in Norway as well.

Regarding the benefits of dual fuel engine, it is very important that they would provide the same performance, reliability and efficiency as the diesel engines to secure the high locomotive utilization. According to Lenz (2014), Caterpillar and Westport Innovations jointly solved this problem by offering the high-pressure direct injection (HPDI) dual fuel technology in US. Before this innovation, the existing engine solutions in the market such as spark ignited or dynamic gas blending (that could take up to 0-60% LNG) were not too much preferable due to lower energy efficiency compared with diesel engine. The following benefits were identified of using HPDI engines (Lenz 2014):

- Substantially lower fuel costs with up to 95% substitution of diesel by natural gas;
- Maintains the same power, transient response and efficiency as diesel engines;
- Engine controls work like a diesel engine;
- Capable of meeting stringent emissions limits with less emission technology; and
- Well suited for heavy-haul and other high-fuel usage applications.

Very important is that this engine removes the risk of sudden delivery stop of LNG -> in such case the locomotive can easily switch to 100% diesel fuel. However, as it was mentioned before, the approval of HPDI dual fuel engine technology will take at least several years to be ready for commercial production in the rail market.

4.6.1.2 Fuel tenders

Figure 8: LNG-powered locomotive and its fuelling option (fuel tender – left side; cryogenic unit placed on locomotive – right side) (Source: Schneider 2014; Lenz 2014)

In general, LNG fuel tank is around 3/4 smaller than typical diesel tank placed in locomotive due to bigger thickness to keep cryogenic fuel. This space penalty substantially reduces the maximum distance that can be done with LNG compared with diesel. For instance, using LNG the operator could go only 58.8% the distance of diesel; therefore, additional refuelling stops would be necessary.

In the United States, where rail distances are around 2500 km from West to East, fuel tender with sufficient tank size to provide long-distance service is very important solution to the refuelling problem. According to Schultz (1992), LNG-tender is double walled and super vacuum-insulated unit that can carry more than 20,000 gallons of the cryogenic fuel – that is enough for two locomotives to complete a 1,600-mile trip. Also, the tank is designed to keep LNG cold for at least 14 days. The regasification of LNG is occurring on the tender (with the help of heat exchangers) flowing through the special hoses to the locomotive for injection into the engine (Schultz 1992). Finally, it is aimed to have easily removable ISO fuel tanks (e.g. 20ft’ or 40ft’ in length) to make the fuelling process simple and fast just by replacing empty tanks with tanks filled at an off-site location and transported by truck (Schneider 2014).

Currently, the major US railway companies (Canadian Railway, BNSF) are developing standardized LNG tenders for locomotives paying a lot of attention to safety issues. In order to control the methane leakage, special methane detectors are installed which would give the signals to control system about shutting off the gas supply in case of accident. Finally, Schultz (1992) claims that natural gas has higher ignition temperature than petroleum products; therefore, a fire (or explosion) is less likely.

In figure 8b) there is shown an innovative TEM19 LNG-powered shunting locomotive that was developed two years ago by Russian Research Institute. Even though this type of locomotive is not suitable for the case (only main-line locomotives are analysed), still it represents another idea to keep the fuelling operation going during the trip. The standard 20ft' ISO LNG tank can be placed on the locomotive (no extra wagon is necessary) which would substantially simplify the locomotive's maintenance and repairs. It is convenient when the distances are not long -> the 20ft' fuel tank would be sufficient.

However, during the discussion with Hubert, CEO of VIS Systems about the TEM19 locomotive, it was found out that it is very hard to say whether 20ft' ISO tank could be placed on board of mainline locomotive. For this purpose another technical feasibility analysis should be made; however, for this research it would be better to assume usage of fuel tender with 20ft' fuel tank capacity instead of placing it on locomotive itself.

To sum up, there are even more engine, locomotive and fuel tender designs that perform equally to diesel locomotives but with much lower air pollution that could be discussed; however, the idea of this sub-chapter is not to get into much technical details but rather proof the existence of technical solutions for LNG-technology in the market.

4.6.2 Infrastructure

Norway has the largest proven natural gas reserves in Europe (see: section 2.2.1) and the most developed small scale LNG production and distribution network with a worldwide production of up to 500 000 tons/year. This gives a high competitive advantage for small-scale customers of LNG in Norway -> flexibility to transport LNG in small amounts across the country without necessity of building expensive on-land pipelines.

Table 3: Overview of LNG production facilities in Norway

LNG Production Plants			
Melkøya	Operated by Statoil	Large scale LNG production facility	4.300.000 tons/year
Kollsnes (2 production plants)	Operated by Gasnor	Small scale facility	120.000 tons/year
Karmøy	Operated by Gasnor	Small scale facility	20.000 tons/year
Risavika	Operated by Lyse/Skangass	Small scale facility	300.000 tons/year

Source: author based on Baumgart and Bolstad (2010, 58)

According to Gasnor (2015), today Norway has five LNG production plants with the biggest one large-scale LNG export terminal in the Melkøya island. In addition, 35 LNG receiving terminals are operating along the Norwegian coast; some of them providing bunkering services for ships (appendix 2). According to LNG Industry (2014b), operating storage and bunkering operations already include NaturgassMøre in Alesund, Sunndalsøra (Gasnor-Shell), Høyanger, Mosjøen, Ågotness Coast Centre Base (CCB), Halhjem terminal, and Florø (Saga Fjordbase). The sizes of these terminals can range between 100 m^3 – 3500 m^3 (Gasnor 2015). At these terminals, LNG is stored in specialized tanks with a limited vaporization levels.

The supply to rail yards would be possible only by trucks since building pipelines would be too expensive and fuel transportation by rail currently is not provided in Norway. The more detailed LNG procurement scenario to the Nordland Line is provided in section 5.2.1. The main idea of this sub-chapter is that Norway has abundant natural gas reserves, already existing LNG production plants and a great potential to distribute it by trucks inside the country's territory. However, regarding LNG supply to the Nordland Line the specialised depots still have to be built as well as new logistics network and practise in order to secure a stable supply for locomotives. Or, in other words, the downstream LNG supply infrastructure must be extensively developed in Northern Norway in order to unlock LNG potential in the railway industry.

4.6.3 LNG price competitiveness

As it was mentioned in section 2.1.4, there exist two major natural gas pricing systems: oil-indexed pricing and gas-on-gas based pricing (GOG). In the GOG system, the price is determined by interplay of supply and demand. Trading takes place at physical hubs (e.g. Henry Hub) or notional hubs (NBP in the UK) (IGU 2014b). Not all gas is sold under short term fixed price basis, still some amount of agreements go under long term contracts but, according to IGU (2014b), these will use gas price indices to determine the monthly price rather than competing fuel indices. The spot LNG is also included in this category.

Another thing important to mention, is that natural gas market is a continental market whereas crude oil – could be regarded as a global market (Conerly2015). This means that for example increasing natural gas production in the United States will impact only its continental prices but not the global ones. This is why we have the spread of natural gas prices among different world regions (figure 9).

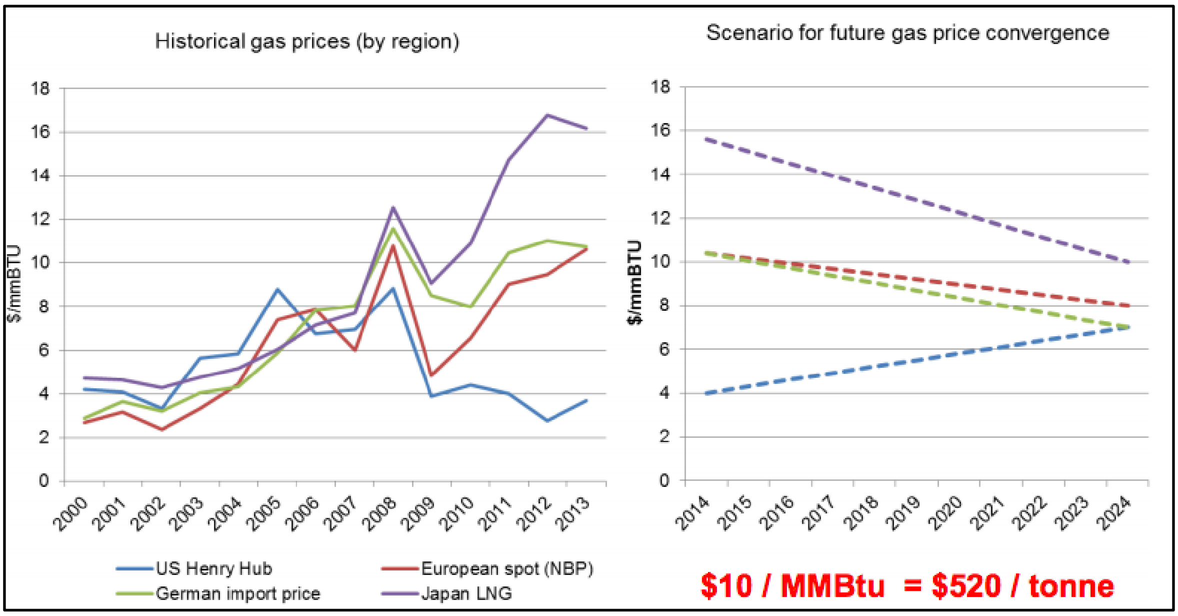

Figure 9: Global gas prices and future projection (Source: SundEnergy 2014)

It can be seen that currently Japan pays the most for natural gas, whereas Americans – the cheapest. This is because US shale boom brought down gas prices there while Japan faced a substantial increase of LNG prices from 2008 due to the accident in Fukushima nuclear power plant and high imported oil prices. SundEnergy (2014) projects that in the long term natural gas prices among different parts of the world should converge at around $ 10/mmbtu because LNG (its possibility to ship overseas) will act as "equalizer" for new supplies. Probably, the price level won't be lower because bringing US LNG to Europe would cost around 10.5 $/mmbtu (5.5 $/mmbtu Henry Hub, plus 3.0 $/mmbtu regas fee, plus 1.5 $/mmbtu shipping and plus again 0.50 $/mmbtu regas fee (Stern and Rogers 2014).

UK NBP is widely used pricing system for spot-traded European natural gas market. According to IGU (2014b), in Europe there has been continuous move from oil price escalation to GOG since 2005. Today more than 50% of gas trading happens using GOG system; however, not in all regions. The system is mostly spread in Northwest Europe (80%) (UK, Netherlands, France, Germany, etc.) whereas in Southeast Europe there is no GOG competition (Bulgaria, Croatia, Romania, etc.).

According to Stern and Rogers (2014), Norway was also pushed to renegotiate the long-term contract prices with its customers by moving to hub prices (to GOG system) due to the complex change of market pricing model in Northwest Europe. Regarding the natural gas prices in Norway, only wholesale market prices are available at the hubs, like UK NBP (Velazquez 2014). In addition, Statoil points that volumes of natural gas are sold under regular sale contracts or in the spot market using quotations at UK NBP or Title Transfer Facility (TTF). Also, certain LNG volumes are priced at Henry Hub quotations.

LNG prices across Norway differ; it depends on the different premiums that the local fuel distributors (e.g. *NaturGass* or *Gasnor*) are setting for the final customer.

Regarding the price differential of natural gas versus oil-based products, historically the Brent price was always higher even though it has been decreasing to $ 50-60 per barrel in time period 2014-2015 due to slowing down China's economy, US shale oil revolution and possible geopolitical speculations (to reduce Russia's aggression towards Ukraine) (figure 10).

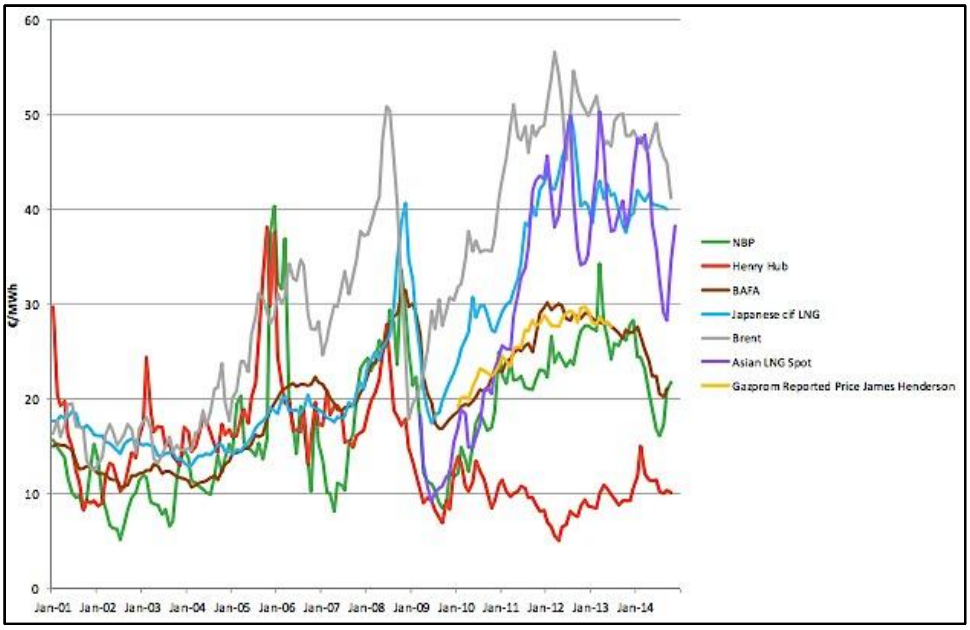

Figure 10: International gas prices, 2001-2014 (Source: Stern and Rogers 2014, 31)

However, having oil prices currently down, the investors' willingness to invest into natural gas vehicles becomes lower since they are not sure about: "For how long the gap between natural gas and oil price is going to continue?" or "will that differential be enough to justify the high investments into LNG-technology?"

At least, in the short term (2015 - 2016) it is forecasted the slight drop of LNG prices in all regions except US due to decreased worldwide demand for natural gas and low crude oil prices (Energy Aspects 2014):

- Latin America and Northeast Asia are paying at around 9.6 $/mmbtu level. In 2016, it should stick at 9.0-9.5 $/mmbtu level.
- North American prices are going to remain the lowest globally, with delivered LNG prices quoted at a discount to Henry Hub at 3.40 $/mmbtu.
- Northern European hub prices are forecasted to keep at 8.4 $/mmbtu levels.

Regarding the long - term projection, - it is difficult to say. According to Stern and Rogers (2014), the nature of the gas market is complex and uncertain; therefore, hard to predict the long term LNG prices. There are many macro- (economic indicators, weather) and micro- environment factors (company's strategies towards switching to natural gas fuel) that influence the demand and supply of LNG with 6 major key uncertainties in the short term LNG market:

1. Demand for natural gas and LNG in Asia. Firstly, Japan's rate at which she turns on its nuclear power plants and China's growth rate.
2. Transition away from JCC (oil-based pricing) to GOG in Asian LNG markets.
3. Scale and pace of US LNG export approvals and construction;
4. Scale of LNG supply ramp-up from non-US suppliers (e.g. Australia);
5. Shale gas development outside North America;
6. Russian response to "over-spill" of excess LNG into the European market.

These factors create a high uncertainty about how LNG market will look after 2018. However, Stern and Rogers (2014) conclude that one thing is clear that the spot LNG market should continue to growth with GOG pricing system all over the world leading to volatile LNG prices with higher price risk premiums.

Chase (2014) takes this task and demonstrates its own predictions about the long-term price gap between the Henry Hub natural gas and Brent crude oil price (figure 11).

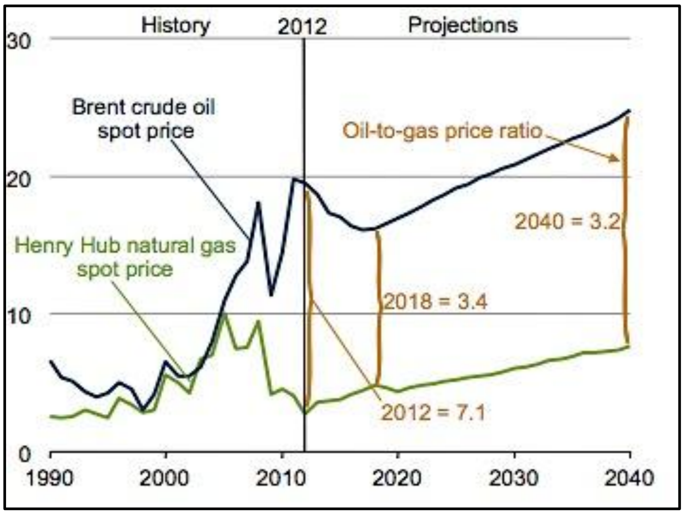

Figure 11: Comparison of spot prices for Brent crude oil and Henry Hub natural gas, 1990 - 2040 (2012 dollars per million Btu) (Source: Chase 2014)

The analyst claims that the biggest gap was in 2010 (the ratio 7.1 times Brent price higher than Henry Hub); however by 2018 the oil-to-gas price ratio is forecasted to narrow to 3.4 times and remain around this level till 2040 on an energy equivalent basis. However, Chase (2014) does not give any concrete arguments for these estimations although he firmly believes in more favourable LNG economics compared with diesel fuel.

Also, it is important to notice that prices were taken till 2013 before drastic decrease of crude oil prices globally (till 40-55 US Dollars per gallon). Therefore, this projection would look less favourable if it would be made in the current market realities of 2015.

To sum up, it can be stated that following the market logic projects involving fuel change to natural gas today should be much more favourable from cost point of view than doing it after 15 years. The argument is that low wholesale prices of natural gas should remain till 2025 due to much bigger supply than demand in the market (Australia, North America, Russia will compete for demand) (see World Bank commodity price forecast in appendix 3). Regarding crude oil prices, the profitable price to produce it is around 83-93 US Dollars a barrel for most producing oil companies (MercoPress 2014); therefore, the current low price levels are just temporary phenomenon that should diminish in 3-5 years leading to increase of diesel price in the market. It is very hard to state how long the price differential will stay (15, 20 or 30 years?), but it is clear that with the time the demand for natural gas will increase (especially when transport and manufacture sector will turn to natural gas fuel) and with it – the price. Therefore, the elementary logic dictates that if the certain project pays back in 5-8 years then it is worth doing now since by that time even though the price differential will be lower your project costs will be recovered and you will work on environmentally friendly vehicles paying much lower taxes for air pollution. In addition, LNG user can always fix or hedge low LNG prices for coming 7-10 years and in this way reduce the risk of price fluctuation.

Finally, speaking about LNG prices in Norway, SundEnergy (2013) states that for now the difference between wholesale and retail prices is still significant. The gap can reach 80-100% depending on the region where trading is done (in North of Norway LNG prices are higher than in South of Norway). It is expected that in near future the price differential will reduce with increased competition and developed LNG distribution chain.

4.6.4 Regulations

The idea of LNG-fuelled locomotives in the Norwegian rail sector is the new phenomenon requiring a profound research and numerous tests for the final introduction to the market. Naturally, the regulatory environment supporting LNG locomotive operations, fuel tender cars, and various safety standards dealing with handling and using LNG is not established in Norway. In addition, the contracting environment for delivering LNG would be new compared with the existing practise of diesel fuel operations. The absence of regulatory environment would act as a significant brake for accelerating LNG adoption in railroading; therefore, in case of favourable economics of the project the role of government would be crucial to support it by establishing the necessary regulations and creating the right economic incentives to proceed with the project.

Regarding locomotive emission standards in Norway, it can be stated that they are unregulated. No information was found about their existence in the Norwegian rail sector. The contact person of Jernbaneverket confirmed the same information.

Meanwhile in US (EPA requirements) and European Union (Stage I..V standards) the requirements for new engines used in non-road mobile machinery are set. In EU, Stage III A and III B standards have been adopted for locomotives and railcars (Stage I, II and IV regulations do not cover railroad sector) to limit the air pollution (European Commission, quoted in DieselNet.com, 2014). The directives were phased-in from 2006 to 2013, with the offer to introduce Stage V standards on 2014 (the date of coming into force is not agreed). Currently, the engine producers have to limit the NO_X and PM emissions: max 6.0 g/kWh and 0.2 g/kWh respectively. The emission regulations should become even more stringent in EU countries forcing buyers to pay higher price for new diesel-fuelled locomotives when replacing the old ones. Since Norway does not produce locomotives itself – must purchase in US or Europe - these regulations have the indirect effect on rail operators as well in terms of higher price and requirement to stick to those regulations in case of exporting the products to Sweden.

The similar case is with taxes for rail operators using diesel fuel in Norway. Today diesel for rail engines is not taxed. This is opposite to road or shipping transport users where environmental taxes such as CO_2 and NO_X are applied.

Overall, without regulations and taxes limiting air pollution on diesel there is very little incentive to switch to LNG in Norwegian railroading. This also implies that LNG price becomes the only critical factor determining the rail operators' decision in Norway. Even though price is a strong *pusher* it should be supported by additional incentives such as environmental taxes to facilitate LNG transformation in case it is more beneficial to society compared with current situation.

<u>To sum up</u> various findings about LNG as a fuel alternative in scientific literature and companies' experiences in using it, the following SWOT matrix can be established. It

summarizes the main fuel's strengths, weaknesses, opportunities and threats compared with diesel fuel alternative that can arise in the Norwegian railroad industry.

Table 4: SWOT matrix for LNG fuel versus diesel fuel from rail operator's perspective

Strengths	**Weaknesses**
• Clean-burning fuel: substantial reduction of NO_X, SO_X, PM and CO_2 tailpipe emissions • High safety record • HPDI engine technology solution providing the same engine performance, reliability and efficiency as diesel's one • Abundant local natural gas resources • Existing upstream LNG infrastructure	• Lower energy content compared with diesel (-> reduced operating range, weight and space penalties of fuel tanks) • Need for expensive cooling and cryogenic tanks • Engine technology is not matured and commercialized in European market • High ignition temperature which requires an additional ignition source (diesel) • Higher LNG vehicle costs • Retrofit difficult from technological side • Less developed downstream fuel distribution systems and infrastructure compared with diesel fuel -> lower commercial practice • Absence of supportive regulatory environment and industry standards • Absence of environmental incentives to switch to LNG • Additional training and certificates
Opportunities	**Threats**
• Fuel cost savings • Increased operational efficiency with fuel tender (longer distances without refuelling) • Increased social welfare: reduced air pollution • Positive NPV	• High uncertainty about long term LNG price -> risk for a longer payback period • The time and content of regulatory processes for the LNG technology • The time and costs for engine approval • Risk of lower NG engine pulling capacity over mountains at acceptable speeds • Life cycle GHG emissions can be similar as diesel counterpart (since LNG is produced locally) • Too low market potential for LNG

Source: own display

5.0 CASE STUDY AND ITS ANALYSIS METHOD

This section aims to present the case to the reader from a general point of view and, subsequently, to select the best methodological tool to approach it in order to generate reliable empirical evidence. Moreover, the evaluation process is briefly presented.

5.1 Case description

One of the main keys of LNG attractiveness compared with diesel is related with financial benefits – substantial fuel cost savings – that *should* offset the high initial investment costs. In order to investigate this common statement in the Norwegian rail freight industry, the concrete case must be chosen as well as the best method to approach it to be able to generate reliable empirical evidence.

In Norway most of the railway lines are electrified; except the Nordland Line going from Bodø to Trondheim; and the Røros Line connecting Trondheim with Oslo capital of Norway (figure 12). After discussions with the representative of Nordland County Council the Nordland Line was chosen as the case study for the Thesis.

The Nordland Line is the northernmost and the longest (729 km) railway line in Norway. Currently it has two freight operators: the major CargoNet and the smaller player – CargoLink company. The railway line is important for cargo transport between north and south of Norway. The main cargo flows consist of various consumer goods and recycling products. Additional information about the Nordland Line is provided in the table 5.

Table 5: General information about the Nordland Line

General Information – Nordland Line	
Distance	729 km
Number of rail operators	2 (CargoNet and CargoLink)
Number of freight trains per week	12 departures (fixed schedule)
Direction	Bodø – Fauske – Mo i Rana - Trondheim
The shortest meeting area	390 meters
Diesel Locomotive VosslohEURO4000 technical information	
Engine effect	3178 kW
UIC Classification	Co´Co
Fuel capacity of diesel	7000 litres
Loco weight	123 tons
Maximum speed	120 km/h
Max gradient	19%
Fuel consumption	4,0 litres/km
Maximum pulling capacity	1600 tons

Source: Jernbaneverket

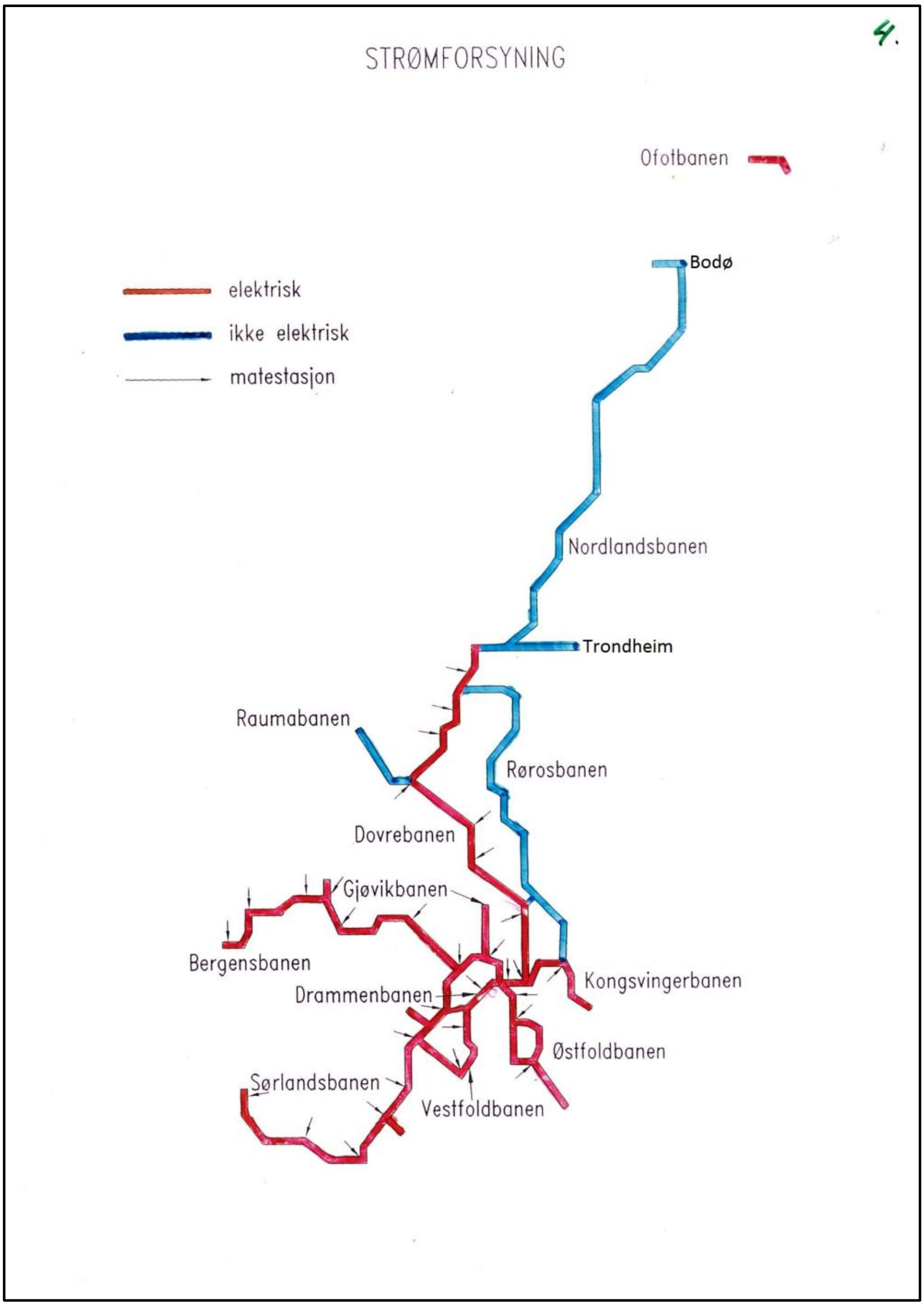

Figure 12: The Nordland Line (Source: Jernbaneverket)

It is also important to notice that Jernbaneverket owns terminals and railway lines whereas the cargo trains belong to rail operators. The latter ones have to pay the fee for using the railway line to Jernbaneverket; however, today the companies operating on the Nordland line are exempted from this tax.

Another crucial thing is that the railway lines in Norway are single track (only 6,02% is double track close to Oslo area). This fact acts as a serious infrastructural bottleneck for expanding the freight capacity to be transported on the Nordland Line since the trains (which are going to opposite directions) have limited place to pass through each other. If the length of the train is too long it cannot fit into the waiting area to let another train continue going. This was the main problem why CNG fuel could not be implemented instead of diesel in the early 2000s. It required two extra wagons for CNG storage that added to much length penalty – not adequate to Norwegian single-track railway line. Therefore, it is important to take into account the max length of meeting areas when determining the max wagons per trains on the Nordland Line.

The main motive for Jernbaneverket to adopt the LNG technology in its railway network is better environmental performance (the incentives for rail operators are listed in section 4.6). However, it must be noticed that currently the railway industry is the cleanest transport in terms of GHG emissions production compared with the rest of transport modes in Norway. According to Norwegian Statistics Database (2015a), the railways produced 0.1 million tonnes of GHGs (or 0.19% of total GHGs emissions) in 2013 whereas the road traffic (the biggest polluter) emitted 10.1 million tonnes of GHGs (19% of total). Therefore, even though the railway industry would switch to cleaner fuel LNG, the environmental effect on total domestic pollution in country would be marginal.

The similar situation would be also with the impact on LNG fuel demand in Norway. The potential demand of LNG could reach 0,01 million Sm3 (or 10 mln. litres) per year in Norwegian rail freight industry[6]. Compared with current annual demand of water transport (105 million Sm3), LNG fuel demand looks insignificant. Therefore, it could be stated that implementing LNG would have stronger micro economical rather than macro economical effect due to its low fuel potential demand and already existing efficient diesel engines that offer more environmentally friendly cargo transportation compared with road or shipping transport modes in Norway.

5.2 Project description

As it was mentioned before, the main motivation to switch to LNG technology is to improve the performance of Norwegian rail freight operations in terms of reduced fuel costs and lower air pollution. In order to assess this alternative, the empirical research must be done that would reveal the economy of LNG compared with currently used diesel fuel. However, before starting the analysis it is important to overview the logistics scenario of LNG supply to locomotives operating on the Nordland Line. The project cannot be feasible if LNG is not available for every day operations.

[6]In 2014 annual report the biggest rail freight operator CargoNet stated that diesel energy consumption was equal to 6,1 million liters of diesel in 2013.

5.2.1 LNG supply scenario

Norway has abundant domestic supplies of LNG and already existing a huge LNG production plant in the Melkøya Island. However, the downstream LNG distribution network is not sufficiently developed to procure LNG at the minimal cost as it is done in the diesel fuel distribution network.

Today there are several options to distribute LNG where pipelines are not available – to use dedicated ships or trucks. In the first option, the demand for fuel must be large enough to transport it to refuelling site by ship; whereas LNG trucks are more favourable when demand for fuel is marginal.

Currently there are two distributors that could supply LNG to the Nordland Line. First one is *Barents NaturGass* that operates in Northern Norway and has two storage tanks for LNG in Bodø. The company is supplying LNG for two ferries operating between Bodø and Lofoten islands, and for industrial customer. The supply chain starts from Hammerfest where several times per week trucks are loaded with 50 m^3 or 80 m^3 specialised cryogenic tanks; and brings the fuel to Bodø port. The refuelling to ferries can take straight from LNG trucks and that is the main advantage of such transportation chain since it may cut additional infrastructural costs. Finally, *Barents NaturGass* is now intensively working on developing the effective supply chain from Hammerfest to the south of Norway (Stavanger) (Torghatten Nord 2013); therefore, the capabilities of distributor are growing.

Second option is to use another distributor's - *Gasnor* - services and refuel LNG either in Mosjøen or in Trondheim. Currently, *Gasnor* owns LNG terminal in Mosjøen and can easily transport LNG fuel to Trondheim by trucks from Mosjøen. *Gasnor* brings LNG by ship from LNG production plant in Melkøya Island to Mosjøen. During the telephone conversation with representative of *Gasnor,* it was confirmed that there would be enough capacity in Mosjøen LNG terminal to meet rail freight transport needs on the Nordland Line.

Overall, there shouldn't been any problems of getting LNG on time and in full from one of the LNG distributors. Furthermore, storage facilities already exist either in Bodø or in Mosjøen (appendix 4). If refuelling would take in Trondheim the distributor *Gasnor* would also take care by transporting LNG from Mosjøen and refuelling straight from trucks to locomotives (appendix 5). In any case, the retailer takes care of LNG storage and distribution but not rail operator.

Therefore, the preliminary LNG supply scenario might look as the following:

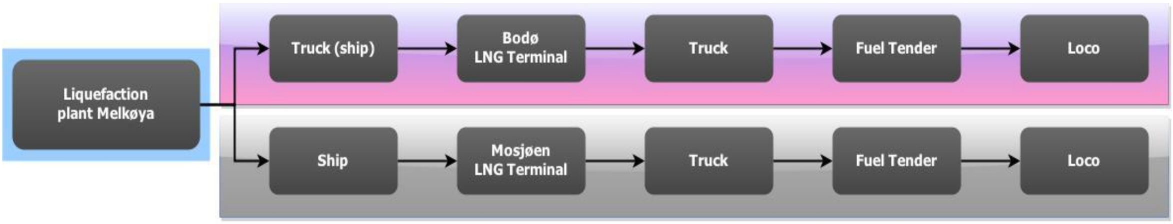

Figure 13: LNG Supply Chain (Source: own display)

The procurement process is also feasible without storage facilities; the refuelling can take directly from the truck. It depends on the fuel demand and technical aspects that should be investigated in a separate research. The standard ISO LNG tanks (20ft' or 40 ft') would be used in the transportation process since they are standardized and easily removable. Also, the regasification of LNG would take on the fuel tender that is technically possible and the most efficient.

Another question is related with the necessary number of refuelling stops for locomotives covering 1458 km distance per trip. The answer depends on the capacity of fuel tank that would be used in train. There are two options:

1. To use LNG tank – the 2/3 of diesel tank size – in the locomotive; or
2. To use a fuel tender that would carry 20ft' ISO tank; however extra wagon would be necessary.

The max distance that could be done with these options is summarized in the following table 6:

Table 6: The max distance on different tank size options

Parameters	Diesel	LNG	LNG_20ft ISO tank
Tank capacity in litres	7 000	4 667	20 000
Power eq on diesel in litres	7 000	2 745	11 765
Litres/km	4,0	4,0	4,0
Kilometres	1 750	686,3	2 941,2
Difference	1	-39%	168%

Source: own display

It can be seen that without a fuel tender the max distance using LNG fuel is 39% lower than the distance produced by diesel due to LNG cylindrical tank shape (reduces space) and lower fuel density. As a result, having the distance 729 km the number of refuelling stops necessary for LNG locomotives without a fuel tender would reach at least 2 times (apart from initial refuelling in Bodø): (1) in the middle of the route; (2) and in Trondheim. This outcome would complicate LNG distribution chain and, probably, the retail LNG prices would increase since a new depot would have to be built.

The second scenario – with fuel tender – the max distance is around 168% higher compared with standard diesel tank used in locomotives. Theoretically, with 20ft' tank it should be possible to go to both ends without refuelling. However, for the sake of security the refuelling can be done also in Trondheim – would be enough to have one truck per two locomotives. Regarding the Norwegian infrastructural constraint (the shortest meeting area is 390 meters), having additional 20ft' fuel tender would not be a problem. The total length of loco + fuel tender is equal to 40 metres whereas the length of standard loco is 23 metres. Therefore, having 16 wagons per train (that is enough to satisfy current demand), with the length about 20 metres per wagon, the train could fit within infrastructural limits.

In general, the distribution of LNG would not be more complicated compared with diesel chain when the downstream supply infrastructure and the efficient and effective distribution system will be built. However, for now the costs of LNG procurement should be higher due to more expensive cryogenic tanks, longer distances from the source and etc. Overall, the most important for this research is to state that there is a possibility to transport LNG using the services of already existing distributors in the Western Norway.

To sum up, there is a belief based on US rail freight industry optimism that LNG technology could strengthen the competitiveness of Norwegian railroading due to economical and environmental effectiveness of fuel compared with currently used diesel. The main expected outcome or benefit of the project is increased producer (rail operators') surplus and overall society welfare.

In research the author assumes LNG fuel to be implemented in freight locomotives operating on the Nordland Line. New trains should use 20ft' fuel tender since without it would be not economical to stop every 500-600 km for additional refuelling. In addition, having more refuelling stops would increase operating costs as well as retailer's final LNG price (the latter can differ among regions). The investments to new locomotives and fuel tenders should be carried out by rail operators whereas the fuel distributor (e.g. *Barents NaturGass* or *Gasnor*) should invest into new refuelling infrastructure – LNG trucks and storage facilities if necessary. Government's role is especially important in the launch of new technology due to the need to issue new industry regulations and establish additional incentive programs. However, the project itself would be justified only if it proves favourable fuel economy compared to current situation.

To do that, the most appropriate method has to be chosen given the time and data constraints. The possible appraisal methods are overviewed in the following subsection.

5.3 Appraisal methods

Cellini and Kee (2010) state that the most commonly used analytical tools for evaluation of transport sector project are: cost-effectiveness analysis (CEA) and cost-benefit analysis (CBA). Both tools can be applied before, after, or during the project, and they can greatly assist decision makers in evaluating program's efficiency. However, depending on the situation one tool is more suitable than another one; therefore, its crucial to know what result you want to achieve before applying a particular analysis method.

Authors Cellini and Kee (2010) explain that CEA is a tool that relates the costs of a program to its key outcomes or benefits while CBA takes a broader picture by comparing the total expected costs against the total expected benefits of a project.

CEA is most useful when the decision maker knows the outcome he desires and the objective is to determine which set of alternative projects achieves the greatest outcome (Cellini and Kee 2010). According to Madsen and Olsson (2012), the aim of the CEA is to maximise the level of benefits relative to the costs. The main difficulty is that it does not give any value for the output, leaving that to the subjective judgement of the decision maker.

CBA is the most beneficial when the single program is analysed to determine whether the program's total benefits to society exceed the costs or when the alternative projects are compared in order to decide which one achieves the greatest benefit to community (Cellini and Kee 2010). Costs and benefits are not always easy to measure; therefore, the main challenge in CBA is to monetize them.

Even though CBA in general is considered as a very time consuming and difficult to apply tool, the research requires this method mainly because the outcomes of the project are not known. Moreover, many researchers (Bråthen et al. 2000; Vickerman 2007; Mackie et al. 2014) claim that CBA is often chosen technique for transport appraisal projects. In addition, Bråthen et al. (2000) distinguish several project categories where CBA can be applied with one of suitable for this research: projects with environmental effects. The latter ones cannot be captured solely in the financial analysis, requiring additional economic analysis to assess the wider impacts of the project on society.

Moreover, during the discussion with Fredrik Bärthel, a researcher in transportation at Göteborg University (Sweden), it was found out that production cost analysis (PCA) is also a good methodological tool for this kind of research. The primary aim of production cost analysis is to assess the costs of transportation of one unit before and after the implementation of particular project. In this case, PCA would show how the adoption of

LNG fuel would impact the rail operator's cost structure, or more precisely, its cost of transportation per unit. Income data is not required and the evaluation process is not complicated.

To sum up, based on the scientific literature and discussion with Fredrik Bärthel, a researcher in transportation, the best appraisal methods for transport projects with no clear outcomes are cost-benefit analysis and production cost analysis. Using these methods the complexity of analysis and the amount of required data depend on the choice of author; but, in general, the more data is elaborated the better empirical results can be generated.

The structure of the evaluation is briefly explained in the following subsection.

5.4 Evaluation process

The empirical assessment starts with production cost analysis. As it was mentioned before the preliminary data regarding operating structure of diesel locomotives was given; therefore author conducts the data analysis and sensitivity analysis with different price scenarios. The aim of production cost analysis is to calculate the transporting cost per unit (cpu) using either diesel or LNG and to assess the effect of LNG price indicator on cpu. Also, fuel costs of diesel and LNG are compared based on different cargo volume transported.

Further the empirical research continues with the cost-benefit analysis. This method differs from production cost analysis since it aims to determine the best outcome for society but not for producer. When performing CBA, it is important to include the most significant costs and benefits to society and, in result, to get the net total benefits that would indicate whether the project is worth implementing compared with current situation or not. The methodology of CBA lies in the nine main steps described by Boardman et al. (2014, 6-15):

STEP 1: Specify the set of alternative projects

This step requires describing and examining:

- The base case scenario which simply indicates what would happen if the project wouldn't be performed.
- The set of alternative projects; why they have been chosen and how they are going to be implemented.

STEP 2: Decide whose benefits and costs count (standing)

Almost every project can affect many different stakeholders within society, and every cost or benefit impacts a particular group of people. Therefore, it is important to choose the most affected group "the one that bears the most costs and receive the majority of the benefits" (Cellini and Kee 2010).

STEP 3: Identify the impact categories, catalogue them, and select measurement indicators

Step 3 requires the analyst to identify the physical impact categories of the proposed alternatives, catalogue them as benefits or costs, and specify the measurement indicator of each impact category. Since all costs and benefits cannot be known for certain; only the most significant have to be addressed.

STEP 4: Predict the impacts quantitatively over the life of the project

When the most important impacts are identified, the analyst has to quantify them in each time period. Or, in other words, the analyst has to set the time frame and predict how the costs and benefits will change over time.

STEP 5: Monetize all impacts

In this step the analyst has to attach dollar values to all impacts. According to Cellini and Kee (2010) it is important to state the nature of the cost, how it is measured and the assumptions being made. Those assumptions need to be subjected to a sensitivity analysis in Step 8 to determine to what extent the outcome of the analysis is controlled by the assumptions made.

STEP 6: Discount benefits and costs to obtain present values

Here the future benefits and costs have to be *discounted* relative to present benefits and costs in order to obtain their *present values (PV)*. Discounting is necessary due to opportunity costs in recourses used in the project and due to the fact that most people prefer to consume now rather than later. Analyst has to choose the social discount rate (s) to obtain the present values of costs (C) and benefits (B):

$$PV(B) = \sum_{t=0}^{n} \frac{B_t}{(1+s)^t}$$

$$PV(C) = \sum_{t=0}^{n} \frac{C_t}{(1+s)^t}$$

STEP 7: Compute the net present value of each alternative

The *net present value (NPV)* of an alternative equals the difference between the *PV* of the benefits and the *PV* of the costs:

$$NPV = PV(B) - PV(C)$$

The basic decision rule for an alternative project is simple: implement the project if its *NPV* is positive. If no *NPV* is positive, then none of the specified alternatives are superior to the status quo, which should remain in place.

Also, it must be noticed that positive *NPV* criterion leads to a more efficient outcome than the status quo; however, not necessarily the most efficient outcome. *NPV* criterion applies only to the actual alternative defined. Cellini and Kee (2010) point out two additional ratios that supplement *NPV* calculation:

- *Benefit-cost ratio (BCR).* It makes easier to compare the alternatives and shows whether a specific benefit gained per dollar of cost is sufficient given other investment alternatives. If ratio is higher than 1, the alternative is considered as an efficient allocation of recourses.
- *Economic rate of return (ERR). ERR* is simply the discount rate that would yield total present value benefits equal to costs. This ratio helps to assess the value of the project based on whether a certain percentage rate of return is satisfactory given other opportunities the organization might have had in year 1.

STEP 8: Perform sensitivity analysis

The purpose of sensitivity analysis is to show how large the risks of a project are and in particular to demonstrate whether a favourable project becomes unfavourable if some assumption is changed (Heatco 2006, 50). In this way, the risk of generating questionable results is reduced when different scenarios against sensitive indicators are performed.

STEP 9: Make a recommendation

In general, the alternative having the biggest NPV value has to be selected. However, it does not have to be always a right case – the sensitivity analysis can show different outcomes. Also, the results of CBA serve only as the guide but not as the final basis for the decision.

5.5 Limitations of empirical analysis

5.5.1 Production Cost Analysis

One of the major drawbacks of production cost analysis performed in this research is the data accuracy. The operating cost structure for diesel locomotives is the preliminary one; however, not the actual data received from rail operator. For instance, in order to allocate costs for LNG locomotives several assumptions were made; therefore, the final results might have some degree of deviation from the real transportation costs per unit (cpu). However, it must be noted that Jernbaneverket consulted with CargoLink operator before making diesel cost structure; therefore, it can be assumed that the deviation of data is small.

Another thing is that PCA does not show the payback rate (or period) of the project or the benefits to the society; it simply compares the transportation cpu using two different fuels. From another point of view, the easy cost per unit comparison is the strongest advantage of PCA for rail operator.

5.5.2 Cost Benefit Analysis

Despite the fact, that CBA provides comprehensive and systematic evaluation structure for the project, it contains several important limitations as well. According to Mackie et al. (2014, 5), there are various technical issues related with the value judgments: "Where do the values come from, how reliable are they and should they be private values or adjusted to social values? Another question according to the authors is how to handle impacts for which there are no values such as loss of natural or heritage assets. The human error in conducting cost-benefit analysis cannot be avoided, therefore, it can be that analyst won't include all the impacts of the project, or will monetize them not in the most precise way. This can contribute to misleading results of CBA.

Another criticism area of CBA is related with the problem of capturing external effects of the project. There is belief that some of them might not be included into the analysis due to bounded rationality of analyst. According to Bråthen and Hervik (1997, quoted in Shaton 2011, 50), regional impacts of new infrastructure are usually not in focus in the CBA, but they are very important for politicians who are to make the decision: “In general, regional impacts are mid- and long-term effects of the infrastructure investments, even though some shifts in economic activity based on expectations may take place even before the new infrastructure is constructed”.

Karine Nyborg (2014) argues that CBA is not value-free: “When CBA is used to measure welfare, it is based on highly controversial value judgments. When used to measure efficiency, it is based on assumptions of limited relevance to democratic decision-making processes”. Therefore, author states that CBA measures only the population’s total net willingness to pay. And it is not bad, since this indicator may contribute decision makers’ factual understanding of the trade-offs they are about to make.

One of the ways to reduce the uncertainty of the reliability of final results is to conduct the sensitivity analysis relating to key variables such as investment costs, social discount rate, price ant etc. Another method that would help to overcome the shortcoming of CBA is to do ex-post analysis. This should help to evaluate the real actual costs and benefits related from a project, and improve the overall quality and objectivity of ex ante analysis of likely projects (Shaton 2011).

6.0 TECHNICAL FRAMEWORK FOR ANALYSIS

This section provides readers with the technical framework for empirical analysis for both PCA and CBA tools. In each subsection scenarios, assumptions, identified impacts and explanation of cost (or emissions) calculations of two different analyses are overviewed.

6.1 Production Cost Analysis

6.1.1 Scenarios

PCA is done to assess the impact of LNG technology on rail operator's cost structure. The interests from third parties (society) are not analysed in PCA since it is concentrated only on producer's financial surplus or loss. It is assumed the hypothetical situation in which rail operator is considering either to invest into diesel or LNG locomotive with fuel tender knowing the existing market price of trains. He must consider two things:

1. Which type of train will be more expensive to operate?
2. Will cost savings be enough to compensate the investments into LNG locomotives and fuel tenders by currently existing price differential between diesel and LNG fuel?

Therefore, two scenarios can be defined:

1. <u>Base case scenario.</u> Rail operator chooses to purchase diesel locomotive; therefore, the freight operations are run further in the same pattern as it was before.
2. <u>LNG case scenario.</u> Rail operator chooses to invest into LNG locomotive with fuel tender expecting that fuel cost savings will be high enough to offset the more expensive locomotive.

6.1.2 Assumptions

These assumptions are made for production cost analysis:

- The rail operator uses only its own financial capital for purchasing locomotive;
- The annual cargo transportation is 30 000 TEU per year given the max train length 390 meters in the meeting area. To satisfy this demand two trains per day with 15 wagons per train are considered. It is assumed that one wagon can contain 4 TEU.
- Interest rate is 4.5%;
- Depreciation period for locomotive is 30 years (Floden, 2011);

- Days of usage per year – 313 (subtracting maintenance and national holidays) and loop time is 48 hours;
- No difference between engine performance, reliability and efficiency;
- The fuel distributor has enough capacity to meet increased LNG demand from rail operator.

6.1.3 Impacts

In PCA only two major impacts on cost structure can be identified if diesel would be changed to LNG fuel:

1. Difference in fuel costs;
2. Increased maintenance costs due to additional wagon (fuel tender).

Other operating cost elements such as staff costs, overhead costs, infrastructure charges and etc. would be status quo since changing fuel would not affect them. Operating income is not considered in PCA; only operating costs of locomotives.

6.1.4 Cost calculation

Before starting explanation of cost calculation for PCA analysis, it is important to mention that the preliminary operating cost structure for diesel engines in Norway was received from Jernbaneverket; however, author changed a few parameters such as investment costs, fuel prices, depreciation period for natural-gas fuelled locomotives (from 20 to 30 years based on Floden (2011) research), to more precise values. The explanation of changed cost parameters is given below.

Investment costs

Hubert, CEO of VIS Systems, gave the current price for diesel locomotive in European market and the possible price for LNG-fuelled locomotive with fuel tender that costs around 0,5 mln. EUR in addition.

Table 7: Capital investment costs to locomotives and wagons

CAPEX	Type of Loco	Type of Loco	Type of wagon
	Diesel Euro4000	LNG Euro4000	Sggrss104
Price per unit in EUR	4 000 000	4 945 000	138 250
Price per unit in NOK	34 472 000[7]	42 616 010	1 200 000

Source: own display

Fuel prices

[7]EUR/NOK = 8,618.

In Norway the diesel for rail engines is taxed only with one tax - Excise duty on emissions of NO_X. Currently the tax size for railway vehicles is 19.19 NOK/kg (Toll Customs of Norway 2015, 55). However, it is known that at the end of year rail operators can get full refunding for the tax paid; therefore it could be interpreted that compared with road transport (where diesel fuel is fully taxed) rail operators are *supported* by the Norwegian government in the way that they do not have to pay any taxes even though external costs are incurred (air pollution). Also, it is not intended to say that the tax size should be the same as for road users; however, applying zero tax for diesel fuel strongly facilitates its usage in the market. This follows that with such low diesel price LNG has lower possibility to compete successfully with diesel fuel in Norwegian rail freight. In this way, the non-taxed diesel creates an entrance barrier[8] for LNG to entry rail fuel market.

In the analysis author uses the latest available diesel price from Norwegian Statistics Database (2015b). On February 15 the retail auto diesel price was 12.10 NOK/litre. Subtracting the 2014 taxes (fuel tax (3.82 NOK/litre) and CO_2 tax (0.62 NOK/litre), and VAT tax the diesel costs are 4.64 NOK/litre (including distribution costs). However, the NO_X tax must be added; therefore, the final retail diesel price for rail engines can be calculated in the following way:

Table 8: Retail diesel price for rail engines in Norway

Retail diesel price w/o taxes, NOK/l	**4,64**
Emission factor, g/l diesel	17,0
Emission factor, kg/l diesel	0,017
NO_X tax, NOK/kg emissions	19,19
NO_X tax, NOK/l	0,28
Retail diesel price with tax, NOK/l	**4,92**

Source: own compilation

Regarding LNG prices in Norway, only wholesale prices are available. Author used UK NBP quotation, which is applied for LNG pricing in Northern Europe. Energy Aspects (2014), a research consultancy company in energy markets, stated that the average LNG price was 8.4 $/MMbtu in 2014 and is expected to be the same at 2015 (appendix 6).

Currently, the difference between wholesale and retail LNG price is 100% in Norway (SundEnergy 2013). Therefore, the assumed retail LNG price including distribution costs is:

[8]Entrance barrier – obstacle or difficult that prevents new competitors from easily entering the market. Barriers to entry can exist as a result of government intervention (industry regulation, special tax benefits, etc.) or other reasons (e.g. competitors policy) (source: Investopedia).

Table 9: Retail LNG price for rail engines in Norway

LNG wholesale price w/o taxes, USD/MMBtu	**8,4**
1 ton of LNG contains MMBtu	49,2[9]
USD/ton LNG	413,28
NOK/ton LNG	3314,51
LNG density kg/l	0,435
LNG wholesale price w/o taxes, NOK/l	**1,44**
LNG retail price w/o taxes, NOK/l	**3,00**

Source: own compilation

Operating costs

The cost structure in the rail transport industry can be divided into fixed and variable costs. Fixed costs are often those costs that do not depend on the travelled distance such as administration costs or advertising costs. In opposite variable costs can be time-dependent: financial costs, salary costs, vehicle taxes; or distance-dependent: fuel, maintenance, rail infrastructure fees (Floden 2011). In this research only the costs of operating the train are analysed since changing fuel would not affect the general fixed costs: administration or shunting costs.

Regarding depreciation costs, PCA should assume that the cost of the investment is divided over its entire economic life (the latter is shorter than actual technical life of vehicle). For trains the usual economic life is 30 years depending on its utilization rate (Floden 2011).

In cost structure the maintenance costs of locomotives and wagons were divided into fixed and variable. The size was taken from Floden (2011) research:

- Locomotive:
  - Annual fixed maintenance costs per diesel/LNG engine: 400 000 NOK;
  - Variable maintenance costs for diesel/LNG loco per km: 10 NOK;
- Wagon:
  - Annual fixed maintenance costs per wagon: 20 000 NOK;
  - Variable maintenance costs per km: 0.25 NOK.

Diesel fuel consumption data for each additional 1000 TEU transported was taken from received cost structure.

Operating LNG cost-structure is practically the same as diesel. Only these values were changed:

[9] http://www.ihrdc.com/els/po-demo/module01/mod_001_03.htm

- Fuel consumption data. This was calculated by multiplying total diesel consumption by 1.7 factor due to difference in fuel density.
- Increased number of wagons by 1 -> this led to the higher total maintenance costs for wagons (fuel tender).
- Increased loco weight by 40 tonnes (approx. weight of filled fuel tender).

Transporting costs per unit

This formula was used for cpu calculation:

Cost per TEU = (Annual Total Operating Costs / Annual TEU Volume) / 2

It is necessary to divide by 2 since the cost per TEU is calculated to one side: Bodø – Trondheim. Also, after assessment of cpu the sensitivity analysis was done with different LNG price scenarios in order to see the price effect on cpu.

6.2 Cost Benefit Analysis

6.2.1 Scenarios

The project is intended to bring benefits not only to rail operators but also to society in terms of lower air pollution. Therefore, it is necessary to estimate LNG technology social value and to see whether the project is worth of additional public investments in case rail operators are not able to handle the initial investments on their own.

In CBA only two scenarios are defined:

1. Base case scenario. The project is not implemented; however, the investments in two new diesel trains are made. For the sake of comparison, it is assumed that investments are done in year 0 -> the same as for LNG locomotives.
2. LNG case scenario. The project is implemented where diesel fuel is switched to LNG. Here, rail operators expect that fuel cost savings will compensate the initial investments in few years whereas Norwegian government supports the project as it substantially contributes to lowering air pollution in the Nordland region.

In CBA only affected cost categories are considered: investment, maintenance for wagons, fuel costs and social environmental costs (air pollution). Since other costs such as staff, locomotive maintenance costs are not affected by the fuel change – they are not considered in CBA analysis. Finally, it is assumed that fuel change would not affect operating revenues (demand); therefore, in CBA the value of those, for simplicity reasons, is assumed to be zero.

It is obvious that in both cases negative cash flows are generated (NPV as well); but it does not mean that companies are in financial loss (since revenues are not considered). It is simply done in order to compare NPV values between base and alternative cases in simpler way. The more negative NPV value means lower cost advantage/lower profitability compared with another case.

Also, CBA should indicate the relative cost advantage of using different type of locomotives. These cumulative cost savings are important in the analysis because it can show in how many years the difference in investment costs of trains can be repaid back.

6.2.2 Assumptions

These assumptions were made in CBA:

- Rail operators use only their own financial capital for purchasing locomotives. No EU funds or government subsidies are included into analysis.
- Rail operators have to purchase two locomotives in year 0 in order to replace out of service locomotives. Therefore, the investments have to be made anyway.
- Depreciation period for locomotive and wagon is 30 years (Floden, 2011).
- The demand for cargo transportation is not affected by the type of fuel used. The value of revenues is, for simplicity, assumed to be zero.
- The annual cargo transportation is 30 000 TEU per year given max train length 390 meters in the meeting area. To satisfy this demand two trains with 15 wagons per train per day are considered.
- Social discount rate is 4.0% (Detkongeligefinansdepartement 2014) and project evaluation period is 30 years (locomotive depreciation period).
- No difference between engine performance, reliability and efficiency.
- The fuel distributor has enough capacity to meet increased LNG demand from rail operators. There is no change in the fuel distributor's profit margin after project implementation.

6.2.3 Impacts

In research the simplistic version of CBA is applied where only the most important impacts and beneficiary groups are analysed.

The following table depicts the project beneficiaries and the impacts:

Table 10: Direct and indirect beneficiaries of the project

	Direct beneficiaries	Indirect beneficiaries
The group of beneficiaries	Rail freight operators	Local people living in the Nordland Region
The impact of project on the specified group of beneficiaries	Increased operating income due to fuel cost savings, and better environmental performance.	Reduced local air pollution

Source: own display

Also, two additional groups of direct beneficiaries could be distinguished in addition to rail freight operators:

1. Customers of rail operators. If fuel cost savings would be substantial, rail operators might be able to reduce the tariff of cargo transported -> this would increase the demand for rail operators and at the same time would benefit customers in lower costs of cargo transportation.
2. The fuel distributor of LNG. The demand for LNG would increase and with it the profit even though some investments into new trucks or storage tank would be necessary to do.

However, the benefits for these two groups are not included into CBA since it requires additional data (rail operators' revenues, distributor's financial data) that is not available for this research. Another thing is that it would be difficult to estimate the decrease of tariff or the distributor's increase of profit margin -> another study should be made. As a result, the assumptions for this research were made that (1) the demand is irrespective to fuel used; (2) there is no change in distributor's profit margin after project implementation.

Finally, it is assumed that the size of monetized benefits and costs would stay the same over the project appraisal period (modifying it would include too much speculation). The inflation is not included into CBA.

6.2.4 Cost calculation

6.2.4.1 Costs

The initial payment that is done in year 0 is:

- 2 Diesel locomotives – 68 944 000 NOK.
- 2 LNG locomotives – 85 232 020 NOK.

Fuel consumption data and maintenance costs are taken from PCA analysis. The assumed annual transported volume by both rail operators on the Nordland Line is 30 000 TEU.

Regarding fuel prices, these values are used:

- Retail diesel price equal to 4.64 NOK/litre without NO_X excise tax. Tax cannot be used since local air emissions are monetized and assessed separately in CBA (avoid duplication problem).
- Retail LNG price is the same as in PCA 3.00 NOK/litre without taxes.

6.2.4.2 Emissions

European Chemical Industry Council and the European Chemical Transport Association (ECTA & CEFIC) (2011) have presented a good methodology for calculation environmental emissions. There are two approaches to do that:

1. Activity – based approach. It is recommended for companies who do not have direct access to fuel consumption data. The formula is:

Tonnes CO_2 emissions = tonnes * km * g CO_2 per tonne-km

2. Energy – based approach. It recommended for transport companies that record fuel consumption and employ standard emission conversion factors. The formula is:

Tonnes CO_2 emissions = litres* kg CO_2 per litre fuel / 1.000

In research the energy-based approach is used since fuel consumption data is given. Regarding other pollutants such as NO_X, PM_{10} and SO_2 the formula is the same.

Emission and shadow prices

Emission factor depends on many variables such as load factor, the energy efficiency of the vehicle, the carbon intensity of the energy source and etc. The author does not calculate the exact emission factors for diesel trains on the Nordland Line but instead takes the indicators from Floden (2011) research done on the same diesel Euro4000 engine estimations in the Sweden rail industry.

In order to ascertain the value of environmental costs, it is necessary to use shadow prices, which would represent the monetary values for annual emissions. The shadow prices used in this study are taken from the research done by the Institute of Transport Economics of Norway (2010).

Table 11: Emission factors and shadow prices for diesel trains

Parameters	Unit	CO_2	NO_X	PM_{10}	$S0_2$
Emission factor	g/l	2 538	17,0	0,42	0,41
Shadow price	NOK/kg	0,21	50,00	440,00	25,00

Source: author based on Floden (2011) and TOI (2010)

Moreover, it is important to mention that shadow prices are not fixed and might depend on many factors with the most important – economic cycle of the country or region. The shadow prices used in research are the latest indicators evaluated by TOI in Norway.

<u>LNG Emissions</u>

There is little information available about LNG fuel emission factors since the testing of locomotives has just recently started in US. Moreover, the information is confidential. However, it was found that Canadian Railway Inc. after testing LNG-fuelled locomotives confirmed the emission reduction of NO_X by 70% and CO_2 by 30% (the measurement unit was not stated) compared with the diesel-fuelled locomotives on 482 km distance. Of course, these values might slightly change on different route with different parameters (e.g. higher gradient, load factor) but in general the reduction of CO_2 and NO_X emissions by similar per cent was also confirmed in road and marine segment after LNG implementation. For instance, Joint Transportation Committee (2012) gives the following emission evaluation indicators for marine diesel oil and LNG in their report about LNG-fuelled ferries in Washington:

Table 12: LNG Emission comparison (g/kWh)

Fuel type	**Sulphur Oxide**	**Nitrous Oxide**	**Particulate Matter**	**Carbon dioxide**
Marine ultra low sulphur diesel oil, 0.1%	0,4	8-11	1,5	580-630
LNG	0	2	0	430-482

Source: Joint Transportation Committee 2012, 11.

It can be noticed that emissions of nitrous oxide and carbon dioxide are reduced by similar percentage (75% and 25-30% respectively) as was noted in Canadian Railway report.

Regarding PM and SO_X emissions, LNG fuel does not contain them and this was stated both in the report of Baltic Transport Journal (2011) after testing LNG in ships (see section 4.4.2) and by Joint Transportation Committee (2012) (table 12).

For this research, the above findings about environmental emissions of diesel and LNG fuel are used in cost benefit analysis.

7.0 ANALYSIS RESULTS

7.1 Production Cost Analysis

As it was mentioned before, PCA as a methodological tool is applied in order to assess the impact of LNG fuel on the rail operator's cost structure. The analysis is intended to reveal whether the rail operator benefits more from investing to natural gas fuelled locomotive compared with diesel train. The main decision criterion is the value of transportation cost per unit.

The operating cost structure for diesel and LNG locomotives is shown in appendix 7. Included cost elements are those directly related with the rail freight service production. All values are annual and in NOK currency. Also, in appendix 7 the general table summarizing total operating costs and transportation cost per unit is shown.

PCA analysis revealed several points:

The more volume is transported, the lower cost per TEU. This is closely related with economies of scale when the cost per unit is dropping with increasing production due to spread of fixed costs over more output units (figure 14). From 17000 TEU there is a slight increase of cost per TEU for both fuels because the second train is added (one train can take max 17000 TEU based on received data from Jernbaneverket). However, it can be seen (figure 14) that further with more cargo transported the cost per TEU is dropping again.

CAPEX including reserve (locomotive) is higher for LNG than for diesel locomotives by 1,2 mln. NOK (the investment cost per year).

Diesel price (4.92 NOK/litre) is too low to make LNG price (3 NOK/litre) competitive for rail operator. Fuel ratio is 1.7; therefore, the energy costs for LNG exceed diesel fuel costs by approximately 6% at the given price levels.

The maintenance costs per LNG train are also higher by 134 thousand NOK each year (or 3,3%) compared with diesel fuel due to additional maintenance for a fuel tender.

As a result, the final transportation costs per TEU using LNG fuel are slightly higher (around 5%-6%) than using diesel fuel at the given price levels. Gradual increase of cargo volume transported reduces the difference of cost per unit (cpu); however, only in small percentage. This is depicted in the table 13 and figure 14.

Price of the fuel is the most sensitive indicator. Other factors determining faster repayment of LNG such as lower maintenance costs or distance have smaller effect compared with the price of fuels.

Overall, it could be implied that on status quo conditions the rail operator is better of choosing diesel locomotive than natural gas fuelled locomotive with currently existing fuel prices in the market. In addition, the listed disadvantages and risks in the SWOT matrix make LNG even less attractive compared with diesel fuel. Finally, differently from shipping sector, environmental regulations do not exist for rail freight transport. This leads to very low motivation to go for LNG fuel purely based on better environmental performance. It must be agreed that the most important factor for rail operators is fuel costs which currently would be higher for LNG fuel than for diesel fuel at the given price levels in the market.

Finally, this situation is very sensitive to the change of price differential of fuels that may alter the picture to different perspective. This is done by sensitivity analysis that shows the different scenarios when fuel prices are changing.

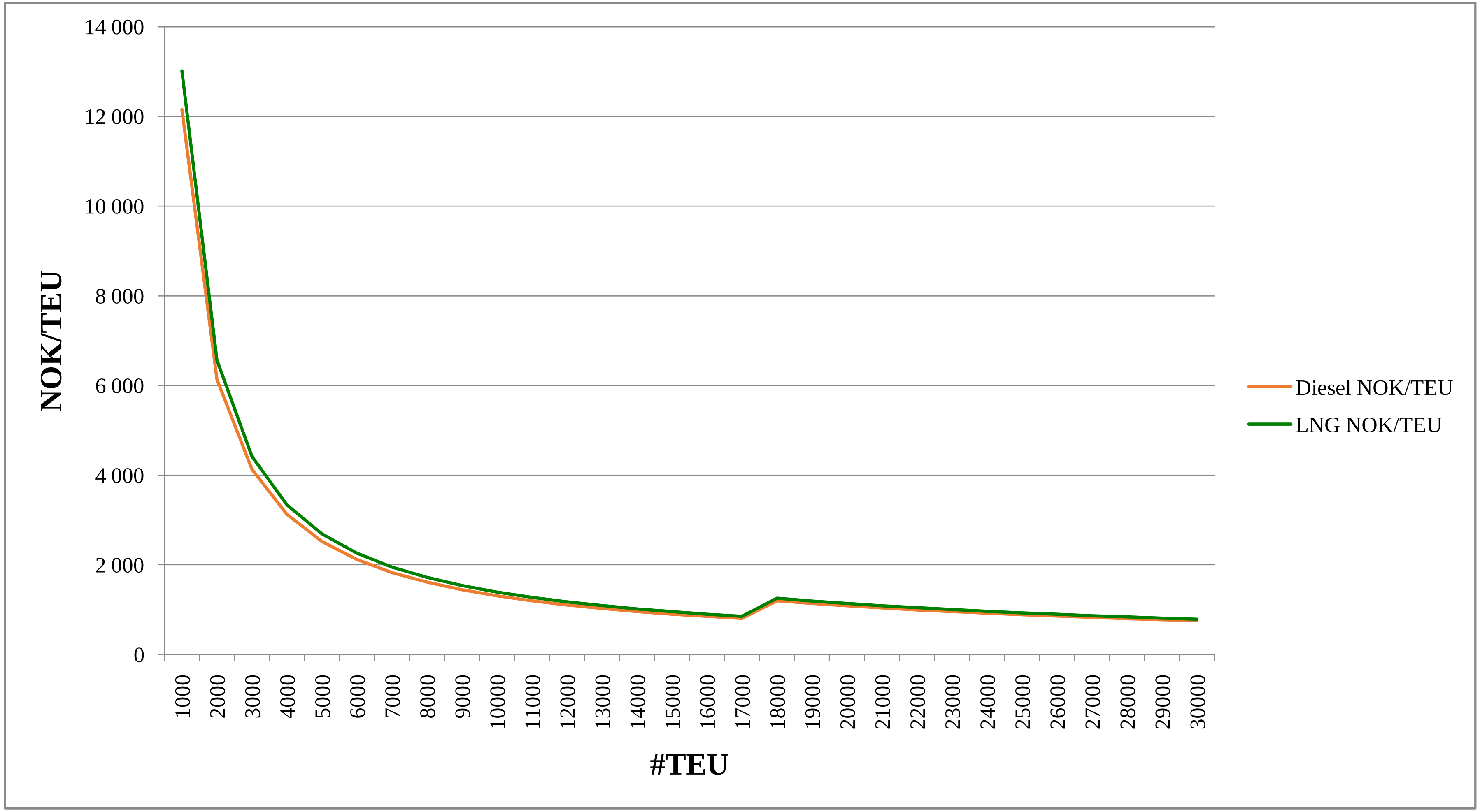

Figure 14: Cost per TEU using different fuels (Source: own display)

Table 13: Cost per TEU using different fuels

Case scenario	Units	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
Diesel	NOK/TEU	12 157	6 137	4 128	3 123	2 519	2 116	1 827	1 610	1 441	1 306
LNG	NOK/TEU	13 018	6 567	4 415	3 338	2 692	2 260	1 951	1 719	1 538	1 393
Price difference	%	107,1%	107,0%	107,0%	106,9%	106,9%	106,8%	106,8%	106,7%	106,7%	106,7%

Case scenario	Units	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000
Diesel	NOK/TEU	1 195	1 103	1 024	957	898	847	801	1 194	1 136	1 084
LNG	NOK/TEU	1 274	1 175	1 091	1 019	957	902	853	1 256	1 195	1 140
Price diff.	%	106,6%	106,6%	106,6%	106,5%	106,5%	106,5%	106,5%	105,2%	105,2%	105,2%

Case scenario	Units	21000	22000	23000	24000	25000	26000	27000	28000	29000	30000
Diesel	NOK/TEU	1 036	993	953	917	884	853	824	798	773	750
LNG	NOK/TEU	1 090	1 044	1 002	964	929	896	866	838	812	788
Price diff.	%	105,2%	105,1%	105,1%	105,1%	105,1%	105,1%	105,1%	105,1%	105,1%	105,1%

Source: own display

7.1.1 Sensitivity Analysis

Before turning into sensitivity analysis, it is obligatory to determine what is the break-even price for LNG fuel given the currently existing diesel price 4.92 NOK/litre. Break-even price intersects at the point where total costs of operating LNG locomotive are equal to the total costs of operating diesel locomotive.

In this case the break-even price for LNG is 2,36 NOK/litre other costs staying status quo (figure 15).

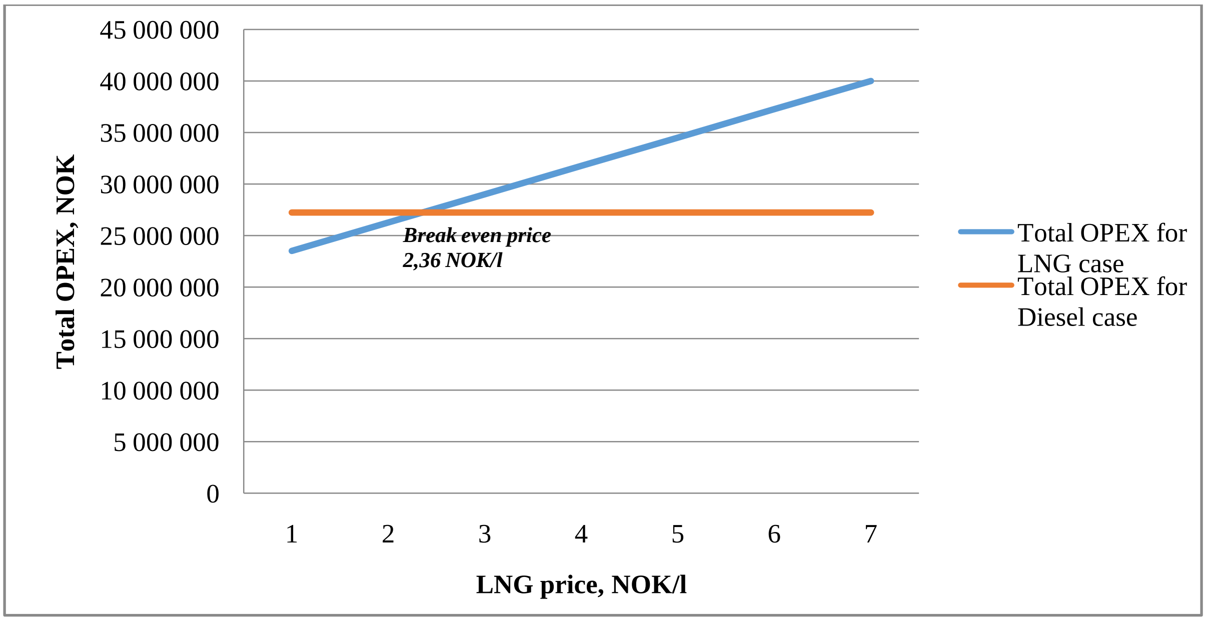

Figure 15: Break-even price for LNG fuel (Source: own display)

Or, in other words, LNG break-even price has to be around 52% lower in order to equalize the costs, and, this is quite difficult to achieve given the higher European natural gas prices and additional distribution costs incurred in Norway. The diesel price must be higher in order LNG could successfully compete with diesel fuel.

Below the break-even point the rail operator accumulates financial savings by operating LNG train compared with diesel. It becomes cheaper to switch to LNG fuel than leave the diesel fuel when LNG price is lower than 2,36 NOK/litre.

Figure 16 illustrates the financial surplus based on different LNG price (from 1 NOK/litre to 7 NOK/litre) while other conditions (including diesel price) stay status quo. It can be seen that rail operator could save 3,7 mln. NOK per train each year when LNG price is 1 NOK/litre; and 0,988 mln. NOK per train when LNG price reaches 2 NOK/litre. However, when LNG prices are higher than 2,36 NOK/litre rail operator incurs financial loss by operating LNG locomotive.

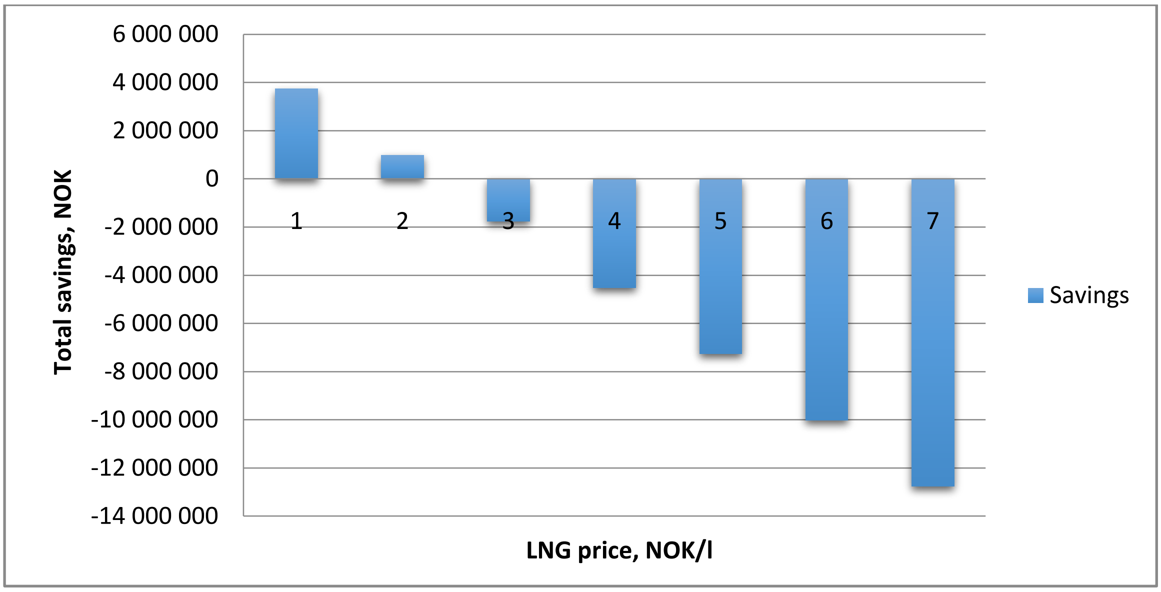

Figure 16: Cost savings based on different LNG prices (Source: own display)

The similar effect is also shown on transportation cost per TEU with different LNG prices. The table below indicates that only with LNG prices till 2,36 is cheaper to transport one TEU with LNG train compared with diesel counterpart.

Table 14: Cost per TEU based on different LNG price scenarios

LNG price NOK/l	LNG NOK/TEU	Diesel NOK/TEU	Difference, %
1	691	801	13,7%
2	772	801	3,6%
3	853	801	-6,5%
4	934	801	-16,6%
5	1 015	801	-26,7%
6	1 096	801	-36,7%
7	1 177	801	-46,8%

Source: own display

The main reasons of lower LNG profitability in Norwegian rail freight setting are related with too high CAPEX per locomotive and competitive diesel price that puts very low price ceiling for LNG. The latter means that there is limited *space* for LNG price fluctuation especially when rail operator needs 1,7 times more fuel compared with diesel to achieve the same travelled distance. Another thing is also related with limited market potential for LNG on the Nordland Line. Currently, only 12 departures per week are done with 729 km to one side; therefore, the investments into new trains would repay back much slower. For instance, in US where distances are 2500 km to one side and wholesale LNG prices are till 1 NOK/litre the accumulated effect of fuel cost savings each year becomes strong and visible in the beginning ensuring fast repayment of investments. In addition, the costs of diesel or LNG locomotives are at least 1,5-2 times lower in US compared with Europe due to much bigger domestic market (economies of scale).

Moreover, it is interesting to analyse the situation where diesel prices are gradually increasing (from 0% till 50%), or the situation, where diesel is taxed like in road sector (without VAT). In the latter case the price increase should be 90% from the current level. LNG price is fixed on 3 NOK/litre. It must be mentioned that the increase of current diesel prices is realistic since crude oil prices from the last year fell by approx. 50%; therefore, diesel prices remain low in most of the markets. Like it was mentioned before, the price level to keep crude oil production at sustainable rates is around 83-93 $/barrel. In addition, one must also bear in mind that crude oil resources are finite leading to the gradual increase of diesel prices in the long term until it reach a point where no longer would be profitable to use diesel fuel.

The table below indicates the effect of the changing diesel prices on cpu:

Table 15: Cost per TEU based on different diesel price scenarios

Diesel Price	Price increase	Diesel NOK/TEU	LNG NOK/TEU	Difference
9,83	100%	1032	853	17,3%
7,38	50%	917	853	6,9%
6,88	40%	894	853	4,5%
6,39	30%	871	853	2,0%
5,90	20%	847	853	-0,7%
5,41	10%	824	853	-3,5%
4,92	0%	801	853	-6,5%

Source: own display

In this case scenario it can be seen that 20% increase of diesel price from current level would make rail operator indifferent which fuel to use whereas 30% or higher percentage increase of prices would incentivize to switch to LNG much strongly than now. It also follows that in future LNG has a real potential to become a serious competitor for diesel fuel in the Norwegian rail industry if the market forces would push diesel prices upwards and LNG prices would sustain at the current low levels.

Finally, if diesel would be taxed in the way road transport users are taxed the rail operator could operate the natural gas fuelled locomotive profitably till 5 NOK/litre. Of course, the author does not recommend taxing diesel fuel in the same manner as it is done in road transport since this would lower the rail freight competition substantially in the cargo transportation market. However, what is intended to imply that if in the mid- or long term Norwegian government would have incentives to use cheaper and cleaner LNG fuel instead of diesel one of the first ways would be to reconsider the taxation of diesel fuel.

This situation is not so far unrealistic if diesel prices would start increasing globally and government would see that it is getting too expensive to ease the tax burden for rail freight operators.

To sum up the results of PCA, it can be stated that today rail operator would be better of investing to the same diesel locomotive than LNG one based on the given price levels and the disadvantages and risks distinguished in the SWOT matrix. For instance, not existing regulatory environment (that would support a change to LNG fuels) or risk for lower engine pulling capacity over mountains (lower fuel efficiency) would add its weight to rail operator's decision. Finally, a rail operator does not pay taxes for diesel fuel (except NO_X that can be fully returned), neither environmental regulations exist limiting the emissions like it is in shipping sector. However, this may be true for short-term period but not necessarily for long-term period (after 7-10 years) when efficient NG engines would be commercialised, LNG refuelling infrastructure fully developed and price differential become sufficiently high to justify investments.

Another point is related with environmental effectiveness of LNG. Rail operators might not be too much concerned about this (no regulations exist); however local people – yes. One of the government's duties is to ensure clean environment for its citizens by adopting environmentally friendly technologies or clean energy solutions. LNG in general is regarded as a cleaner fuel than diesel. In fuel combustion stage it emits lower harmful substances than diesel does. Therefore, when assessing the project it is necessary to have a broader perspective and include third parties interests as well. This is done with CBA analysis in the next subsection.

7.2 Cost Benefit Analysis

As it was mentioned before, two case scenarios are considered in CBA. Base case where rail operator chooses to invest into diesel locomotives, alternative case where LNG locomotives are purchased. Differently from PCA, additional social environmental costs are included (appendix 8) and together with all other affected operating costs, they are discounted in 30 years period. The results of CBA are shown below and in appendix 9.

Table 16: CBA results (Source: own display)

Year	Units	0	1	2	3	…	30	Total Budget
Base Case								
Projected Costs for Diesel Loco								
Investments	NOK	68 944 000	0	0	0	0	0	**68 944 000**
Maintenance costs	NOK	0	7 445 310	7 445 310	7 445 310	…	7 445 310	**223 359 300**
Fuel costs	NOK	0	14 219 868	14 219 868	14 219 868	…	14 219 868	**426 596 032**
Social economic costs	NOK	0	4 836 073	4 836 073	4 836 073	…	4 836 073	**145 082 184**
Total costs	NOK	68 944 000	26 501 251	26 501 251	26 501 251	…	26 501 251	**863 981 516**
Projected Revenues	NOK	0	0	0	0	0	0	**0**
Cash Flow	NOK	-68 944 000	-26 501 251	-26 501 251	-26 501 251	…	-26 501 251	**-863 981 516**
Discounted Cash Flow	NOK	-68 944 000	-25 481 972	-24 501 896	-23 559 515	…	-8 170 830	**-527 204 507**
NPV (4,0%)	NOK	**-527 204 507**						
Alternative Project								
Projected Costs for LNG Loco								
Investments	NOK	85 232 020	0	0	0	0	0	**85 232 020**
Maintenance costs	NOK	0	7 693 487	7 693 487	7 693 487	…	7 693 487	**230 804 610**
Fuel costs	NOK	0	15 879 132	15 879 132	15 879 132	…	15 879 132	**476 373 952**
Social economic costs	NOK	0	1 924 849	1 924 849	1 924 849	…	1 924 849	**57 745 473**
Total costs	NOK	85 232 020	25 497 468	25 497 468	25 497 468	…	25 497 468	**850 156 055**
Projected Revenues	NOK	0	0	0	0	0	0	**0**
Cash Flow	NOK	-85 232 020	-25 497 468	-25 497 468	-25 497 468	…	-25 497 468	**-850 156 055**
Discounted Cash Flow	NOK	-85 232 020	-24 516 796	-23 573 842	-22 667 156	…	-7 861 345	**-526 135 083**
NPV (4,0%)	NOK	**-526 135 083**						
Financial Metrics								
Reduction in OPEX costs	*%*		*3,8%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*	
Benefits Cash Flow	*NOK*	-16 288 020	*1 003 783*	*1 003 783*	*1 003 783*	…	*1 003 783*	***13 825 461***
Discounted Benefits Cash Flow	*NOK*	-16 288 020	*965 176*	*928 054*	*892 359*	…	*309 485*	***1 069 424***
Cumulative Discounted Benefits Cash Flow	*NOK*	-16 288 020	-15 322 844	-14 394 791	-13 502 432	…	1 069 424	
Net Present Value (4,0%)	*NOK*	**1 069 424**						
Economic Rate of Return	*%*	***1%***						
Breakeven	years	***26,7***						

It can be seen that:

- NPV value of Base case is -527 204 507 NOK; and
- NPV value of LNG case is -526 135 083 NOK at the given price levels.

The cost advantage of LNG locomotives compared with diesel trains is marginal at the given fuel price levels. And this advantage is only due to external environmental costs, which for rail operator are not so important, but for society yes. It also can be seen that with such fuel prices in the market fuel cost savings would be negative, and maintenance costs higher for LNG case. In addition, CAPEX is also too high for LNG.

Overall, since the difference between NPV values is small and breakeven in years (when the difference of investments are fully recovered) would reach more than 26 years it can be doubted that rail operators would choose to invest into LNG locomotives on their own decision (especially when they do not pay for environmental costs). From society's point of view, as long as diesel price will continue to be very low the motivation to switch at the given price levels will also stay low even though NPV value for LNG case is slightly higher than for diesel case. The difference of environmental costs (2.9 mln. NOK) is not high enough in order to accelerate faster repayment of initial investments. This is because currently used diesel-electric engines (EURO4000) on the Nordland Line are much more fuel efficient than they were before complying with Stage III A and III B European emission regulations.

After computing the main CBA indicators in the current market setting the next step is to perform sensitivity analysis. The most sensitive indicators like in PCA analysis are fuel prices that determine fuel cost savings per year. Other chosen indicators are CAPEX and maintenance costs for LNG-fuelled locomotives, and shadow price for CO_2 emissions (the quantity of other emitted air pollutants is much smaller compared with CO_2; therefore, they are not included into analysis). These indicators are the main ones influencing the economy of LNG fuel, and their values are not certain in future.

7.2.1 Sensitivity Analysis

Sensitivity analysis is intended to show the most sensitive indicators for investments and in this way reveal how large the risks of a project are if some assumptions are changed. The decision taker must take into account the most critical variables of the investments; follow their future forecasts and changes before and during the project implementation.

These indicators are selected for sensitivity analysis:

- Diesel fuel price;
- LNG fuel price;
- CO_2 shadow price;
- Investments for LNG-fuelled locomotives;
- Maintenance costs for LNG-fuelled locomotives;

Also, like in primary CBA, it is assumed that rail operator has to purchase 2 locomotives in the short term to replace the old ones; therefore only the difference of train investment costs must be repaid back.

The results are presented in the following tables 17-21.

The most critical variables for NPV values of diesel and LNG cases as it was expected are fuel prices. With the change of fuel prices +/-15 %, the value of NPV changes +42/-40 mln. NOK.

Table 17 also illustrates that even a small increase of diesel price (10%) already gives a stronger motivation towards LNG fuel. In PCA analysis only 30% increase of diesel price from current levels (4.92 NOK/litre) was meaningful for rail operator to consider the purchase of LNG locomotives now in necessity to replace the old ones. This difference happens due to inclusion of environmental costs into CBA analysis, which are much lower for LNG than for diesel fuel.

From another point of view, table 18 shows a high sensitivity of LNG prices on NPV values as well. A small change of price can alter the picture significantly. For instance, 10% decrease of LNG price would increase the difference of NPV value to 28,5 mln. NOK.

Therefore, both tables 17 and 18 illustrate a very high risk of changing fuel prices on project’s cash flows (that affect final NPV and ERR values).

Another critical indicator for project’s NPV value is maintenance costs for LNG-fuelled locomotives. A change of those costs +/-15 % influences the range of the difference in NPV values +21/-19 mln. NOK. This indicator is also expected since maintenance costs (for wagons) are the second biggest cost element (after fuel costs) that is affected by the fuel change.

Table 17: Effect of diesel price change on NPV

	-15%	-10%	-5%	0%	5%	10%	15%
LNG NPV	-526 135 083	-526 135 083	-526 135 083	-526 135 083	-526 135 083	-526 135 083	-526 135 083
Diesel NPV	-490 320 943	-502 615 464	-514 909 986	-527 204 507	-539 499 028	-551 793 550	-564 088 071
Difference in NPV	-35 814 140	-23 519 619	-11 225 097	1 069 424	13 363 945	25 658 467	37 952 988

Table 18: Effect of LNG price change on NPV

	-15%	-10%	-5%	0%	5%	10%	15%
LNG NPV	-484 947 712	-498 676 835	-512 405 959	-526 135 083	-539 864 207	-553 593 330	-567 322 454
Diesel NPV	-527 204 507	-527 204 507	-527 204 507	-527 204 507	-527 204 507	-527 204 507	-527 204 507
Difference in NPV	42 256 795	28 527 671	14 798 548	1 069 424	-12 659 700	-26 388 824	-40 117 947

Table 19: Effect of CO_2 shadow price change on NPV

	-15%	-10%	-5%	0%	5%	10%	15%
LNG NPV	-523 169 406	-524 157 965	-525 146 524	-526 135 083	-527 123 642	-528 112 201	-529 100 760
Diesel NPV	-522 967 825	-524 380 053	-525 792 280	-527 204 507	-528 616 734	-530 028 961	-531 441 188
Difference in NPV	-201 580	222 088	645 756	1 069 424	1 493 092	1 916 760	2 340 428

Table 20: Effect of LNG investments change on NPV

	-15%	-10%	-5%	0%	5%	10%	15%
LNG NPV	-513 350 280	-517 611 881	-521 873 482	-526 135 083	-530 396 684	-534 658 285	-538 919 886
Diesel NPV	-527 204 507	-527 204 507	-527 204 507	-527 204 507	-527 204 507	-527 204 507	-527 204 507
Difference in NPV	13 854 227	9 592 626	5 331 025	1 069 424	-3 192 177	-7 453 778	-11 715 379

Table 21: Effect of LNG maintenance costs on NPV

	-15%	-10%	-5%	0%	5%	10%	15%
LNG NPV	-506 179 678	-512 831 480	-519 483 281	-526 135 083	-532 786 885	-539 438 686	-546 090 488
Diesel NPV	-527 204 507	-527 204 507	-527 204 507	-527 204 507	-527 204 507	-527 204 507	-527 204 507
Difference in NPV	21 024 829	14 373 027	7 721 226	1 069 424	-5 582 378	-12 234 179	-18 885 981

Project's NPV value is also sensitive to the change of investments size to LNG-powered locomotives (it can positively or negatively affect the final result) (table 20). Whereas CO_2 shadow price is the least sensitive variable compared with other analysed indicators (table 19). Its change does not strongly influence the project's NPV value.

For illustrative reasons different diesel price scenarios are shown (table 22) in order to graphically demonstrate the repayment of investments difference in loco costs (16,3 mln. NOK) (not full LNG train costs). Figure 17 depicts how strongly diesel fuel price can determine the attractiveness of the LNG locomotives. For instance, a 5% decrease of diesel price (alternative 1) would not repay investments difference in 30 years period; while a 5% increase can shorten the repayment to 12 years when environmental costs are included. Such high fuel price sensitivity (both diesel and LNG) implies that:

1. LNG fuel can be very attractive alternative to diesel fuel since even a small increase of diesel price (10% from current levels) makes financially justified to invest to LNG locomotives rather than buy diesel trains from society's perspective.
2. From another point of view, putting the LNG future just on fuel prices is a big weakness for the project. Its price change can positively or negatively affect the repayment of investments; therefore, rail operators would require a much higher price differential of fuel prices in order to go on LNG from financial perspective. It is believed that the natural gas-to-diesel price ratio should be at least twice (LNG 3.00 NOK/litre, diesel 6.00 NOK/litre). In addition, the sufficient price differential has to be guaranteed for investors; otherwise, it is doubtful that they would take a high fuel price risk of the project.

Overall, the sensitivity analysis revealed that the most critical variables for the LNG project are fuel prices. In addition, the decision taker has to follow the change of investments and maintenance costs for LNG trains compared with diesel locomotives.

Table 22: Different diesel price scenarios (own display)

Scenarios	Increase %	Diesel price NOK/l	LNG price NOK/l
Base case	0%	4,64	3,00
Alternative 1	-5%	4,41	3,00
Alternative 2	5%	4,87	3,00
Alternative 3	10%	5,10	3,00

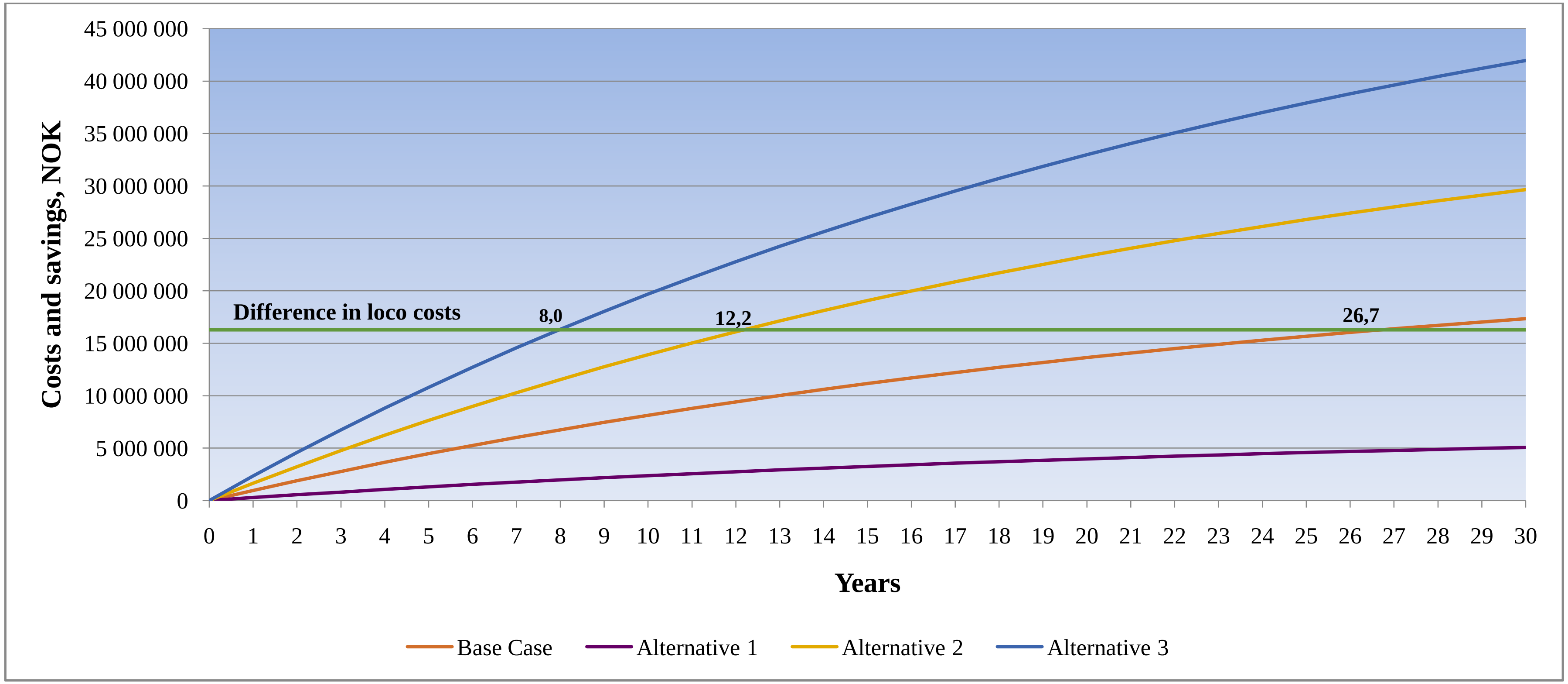

Figure 17: Difference in loco costs repayment analysis based on different diesel price scenarios (own display)

7.3 Discussion

In future LNG as a transportation fuel can have big commercial opportunities in global transportation sector. However its potential differs among transport sectors and countries depending on many successful parameters such as domestic recourses, price, regulations, policy or market potential. The main advantage of LNG is its ability to reduce local air pollution and in some cases to offer a higher cost advantage compared with oil-based fuels.

In Norway LNG was already successfully tried in the short sea shipping sector. The bunker costs were reduced as well as very harmful NO_X and SO_2 emissions. With this success, other transport sectors – road and rail transport – felt a motivation at least to make the first analysis assessing LNG opportunities for them.

Norwegian railway lines are mostly electrified; however, still two lines are based on diesel traction. The longest one – Nordland Line (729 km) – was assessed in the research.

The empirical analysis showed two different perspectives towards LNG fuel: from rail operators' (PCA) and from society's point of view (CBA).

PCA revealed that with current fuel price levels in the market it would be more expensive to operate LNG-fuelled locomotive than diesel train by 5%-6% due to higher CAPEX for LNG technology, maintenance costs and the absence of fuel cost savings (rail operator needs 1,7 times more LNG fuel than diesel fuel, and current price gap is too small). The sensitivity analysis for PCA also showed that rail operator could operate cheaper LNG locomotive than diesel one if diesel prices increase by at least 30% (6.4 NOK) with remaining LNG prices at 3.00 NOK/litre levels. With current diesel price the break-even LNG price is 2.36 NOK/litre, which is very low taking into account that the difference between wholesale and retail LNG prices in Norway is approx. 100%.

The results of CBA analysis indicated that even though NPV value for LNG case is slightly higher than for diesel case (due to inclusion of environmental costs), still the evidence would be too weak to convince rail operators and politicians to go for LNG at the given fuel price levels in the market. It is believed that the price differential needs to be higher because the disadvantages and risks for a project (especially, fuel price risk) are substantial and not easily to be reduced.

In any case it could be stated that LNG faces an *entrance barrier* to the fuel market because currently rail operators do not need to pay any fuel taxes even though the environmental costs are incurred (road transport is fully taxed). As a result, diesel price is too low to make LNG an attractive fuel solution.

Another crucial point is that differently from shipping sector where environmental regulations are strict, there are no such environmental incentives in the rail market to move towards environmentally friendly fuel. Currently, no regulations exist; no taxes have to be paid. This weakens LNG fuel advantage considerable in the light of diesel fuel. Therefore, the fuel price becomes the major influencing factor towards the change in the rail freight industry of Norway. And this is not very good circumstance if the politicians responsible for Norwegian rail transport would decide to facilitate the adoption of LNG technology. Environmental incentives in the rail freight market need to be created in order to strengthen LNG position. The price factor cannot be the only convincing factor since the price gap is not guaranteed to stay sufficient for a long term. Also, if government would support LNG change it should reconsider the taxation of diesel fuel. It would simply be not logical to support diesel and LNG fuel usage at the same time.

The decision towards the right policy for fuel in not electrified railway lines has to be made in the short term; however, its effects on the industry will be long term. Rail projects are capital-intensive and the depreciation period is around 30 years. Therefore, it is very crucial to decide how to shape the Norwegian rail fuel market – to go gradually on environmentally friendly fuel LNG or leave diesel fuel.

Even though, SWOT analysis and PCA showed that LNG technology is not feasible in the short term, there are many positive signs that could facilitate LNG technology adoption in future. Norway has abundant recourses of natural gas as well as already existing upstream supply infrastructure. Even downstream distribution network is developing year by year. In the long-term diesel prices (10-15 years) are intended to increase twice (appendix 3) since the needs for fuel are increasing however the resources are limited. In opposite, the history for natural gas at least in the transport sector has just started. Prices for natural gas are expected to stay low in international gas markets in coming decade based on World Bank forecasts. Therefore, it is believed that LNG has commercial potential in Norwegian rail transport in future even though the change can take several decades.

However, despite positive fuel price forecasts, still an uncertainty about the development of future fuel prices exists in the market complicating the process of taking the right decision towards the best fuel. As a result, it is difficult to say <u>now</u> whether the implementation of LNG project should start soon or leave the open question till *better* times.

Firstly, in order to answer the question, more detailed research must be done as well as more expertise has to be employed on technical issues. This thesis is the first step to understand the current situation in Norwegian rail freight market and the possible opportunities for LNG fuel. It gives a broad picture; however, not very detailed one.

Secondly, the answer depends very much on people's opinion about the long-term development of fuel prices. Those who believe in substantial increase of diesel prices in the long term might better go on LNG projects today. In opposite, people who think that diesel price will stay at around 5-6 NOK level for coming 20 years, would better vote on leaving the situation on status quo conditions.

To sum up, the topic is not easy to solve since it involves many uncertain factors (fuel prices, development of regulatory environment, etc.). In addition, such projects as LNG one are expensive, need a lot of preparation (time, capital, labour), involve many stakeholders (from private sector, government) and have long-term outcomes for the industry. A single study is simply not enough to decide; therefore, the recommendations are given in the further sub-section.

7.4 Recommendations

To finalize the decision about the possibility to adopt LNG fuel instead of diesel, the research must be deepened even more elaborating on different research perspectives such as:

1. Technical feasibility of the LNG technology. Must be more thoroughly examined technical abilities of natural gas engine in comparison with diesel engine. Issues such as engine performance, including fuel efficiency, emissions and necessary maintenance need to be addressed in more detailed manner. Also, fuel tender's position (on board or extra wagon) and its standardization with locomotive have to be examined as well.
2. Future fuel prices. It must be consulted with companies doing forecasts on them. Firstly, it must be clarified the accurate retail LNG price today and, then its future development scenarios. The companies might also give advices how to manage the risk of fluctuating fuel prices (e.g. hedging).

3. The best supply scenarios. It must be consulted (and report done) with suppliers such as *Barents NaturGass* and *Gasnor*. They should give the prices and present their solutions regarding refuelling of locomotives.
4. Inclusion of rail passenger transport, which would allow a higher distribution of fixed costs on more units.
5. Finally, project financing sources. It is important to check whether there would be any possible financing sources for the project such as EU funds or national financial programs.

All these issues were not addressed in detail in the thesis research limiting LNG potential. Therefore, if the project would be decided to continue, the preparation should include several more studies on the areas listed above. It is believed that then the picture about the LNG technology would be more complete; and decision could be done: either to move towards full LNG project implementation (testing stage), or wait for *better times* when the price gap would be substantial, downstream LNG refuelling infrastructure more developed and natural gas engines for rail industry commercialized in Europe.

In general, it is believed that LNG has commercial opportunities in the Norwegian rail market in future and it should not be underestimated. And this is only good news for rail operators to know that they are not depended on one fuel type, which is believed to get more expensive after few decades. They can control this risk by analysing different fuel possibilities today in order to be ready for future challenges. It is important that people taking decisions about the future of rail sector would be open-minded and prepared for different future scenarios.

8.0 CONCLUSION AND FUTURE RESEARCH

8.1 Conclusion

The aim of the work was to investigate the economic advantage of LNG-technology in the Norwegian rail freight industry, and give the discussion/recommendations towards LNG fuel implementation on the Nordland Line. In order to fulfil this aim both scientific and empirical research was done. It revealed the main conclusions that can be formulated in the following way:

1. The importance of LNG is rapidly increasing both within natural gas and global energy markets. The annual growth rate in trade was 7.5% during 1990-2013. The main reasons are related with decreased LNG supply chain costs, increased global energy demands, abundant worldwide recourses, increasing liberalization of natural gas markets, price competitiveness and environmental effectiveness. However, the use of LNG as a fuel in transportation is marginal. Only 1.4% of total gas consumption in 2012 belonged to the transport sector.
2. In Norway LNG fuel is also used in very limited amounts since almost all produced LNG is exported to European markets. However, recently due to strict environmental regulations in shipping sector, more and more ship owners are turning into LNG fuel making Norway the pioneer and global leader in adopting LNG technology. It is generally considered that Norwegian experience in using LNG-fuelled vessels is successful in terms of reduced bunker price and cleaner environment.
3. SWOT analysis, as the main output of various theoretical considerations about LNG fuel implementation in the Norwegian rail freight industry, showed that the main strengths and possibilities are related with fuel cost savings, environmental effectiveness and opportunity to better utilize and diversify domestic energy sources. Also, LNG is safer fuel than diesel. Regarding refuelling infrastructure, Norway has already developed upstream network and year-by-year is developing downstream chain as well.
4. However, SWOT analysis also showed various disadvantages and risks that are hard to eliminate in the short time period. For instance, non-existing regulatory environment, low commercial practice compared with diesel, not matured engine technology, LNG long-term price risk and etc. Also, LNG contains less energy than diesel requiring 1.7 times more fuel (space and weight penalties).

5. Regarding LNG supply to the Nordland Line, there should not be any big problems. Currently, two possible fuel distributors – *Barents NaturGass* and *Gasnor* – already supply LNG to ships or manufacturing plants in Northern Norway investing into storage and distribution network.
6. Empirical research included two analyses: one from rail operator's perspective (PCA), and one from society's viewpoint (CBA). PCA showed that with current market conditions (fuel prices, CAPEX into new locomotives, freight volumes) diesel is still more preferable than LNG. The situation gets even more complicated when the disadvantages and risks listed in the SWOT matrix are included. CBA revealed that LNG project has a marginal advantage over current situation for society; however, it is believed that rail operators would require a much higher price gap between LNG and diesel fuel (2 times) in order to take the risks of the project.
7. From financial point of view the most critical variables for LNG project are fuel prices, investment and maintenance costs for LNG-fuelled trains. In addition, other challenges such as natural gas engine performance, constant fuel availability and refuelling infrastructure, safety and regulatory issues need to be overcome as well in order to unlock LNG potential in the Norwegian rail freight market.
8. In order to make the final decision about LNG fuel potential in the Norwegian rail freight industry additional studies have to be made. The recommendation cannot be based just on this research since several areas such as technical, financial, or logistics, have to be analysed separately and in more detailed level. This research is the first major step identifying the market prospects for LNG as well as the main obstacles. It is strongly recommended to conduct additional analysis and only then to take the final decision regarding LNG project implementation.
9. In general, LNG is believed to have commercial future in the Norwegian rail market as well as in the shipping sector. However, the environmental incentives have to be created in order LNG would compete not only on price that has a risk to be not sustainable factor in future. This task belongs to government in case they decide to move towards energy diversification in the rail freight market.

8.2 Future Research

The Thesis worked to evaluate the current situation and possibilities for LNG-technology in Norwegian rail freight market. As it was mentioned in recommendation part, additional analysis on technical issues, detailed forecasts on future fuel prices and the most optimal logistics scenario could bring additional value to the project. Also, the research could be extended with the analysis of rail passenger transport on the diesel traction lines. This would help to increase market potential for LNG.

Further research could also address strategic issues regarding Norwegian government policy towards the taxation of diesel fuel for freight trains. For instance, till what point (wholesale diesel price) is beneficial for government to support rail operators and not incentivize the fuel diversification? Since with too high diesel price, LNG might look much cheaper to use instead of easing tax burden for rail operators.

Finally, another important issue would be to look into a potential government support for LNG technology as for maritime cases (NO_X funds, investments support for ferries). Incentive programs would be necessary for LNG rail freight fuel adoption since the project would require both political will and industrial cooperation.

Those questions are recommended for further research about LNG potential in the Norwegian rail market.

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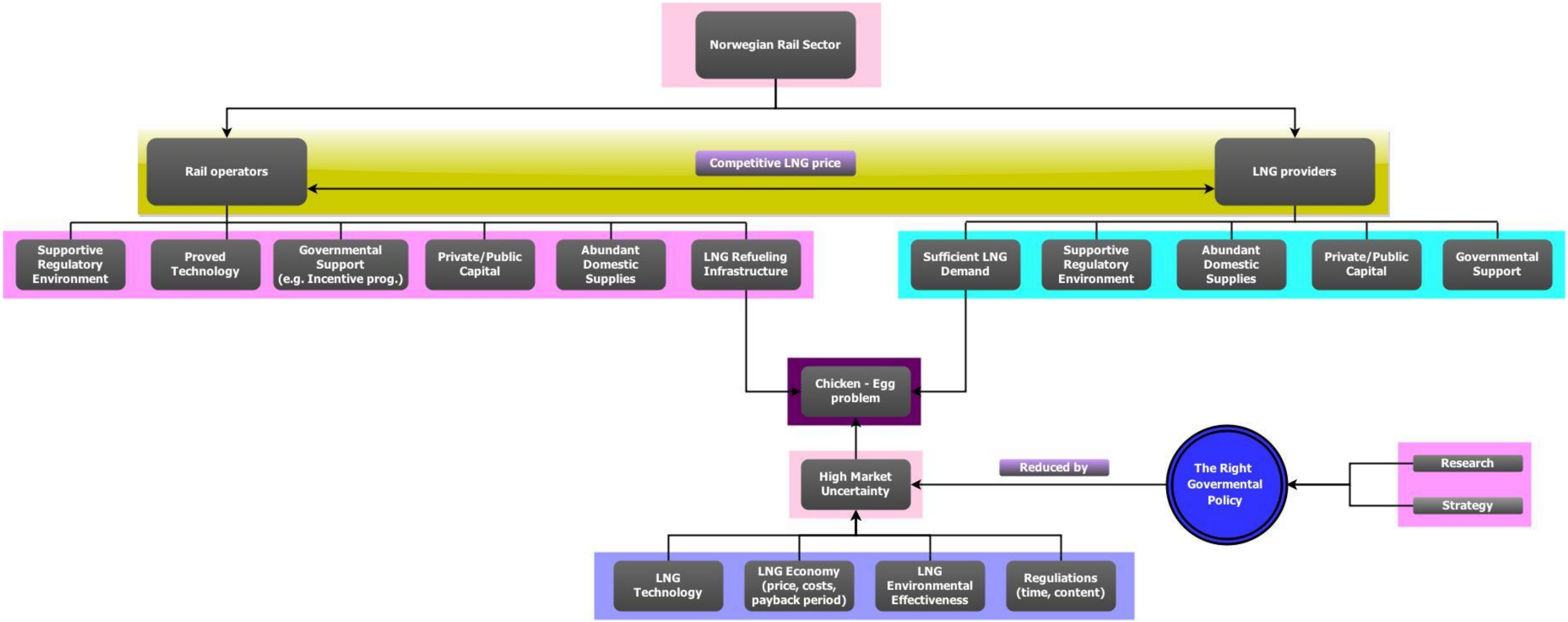
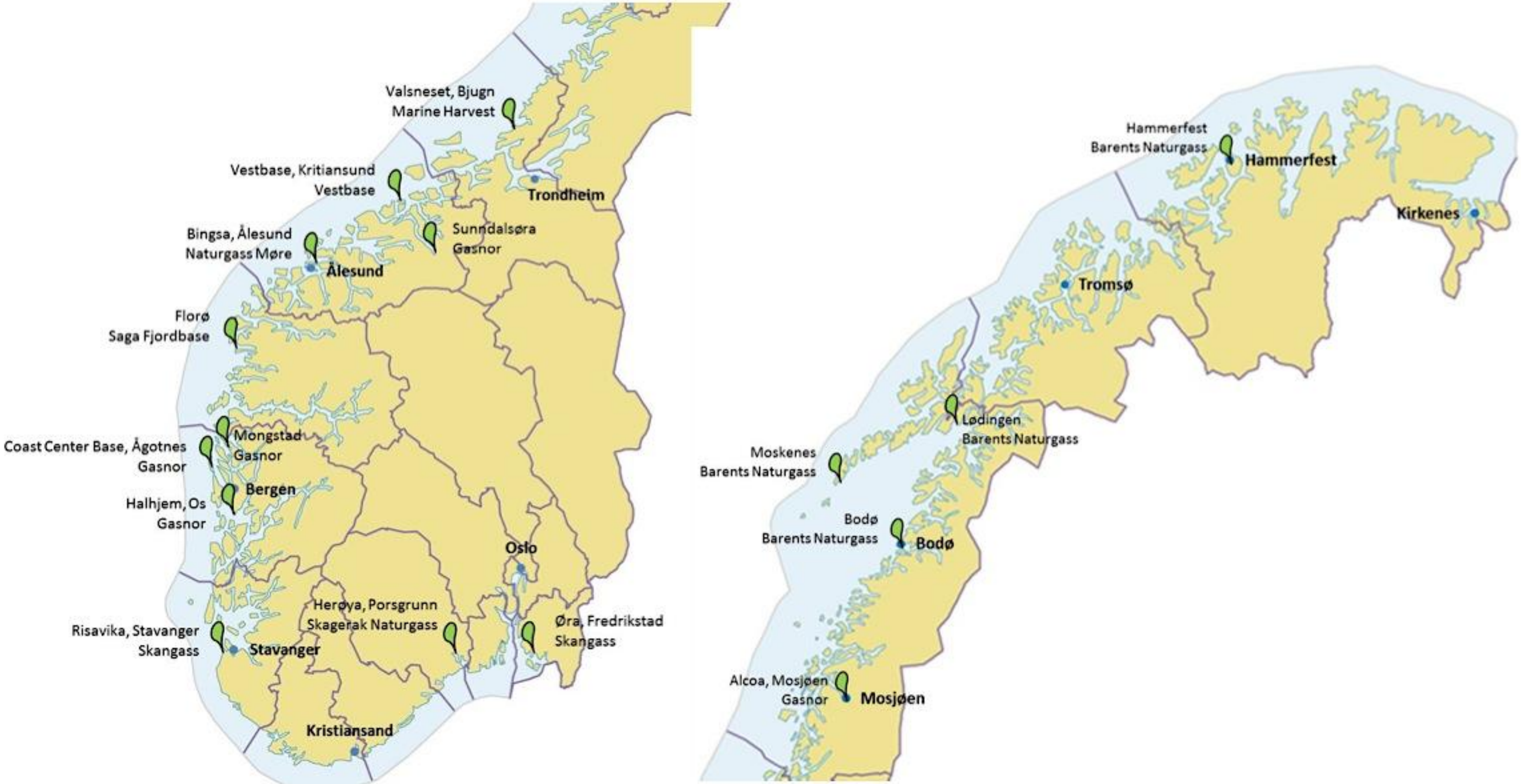
APPENDIX

Appendix 1: "Research problem – current market situation towards adoption of LNG fuel"



Source: own display

Appendix 2: LNG terminals in Norway

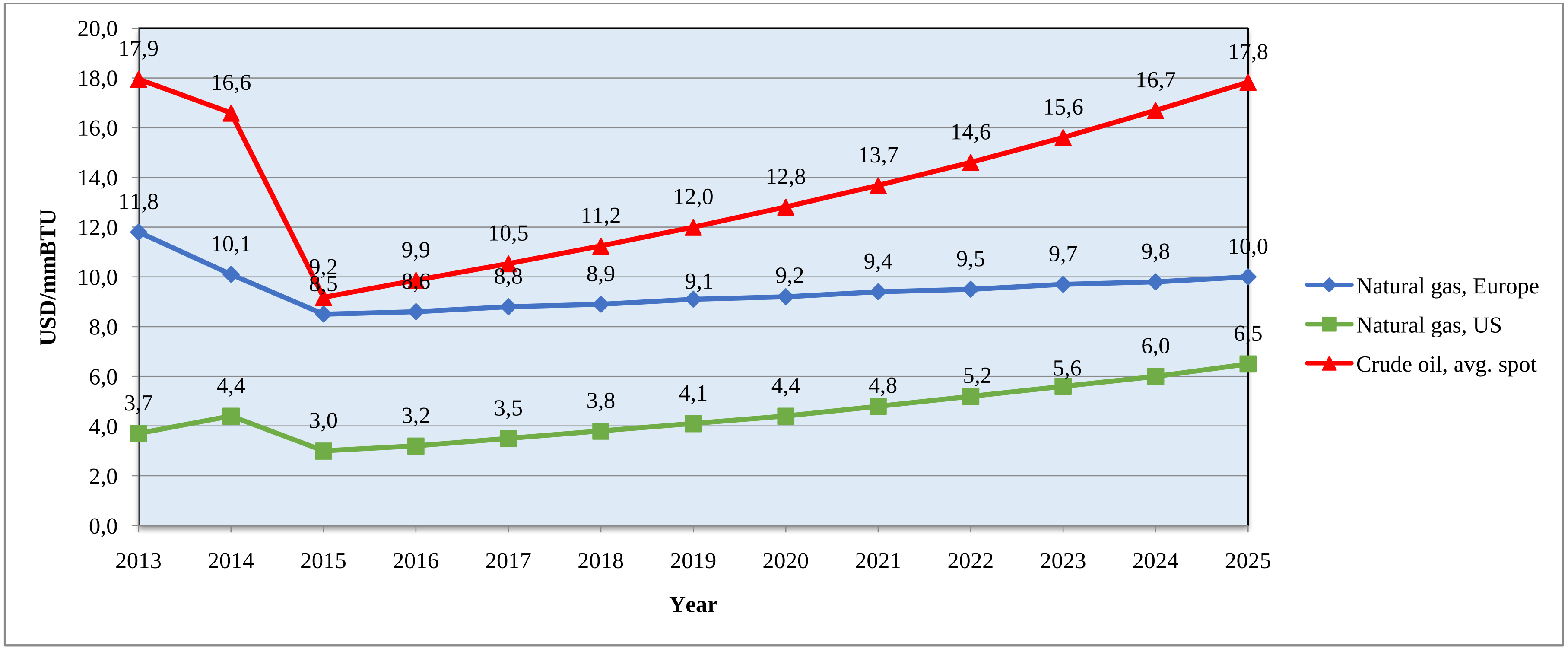


Source: EnergigassNorge 2015

Appendix 3: World Bank commodities price forecast (nominal US Dollars) (April 2015)

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Crude oil, avg. spot $/bbl	104,1	96,2	53,2	57,2	61,1	65,2	69,6	74,3	79,3	84,7	90,5	96,8	103,4
Natural gas, Europe $/mmBTU	11,8	10,1	8,5	8,6	8,8	8,9	9,1	9,2	9,4	9,5	9,7	9,8	10,0
Natural gas, US $/mmBTU	3,7	4,4	3,0	3,2	3,5	3,8	4,1	4,4	4,8	5,2	5,6	6,0	6,5
Crude oil, avg. spot $/mmBTU[10]	18	17	9	10	11	11	12	13	14	15	16	17	18
Price ratio between crude oil and natural gas Europe	1,52	1,64	1,08	1,15	1,20	1,26	1,32	1,39	1,45	1,54	1,61	1,70	1,78

Source: World Bank 2015



Source: author based on World Bank 2015 commodity price forecasts

[10]The conversion rate is 5.8 mmBTU to barrel based on EIA reasoning (quoted in Trading Nrg 2010).

Comment: The table above shows that crude oil price (that mostly determines diesel price) is expected to increase from 53.2 USD/bbl in 2015 to 103.4 USD/bbl in 2025 according to World Bank forecast. Or, in other words, crude oil prices are expected to double (+94%) in coming decade. Meanwhile the increase of natural gas prices in Europe should be more moderate – around +18% from 2015 to 2025.

Using a conversion rate (5.8 mmBTU to barrel) for crude oil price, the prices of fuels can be compared directly. The above graph illustrates that diesel price is expected to be 1.78 times higher than natural gas price in Europe by 2025 even though currently the price gap is very small.

As a result, based on World Bank forecasts it is expected that in future the price differential between crude oil and natural gas fuels will continue to grow in favour of natural gas.

Appendix 4: LNG terminals in Hammerfest, Bodø and Mosjøen

LNG Production Plant in Hammerfest

LNG Terminal in Bodø

LNG Terminal in Mosjøen

Appendix 5: LNG refuelling from truck to locomotive

Source: HHP Insight 2013

Appendix 6: Global LNG prices and forecasts, $/mmBTU

	Japan	India	Spain	Argentina	UK NBP	US HH	y/y change Japan	India	Spain	Argentina	UK NBP	US HH
Annual prices												
2012	*15.2*	*12.9*	*10.5*	*14.2*	*9.5*	*2.8*						
2013	*16.5*	*14.6*	*11.9*	*16.3*	*10.7*	*3.7*	9%	13%	14%	15%	13%	35%
2014	*14.0*	*13.1*	*11.3*	*14.1*	*8.4*	*4.5*	(15%)	(10%)	(5%)	(14%)	(21%)	19%
2015	*10.5*	*10.0*	*8.8*	*10.0*	*8.4*	*3.7*	(25%)	(23%)	(22%)	(29%)	(0%)	(17%)
2016	*9.5*	*9.1*	*7.9*	*9.0*	*7.5*	*3.9*	(10%)	(10%)	(11%)	(10%)	(11%)	4%

Source: Reuters, Energy Aspects 2014 December

Appendix 7: PCA Analysis results 1000 TEU - 30 000 TEU (own display based on received Jernbaneverket data)

General info	**Units**	**BaseCase**	**BaseCase**	**BaseCase**	**BaseCase**	**BaseCase**	**BaseCase**	**BaseCase**
Volume (TEU)	**TEU**	**1 000**	**2 000**	**3 000**	**4 000**	**5 000**	**6 000**	**7 000**
Train utilization per year	days	313	313	313	313	313	313	313
Average velocity	km/h	50	50	50	50	50	50	50
Max train length Nordland Line	m	390	390	390	390	390	390	390
Distance Bodø - Trondheim	km	729	729	729	729	729	729	729
Trains per day and direction	-	1	1	1	1	1	1	1
Train slots per day	-	2	2	2	2	2	2	2
Volume per day	TEU/day	3,2	6,4	9,6	12,8	16,0	19,2	22,4
Loop time	hours	48	48	48	48	48	48	48

Locomotives	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
Main haul engine	-	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000
Operational engines	units	2	2	2	2	2	2	2
Engines including reserve	units	2,5	2,5	2,5	2,5	2,5	2,5	2,5
Investments per engine	NOK/engine	34 472 000	34 472 000	34 472 000	34 472 000	34 472 000	34 472 000	34 472 000
Interest rate	%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30	30	30	30
Train distance	km/year	456 354	456 354	456 354	456 354	456 354	456 354	456 354
Train utilization per year	hours/year	5 008	5 008	5 008	5 008	5 008	5 008	5 008
Pulling capacity	tonnes	1 400	1 400	1 400	1 400	1 400	1 400	1 400
Load weight	tonnes	51	102	153	204	256	307	358
Tare weight	tonnes	476	476	476	476	476	476	476
Total train weight	tonnes	527	578	629	680	732	783	834
CAPEX including reserve	NOK	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461
Fix maintenance	NOK	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000
Var maintenance	NOK	4 563 540	4 563 540	4 563 540	4 563 540	4 563 540	4 563 540	4 563 540
Total maintenance	NOK	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540
Energy consumption	liters	997 943	1 045 212	1 090 434	1 133 854	1 175 671	1 216 051	1 255 133
Diesel price	NOK/liter	4,92	4,92	4,92	4,92	4,92	4,92	4,92
LNG price	NOK/liter	-	-	-	-	-	-	-
Energy cost	NOK	4 907 180	5 139 616	5 361 986	5 575 494	5 781 122	5 979 683	6 171 860

Wagons	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
Wagon model	-	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104
Loop time	hours	48	48	48	48	48	48	48
Number of train sets	units	2	2	2	2	2	2	2
No of wagons (including reserve)	units	30	30	30	30	30	30	30
Investment costs per wagon	NOK/wagon	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000
Wagon distance	km/year	456 354	456 354	456 354	456 354	456 354	456 354	456 354
Interest rate	%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30	30	30	30
CAPEX Wagons	NOK	71 703	71 703	71 703	71 703	71 703	71 703	71 703
CAPEX including reserve	NOK	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086
Fix maintenance	NOK	600 000	600 000	600 000	600 000	600 000	600 000	600 000
Var maintenance	NOK	3 422 655	3 422 655	3 422 655	3 422 655	3 422 655	3 422 655	3 422 655
Total maintenance	NOK	4 022 655	4 022 655	4 022 655	4 022 655	4 022 655	4 022 655	4 022 655

Staff	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
Total staff cost	NOK	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155

Total operating cost	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
CAPEX Locomotive	NOK	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461
Total Maintenance Locomotive	NOK	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540
CAPEX Wagons	NOK	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086
Total Maintenance Wagons	NOK	4 022 655	4 022 655	4 022 655	4 022 655	4 022 655	4 022 655	4 022 655
Energy Cost	NOK	4 907 180	5 139 616	5 361 986	5 575 494	5 781 122	5 979 683	6 171 860
Staff	NOK	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155
Infrastructure cost	NOK	0	0	0	0	0	0	0
Sum	NOK	24 314 076	24 546 513	24 768 883	24 982 391	25 188 019	25 386 580	25 578 757
Cost per unit	NOK/TEU	12 157	6 137	4 128	3 123	2 519	2 116	1 827

General info	**Units**	**BaseCase**	**BaseCase**	**BaseCase**	**BaseCase**	**BaseCase**	**BaseCase**	**BaseCase**
Volume (TEU)	**TEU**	**8 000**	**9 000**	**10 000**	**11 000**	**12 000**	**13 000**	**14 000**
Train utilization per year	days	313	313	313	313	313	313	313
Average velocity	km/h	50	50	50	50	50	50	50
Max train length Nordland Line	m	390	390	390	390	390	390	390
Distance Bodø - Trondheim	km	729	729	729	729	729	729	729
Trains per day and direction	-	1	1	1	1	1	1	1
Train slots per day	-	2	2	2	2	2	2	2
Volume per day	TEU/day	25,6	28,8	31,9	35,1	38,3	41,5	44,7
Loop time	hours	48	48	48	48	48	48	48

Locomotives	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
Main haul engine	-	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000
Operational engines	units	2	2	2	2	2	2	2
Engines including reserve	units	2,5	2,5	2,5	2,5	2,5	2,5	2,5
Investments per engine	NOK/engine	34 472 000	34 472 000	34 472 000	34 472 000	34 472 000	34 472 000	34 472 000
Interest rate	%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30	30	30	30
Train distance	km/year	456 354	456 354	456 354	456 354	456 354	456 354	456 354
Train utilization per year	hours/year	5 008	5 008	5 008	5 008	5 008	5 008	5 008
Pulling capacity	tonnes	1 400	1 400	1 400	1 400	1 400	1 400	1 400
Load weight	tonnes	409	460	511	562	613	665	716
Tare weight	tonnes	476	476	476	476	476	476	476
Total train weight	tonnes	885	936	987	1 038	1 089	1 141	1 192
CAPEX including reserve	NOK	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461
Fix maintenance	NOK	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000
Var maintenance	NOK	4 563 540	4 563 540	4 563 540	4 563 540	4 563 540	4 563 540	4 563 540
Total maintenance	NOK	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540
Energy consumption	liters	1 293 034	1 329 855	1 365 684	1 400 597	1 434 660	1 467 933	1 500 469
Diesel price	NOK/liter	4,92	4,92	4,92	4,92	4,92	4,92	4,92
LNG price	NOK/liter	-	-	-	-	-	-	-
Energy cost	NOK	6 358 230	6 539 292	6 715 473	6 887 149	7 054 648	7 218 261	7 378 247

Wagons	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
Wagon model	-	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104
Loop time	hours	48	48	48	48	48	48	48
Number of train sets	units	2	2	2	2	2	2	2
No of wagons (including reserve)	units	30	30	30	30	30	30	30
Investment costs per wagon	NOK/wagon	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000
Wagon distance	km/year	456 354	456 354	456 354	456 354	456 354	456 354	456 354
Interest rate	%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30	30	30	30
CAPEX Wagons	NOK	71 703	71 703	71 703	71 703	71 703	71 703	71 703
CAPEX including reserve	NOK	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086
Fix maintenance	NOK	600 000	600 000	600 000	600 000	600 000	600 000	600 000
Var maintenance	NOK	3 422 655	3 422 655	3 422 655	3 422 655	3 422 655	3 422 655	3 422 655
Total maintenance	NOK	4 022 655	4 022 655	4 022 655	4 022 655	4 022 655	4 022 655	4 022 655

0

Staff	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
Total staff cost	NOK	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155

Total operating cost	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
CAPEX Locomotive	NOK	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461
Total Maintenance Locomotive	NOK	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540
CAPEX Wagons	NOK	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086
Total Maintenance Wagons	NOK	4 022 655	4 022 655	4 022 655	4 022 655	4 022 655	4 022 655	4 022 655
Energy Cost	NOK	6 358 230	6 539 292	6 715 473	6 887 149	7 054 648	7 218 261	7 378 247
Staff	NOK	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155
Infrastructure cost	NOK	0	0	0	0	0	0	0
Sum	NOK	25 765 127	25 946 188	26 122 369	26 294 045	26 461 544	26 625 158	26 785 144
Cost per unit	NOK/TEU	1 610	1 441	1 306	1 195	1 103	1 024	957

General info	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
Volume (TEU)	**TEU**	**15 000**	**16 000**	**17 000**	**18 000**	**19 000**	**20 000**	**21 000**
Train utilization per year	days	313	313	313	313	313	313	313
Average velocity	km/h	50	50	50	50	50	50	50
Max train length Nordland Line	m	390	390	390	390	390	390	390
Distance Bodø - Trondheim	km	729	729	729	729	729	729	729
Trains per day and direction	-	1	1	1	2	2	2	2
Train slots per day	-	2	2	2	4	4	4	4
Volume per day	TEU/day	47,9	51,1	54,3	28,8	30,4	31,9	33,5
Loop time	hours	48	48	48	48	48	48	48

Locomotives	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
Main haul engine	-	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000
Operational engines	units	2	2	2	2	2	2	2
Engines including reserve	units	2,5	2,5	2,5	2,5	2,5	2,5	2,5
Investments per engine	NOK/engine	34 472 000	34 472 000	34 472 000	34 472 000	34 472 000	34 472 000	34 472 000
Interest rate	%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30	30	30	30
Train distance	km/year	456 354	456 354	456 354	912 708	912 708	912 708	912 708
Train utilization per year	hours/year	5 008	5 008	5 008	10 016	10 016	10 016	10 016
Pulling capacity	tonnes	1 400	1 400	1 400	1 400	1 400	1 400	1 400
Load weight	tonnes	767	818	869	460	486	511	537
Tare weight	tonnes	476	476	476	476	476	476	476
Total train weight	tonnes	1 243	1 294	1 345	936	962	987	1 013
CAPEX including reserve	NOK	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461
Fix maintenance	NOK	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000
Var maintenance	NOK	4 563 540	4 563 540	4 563 540	9 127 080	9 127 080	9 127 080	9 127 080
Total maintenance	NOK	5 563 540	5 563 540	5 563 540	10 127 080	10 127 080	10 127 080	10 127 080
Energy consumption	liters	1 532 313	1 563 510	1 594 096	2 659 711	2 695 778	2 731 368	2 766 501
Diesel price	NOK/liter	4,92	4,92	4,92	4,92	4,92	4,92	4,92
LNG price	NOK/liter	-	-	-	-	-	-	-
Energy cost	NOK	7 534 837	7 688 239	7 838 639	13 078 583	13 255 935	13 430 946	13 603 705

Wagons	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
Wagon model	-	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104
Loop time	hours	48	48	48	48	48	48	48
Number of train sets	units	2	2	2	2	2	2	2
No of wagons (including reserve)	units	30	30	30	30	30	30	30
Investment costs per wagon	NOK/wagon	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000
Wagon distance	km/year	456 354	456 354	456 354	912 708	912 708	912 708	912 708
Interest rate	%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30	30	30	30
CAPEX Wagons	NOK	71 703	71 703	71 703	71 703	71 703	71 703	71 703
CAPEX including reserve	NOK	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086
Fix maintenance	NOK	600 000	600 000	600 000	600 000	600 000	600 000	600 000
Var maintenance	NOK	3 422 655	3 422 655	3 422 655	6 845 310	6 845 310	6 845 310	6 845 310
Total maintenance	NOK	4 022 655	4 022 655	4 022 655	7 445 310	7 445 310	7 445 310	7 445 310

Staff	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
Total staff cost	NOK	2 520 155	2 520 155	2 520 155	5 040 310	5 040 310	5 040 310	5 040 310

Total operating cost	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
CAPEX Locomotive	NOK	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461
Total Maintenance Locomotive	NOK	5 563 540	5 563 540	5 563 540	10 127 080	10 127 080	10 127 080	10 127 080
CAPEX Wagons	NOK	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086
Total Maintenance Wagons	NOK	4 022 655	4 022 655	4 022 655	7 445 310	7 445 310	7 445 310	7 445 310
Energy Cost	NOK	7 534 837	7 688 239	7 838 639	13 078 583	13 255 935	13 430 946	13 603 705
Staff	NOK	2 520 155	2 520 155	2 520 155	5 040 310	5 040 310	5 040 310	5 040 310
Infrastructure cost	NOK	0	0	0	0	0	0	0
Sum	NOK	26 941 734	27 095 135	27 245 535	42 991 830	43 169 182	43 344 192	43 516 951
Cost per unit	NOK/TEU	898	847	801	1 194	1 136	1 084	1 036

General info	**Units**	**BaseCase**	**BaseCase**	**BaseCase**	**BaseCase**	**BaseCase**	**BaseCase**	**BaseCase**
Volume (TEU)	**TEU**	**22 000**	**23 000**	**24 000**	**25 000**	**26 000**	**27 000**	**28 000**
Train utilization per year	days	313	313	313	313	313	313	313
Average velocity	km/h	50	50	50	50	50	50	50
Max train length Nordland Line	m	390	390	390	390	390	390	390
Distance Bodø - Trondheim	km	729	729	729	729	729	729	729
Trains per day and direction	-	2	2	2	2	2	2	2
Train slots per day	-	4	4	4	4	4	4	4
Volume per day	TEU/day	35,1	36,7	38,3	39,9	41,5	43,1	44,7
Loop time	hours	48	48	48	48	48	48	48

Locomotives	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
Main haul engine	-	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000
Operational engines	units	2	2	2	2	2	2	2
Engines including reserve	units	2,5	2,5	2,5	2,5	2,5	2,5	2,5
Investments per engine	NOK/engine	34 472 000	34 472 000	34 472 000	34 472 000	34 472 000	34 472 000	34 472 000
Interest rate	%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30	30	30	30
Train distance	km/year	912 708	912 708	912 708	912 708	912 708	912 708	912 708
Train utilization per year	hours/year	10 016	10 016	10 016	10 016	10 016	10 016	10 016
Pulling capacity	tonnes	1 400	1 400	1 400	1 400	1 400	1 400	1 400
Load weight	tonnes	562	588	613	639	665	690	716
Tare weight	tonnes	476	476	476	476	476	476	476
Total train weight	tonnes	1 038	1 064	1 089	1 115	1 141	1 166	1 192
CAPEX including reserve	NOK	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461
Fix maintenance	NOK	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000
Var maintenance	NOK	9 127 080	9 127 080	9 127 080	9 127 080	9 127 080	9 127 080	9 127 080
Total maintenance	NOK	10 127 080	10 127 080	10 127 080	10 127 080	10 127 080	10 127 080	10 127 080
Energy consumption	liters	2 801 194	2 835 462	2 869 320	2 902 784	2 935 866	2 968 580	3 000 937
Diesel price	NOK/liter	4,92	4,92	4,92	4,92	4,92	4,92	4,92
LNG price	NOK/liter	-	-	-	-	-	-	-
Energy cost	NOK	13 774 297	13 942 802	14 109 296	14 273 847	14 436 522	14 597 385	14 756 495

Wagons	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
Wagon model	-	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104
Loop time	hours	48	48	48	48	48	48	48
Number of train sets	units	2	2	2	2	2	2	2
No of wagons (including reserve)	units	30	30	30	30	30	30	30
Investment costs per wagon	NOK/wagon	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000
Wagon distance	km/year	912 708	912 708	912 708	912 708	912 708	912 708	912 708
Interest rate	%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30	30	30	30
CAPEX Wagons	NOK	71 703	71 703	71 703	71 703	71 703	71 703	71 703
CAPEX including reserve	NOK	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086
Fix maintenance	NOK	600 000	600 000	600 000	600 000	600 000	600 000	600 000
Var maintenance	NOK	6 845 310	6 845 310	6 845 310	6 845 310	6 845 310	6 845 310	6 845 310
Total maintenance	NOK	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310

Staff	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
Total staff cost	NOK	5 040 310	5 040 310	5 040 310	5 040 310	5 040 310	5 040 310	5 040 310

Total operating cost	Units	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase	BaseCase
CAPEX Locomotive	NOK	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461	5 149 461
Total Maintenance Locomotive	NOK	10 127 080	10 127 080	10 127 080	10 127 080	10 127 080	10 127 080	10 127 080
CAPEX Wagons	NOK	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086
Total Maintenance Wagons	NOK	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310
Energy Cost	NOK	13 774 297	13 942 802	14 109 296	14 273 847	14 436 522	14 597 385	14 756 495
Staff	NOK	5 040 310	5 040 310	5 040 310	5 040 310	5 040 310	5 040 310	5 040 310
Infrastructure cost	NOK	0	0	0	0	0	0	0
Sum	NOK	43 687 544	43 856 049	44 022 542	44 187 093	44 349 769	44 510 632	44 669 741
Cost per unit	NOK/TEU	993	953	917	884	853	824	798

General info	**Units**	**BaseCase**	**BaseCase**	**LNGCase**	**LNGCase**	**LNGCase**	**LNGCase**	**LNGCase**
Volume (TEU)	**TEU**	**29 000**	**30 000**	**1 000**	**2 000**	**3 000**	**4 000**	**5 000**
Train utilization per year	days	313	313	313	313	313	313	313
Average velocity	km/h	50	50	50	50	50	50	50
Max train length Nordland Line	m	390	390	390	390	390	390	390
Distance Bodø - Trondheim	km	729	729	729	729	729	729	729
Trains per day and direction	-	2	2	1	1	1	1	1
Train slots per day	-	4	4	2	2	2	2	2
Volume per day	TEU/day	46,3	47,9	3,2	6,4	9,6	12,8	16,0
Loop time	hours	48	48	48	48	48	48	48

Locomotives	Units	BaseCase	BaseCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase
Main haul engine	-	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000
Operational engines	units	2	2	2	2	2	2	2
Engines including reserve	units	2,5	2,5	2,5	2,5	2,5	2,5	2,5
Investments per engine	NOK/engine	34 472 000	34 472 000	42 616 010	42 616 010	42 616 010	42 616 010	42 616 010
Interest rate	%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30	30	30	30
Train distance	km/year	912 708	912 708	456 354	456 354	456 354	456 354	456 354
Train utilization per year	hours/year	10 016	10 016	5 008	5 008	5 008	5 008	5 008
Pulling capacity	tonnes	1 400	1 400	1 400	1 400	1 400	1 400	1 400
Load weight	tonnes	741	767	51	102	153	204	256
Tare weight	tonnes	476	476	516	516	516	516	516
Total train weight	tonnes	1 217	1 243	567	618	669	720	772
CAPEX including reserve	NOK	5 149 461	5 149 461	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021
Fix maintenance	NOK	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000
Var maintenance	NOK	9 127 080	9 127 080	4 563 540	4 563 540	4 563 540	4 563 540	4 563 540
Total maintenance	NOK	10 127 080	10 127 080	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540
Energy consumption	liters	3 032 949	3 064 627	1 759 695	1 837 291	1 911 739	1 983 396	2 052 552
Diesel price	NOK/liter	4,92	4,92	-	-	-	-	-
LNG price	NOK/liter	-	-	3,00	3,00	3,00	3,00	3,00
Energy cost	NOK	14 913 907	15 069 675	5 279 085	5 511 872	5 735 218	5 950 187	6 157 656

Wagons	Units	BaseCase	BaseCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase
Wagon model	-	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104
Loop time	hours	48	48	48	48	48	48	48
Number of train sets	units	2	2	2	2	2	2	2
No of wagons (including reserve)	units	30	30	31	31	31	31	31
Investment costs per wagon	NOK/wagon	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000
Wagon distance	km/year	912 708	912 708	456 354	456 354	456 354	456 354	456 354
Interest rate	%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30	30	30	30
CAPEX Wagons	NOK	71 703	71 703	71 703	71 703	71 703	71 703	71 703
CAPEX including reserve	NOK	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086
Fix maintenance	NOK	600 000	600 000	620 000	620 000	620 000	620 000	620 000
Var maintenance	NOK	6 845 310	6 845 310	3 536 744	3 536 744	3 536 744	3 536 744	3 536 744
Total maintenance	NOK	7 445 310	7 445 310	4 156 744	4 156 744	4 156 744	4 156 744	4 156 744

Staff	Units	BaseCase	BaseCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase
Total staff cost	NOK	5 040 310	5 040 310	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155

Total operating cost	Units	BaseCase	BaseCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase
CAPEX Locomotive	NOK	5 149 461	5 149 461	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021
Total Maintenance Locomotive	NOK	10 127 080	10 127 080	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540
CAPEX Wagons	NOK	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086
Total Maintenance Wagons	NOK	7 445 310	7 445 310	4 156 744	4 156 744	4 156 744	4 156 744	4 156 744
Energy Cost	NOK	14 913 907	15 069 675	5 279 085	5 511 872	5 735 218	5 950 187	6 157 656
Staff	NOK	5 040 310	5 040 310	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155
Infrastructure cost	NOK	0	0	0	0	0	0	0
Sum	NOK	44 827 154	44 982 921	26 036 630	26 269 417	26 492 764	26 707 733	26 915 201
Cost per unit	NOK/TEU	773	750	13 018	6 567	4 415	3 338	2 692

General info	**Units**	**LNGCase**	**LNGCase**	**LNGCase**	**LNGCase**	**LNGCase**	**LNGCase**	**LNGCase**
Volume (TEU)	**TEU**	**6 000**	**7 000**	**8 000**	**9 000**	**10 000**	**11 000**	**12 000**
Train utilization per year	days	313	313	313	313	313	313	313
Average velocity	km/h	50	50	50	50	50	50	50
Max train length Nordland Line	m	390	390	390	390	390	390	390
Distance Bodø - Trondheim	km	729	729	729	729	729	729	729
Trains per day and direction	-	1	1	1	1	1	1	1
Train slots per day	-	2	2	2	2	2	2	2
Volume per day	TEU/day	19,2	22,4	25,6	28,8	31,9	35,1	38,3
Loop time	hours	48	48	48	48	48	48	48

Locomotives	Units	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase
Main haul engine	-	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000
Operational engines	units	2	2	2	2	2	2	2
Engines including reserve	units	2,5	2,5	2,5	2,5	2,5	2,5	2,5
Investments per engine	NOK/engine	42 616 010	42 616 010	42 616 010	42 616 010	42 616 010	42 616 010	42 616 010
Interest rate	%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30	30	30	30
Train distance	km/year	456 354	456 354	456 354	456 354	456 354	456 354	456 354
Train utilization per year	hours/year	5 008	5 008	5 008	5 008	5 008	5 008	5 008
Pulling capacity	tonnes	1 400	1 400	1 400	1 400	1 400	1 400	1 400
Load weight	tonnes	307	358	409	460	511	562	613
Tare weight	tonnes	516	516	516	516	516	516	516
Total train weight	tonnes	823	874	925	976	1 027	1 078	1 129
CAPEX including reserve	NOK	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021
Fix maintenance	NOK	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000
Var maintenance	NOK	4 563 540	4 563 540	4 563 540	4 563 540	4 563 540	4 563 540	4 563 540
Total maintenance	NOK	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540
Energy consumption	liters	2 119 453	2 184 306	2 247 288	2 308 552	2 368 232	2 426 445	2 483 293
Diesel price	NOK/liter	-	-	-	-	-	-	-
LNG price	NOK/liter	3,00	3,00	3,00	3,00	3,00	3,00	3,00
Energy cost	NOK	6 358 359	6 552 917	6 741 863	6 925 657	7 104 697	7 279 335	7 449 880

Wagons	Units	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase
Wagon model	-	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104
Loop time	hours	48	48	48	48	48	48	48
Number of train sets	units	2	2	2	2	2	2	2
No of wagons (including reserve)	units	31	31	31	31	31	31	31
Investment costs per wagon	NOK/wagon	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000
Wagon distance	km/year	456 354	456 354	456 354	456 354	456 354	456 354	456 354
Interest rate	%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30	30	30	30
CAPEX Wagons	NOK	71 703	71 703	71 703	71 703	71 703	71 703	71 703
CAPEX including reserve	NOK	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086
Fix maintenance	NOK	620 000	620 000	620 000	620 000	620 000	620 000	620 000
Var maintenance	NOK	3 536 744	3 536 744	3 536 744	3 536 744	3 536 744	3 536 744	3 536 744
Total maintenance	NOK	4 156 744	4 156 744	4 156 744	4 156 744	4 156 744	4 156 744	4 156 744

Staff	Units	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase
Total staff cost	NOK	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155

Total operating cost	Units	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase
CAPEX Locomotive	NOK	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021
Total Maintenance Locomotive	NOK	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540
CAPEX Wagons	NOK	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086
Total Maintenance Wagons	NOK	4 156 744	4 156 744	4 156 744	4 156 744	4 156 744	4 156 744	4 156 744
Energy Cost	NOK	6 358 359	6 552 917	6 741 863	6 925 657	7 104 697	7 279 335	7 449 880
Staff	NOK	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155
Infrastructure cost	NOK	0	0	0	0	0	0	0
Sum	NOK	27 115 904	27 310 462	27 499 409	27 683 202	27 862 242	28 036 880	28 207 425
Cost per unit	NOK/TEU	2 260	1 951	1 719	1 538	1 393	1 274	1 175

General info	**Units**	**LNGCase**	**LNGCase**	**LNGCase**	**LNGCase**	**LNGCase**	**LNGCase**	**LNGCase**
Volume (TEU)	**TEU**	**13 000**	**14 000**	**15 000**	**16 000**	**17 000**	**18 000**	**19 000**
Train utilization per year	days	313	313	313	313	313	313	313
Average velocity	km/h	50	50	50	50	50	50	50
Max train length Nordland Line	m	390	390	390	390	390	390	390
Distance Bodø - Trondheim	km	729	729	729	729	729	729	729
Trains per day and direction	-	1	1	1	1	1	2	2
Train slots per day	-	2	2	2	2	2	4	4
Volume per day	TEU/day	41,5	44,7	47,9	51,1	54,3	28,8	30,4
Loop time	hours	48	48	48	48	48	48	48

Locomotives	Units	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase
Main haul engine	-	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000
Operational engines	units	2	2	2	2	2	2	2
Engines including reserve	units	2,5	2,5	2,5	2,5	2,5	2,5	2,5
Investments per engine	NOK/engine	42 616 010	42 616 010	42 616 010	42 616 010	42 616 010	42 616 010	42 616 010
Interest rate	%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30	30	30	30
Train distance	km/year	456 354	456 354	456 354	456 354	456 354	912 708	912 708
Train utilization per year	hours/year	5 008	5 008	5 008	5 008	5 008	10 016	10 016
Pulling capacity	tonnes	1 400	1 400	1 400	1 400	1 400	1 400	1 400
Load weight	tonnes	665	716	767	818	869	460	486
Tare weight	tonnes	516	516	516	516	516	516	516
Total train weight	tonnes	1 181	1 232	1 283	1 334	1 385	976	1 002
CAPEX including reserve	NOK	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021
Fix maintenance	NOK	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000
Var maintenance	NOK	4 563 540	4 563 540	4 563 540	4 563 540	4 563 540	9 127 080	9 127 080
Total maintenance	NOK	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540	10 127 080	10 127 080
Energy consumption	liters	2 538 869	2 593 254	2 646 522	2 698 738	2 749 964	4 617 104	4 677 165
Diesel price	NOK/liter	-	-	-	-	-	-	-
LNG price	NOK/liter	3,00	3,00	3,00	3,00	3,00	3,00	3,00
Energy cost	NOK	7 616 608	7 779 763	7 939 566	8 096 215	8 249 891	13 851 313	14 031 496

Wagons	Units	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase
Wagon model	-	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104
Loop time	hours	48	48	48	48	48	48	48
Number of train sets	units	2	2	2	2	2	2	2
No of wagons (including reserve)	units	31	31	31	31	31	31	31
Investment costs per wagon	NOK/wagon	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000
Wagon distance	km/year	456 354	456 354	456 354	456 354	456 354	912 708	912 708
Interest rate	%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30	30	30	30
CAPEX Wagons	NOK	71 703	71 703	71 703	71 703	71 703	71 703	71 703
CAPEX including reserve	NOK	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086
Fix maintenance	NOK	620 000	620 000	620 000	620 000	620 000	620 000	620 000
Var maintenance	NOK	3 536 744	3 536 744	3 536 744	3 536 744	3 536 744	7 073 487	7 073 487
Total maintenance	NOK	4 156 744	4 156 744	4 156 744	4 156 744	4 156 744	7 693 487	7 693 487

Staff	Units	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase
Total staff cost	NOK	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155	5 040 310	5 040 310

Total operating cost	Units	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase
CAPEX Locomotive	NOK	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021
Total Maintenance Locomotive	NOK	5 563 540	5 563 540	5 563 540	5 563 540	5 563 540	10 127 080	10 127 080
CAPEX Wagons	NOK	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086
Total Maintenance Wagons	NOK	4 156 744	4 156 744	4 156 744	4 156 744	4 156 744	7 693 487	7 693 487
Energy Cost	NOK	7 616 608	7 779 763	7 939 566	8 096 215	8 249 891	13 851 313	14 031 496
Staff	NOK	2 520 155	2 520 155	2 520 155	2 520 155	2 520 155	5 040 310	5 040 310
Infrastructure cost	NOK	0	0	0	0	0	0	0
Sum	NOK	28 374 153	28 537 308	28 697 111	28 853 761	29 007 436	45 229 297	45 409 479
Cost per unit	NOK/TEU	1 091	1 019	957	902	853	1 256	1 195

General info	**Units**	**LNGCase**	**LNGCase**	**LNGCase**	**LNGCase**	**LNGCase**	**LNGCase**	**LNGCase**
Volume (TEU)	**TEU**	**20 000**	**21 000**	**22 000**	**23 000**	**24 000**	**25 000**	**26 000**
Train utilization per year	days	313	313	313	313	313	313	313
Average velocity	km/h	50	50	50	50	50	50	50
Max train length Nordland Line	m	390	390	390	390	390	390	390
Distance Bodø - Trondheim	km	729	729	729	729	729	729	729
Trains per day and direction	-	2	2	2	2	2	2	2
Train slots per day	-	4	4	4	4	4	4	4
Volume per day	TEU/day	31,9	33,5	35,1	36,7	38,3	39,9	41,5
Loop time	hours	48	48	48	48	48	48	48

Locomotives	Units	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase
Main haul engine	-	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000	Euro4000
Operational engines	units	2	2	2	2	2	2	2
Engines including reserve	units	2,5	2,5	2,5	2,5	2,5	2,5	2,5
Investments per engine	NOK/engine	42 616 010	42 616 010	42 616 010	42 616 010	42 616 010	42 616 010	42 616 010
Interest rate	%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30	30	30	30
Train distance	km/year	912 708	912 708	912 708	912 708	912 708	912 708	912 708
Train utilization per year	hours/year	10 016	10 016	10 016	10 016	10 016	10 016	10 016
Pulling capacity	tonnes	1 400	1 400	1 400	1 400	1 400	1 400	1 400
Load weight	tonnes	511	537	562	588	613	639	665
Tare weight	tonnes	516	516	516	516	516	516	516
Total train weight	tonnes	1 027	1 053	1 078	1 104	1 129	1 155	1 181
CAPEX including reserve	NOK	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021
Fix maintenance	NOK	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000
Var maintenance	NOK	9 127 080	9 127 080	9 127 080	9 127 080	9 127 080	9 127 080	9 127 080
Total maintenance	NOK	10 127 080	10 127 080	10 127 080	10 127 080	10 127 080	10 127 080	10 127 080
Energy consumption	liters	4 736 465	4 795 031	4 852 890	4 910 067	4 966 587	5 022 470	5 077 738
Diesel price	NOK/liter	-	-	-	-	-	-	-
LNG price	NOK/liter	3,00	3,00	3,00	3,00	3,00	3,00	3,00
Energy cost	NOK	14 209 394	14 385 092	14 558 669	14 730 202	14 899 760	15 067 410	15 233 215

Wagons	Units	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase
Wagon model	-	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104
Loop time	hours	48	48	48	48	48	48	48
Number of train sets	units	2	2	2	2	2	2	2
No of wagons (including reserve)	units	31	31	31	31	31	31	31
Investment costs per wagon	NOK/wagon	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000
Wagon distance	km/year	912 708	912 708	912 708	912 708	912 708	912 708	912 708
Interest rate	%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30	30	30	30
CAPEX Wagons	NOK	71 703	71 703	71 703	71 703	71 703	71 703	71 703
CAPEX including reserve	NOK	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086
Fix maintenance	NOK	620 000	620 000	620 000	620 000	620 000	620 000	620 000
Var maintenance	NOK	7 073 487	7 073 487	7 073 487	7 073 487	7 073 487	7 073 487	7 073 487
Total maintenance	NOK	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487

Staff	Units	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase
Total staff cost	NOK	5 040 310	5 040 310	5 040 310	5 040 310	5 040 310	5 040 310	5 040 310

Total operating cost	Units	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase	LNGCase
CAPEX Locomotive	NOK	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021	6 366 021
Total Maintenance Locomotive	NOK	10 127 080	10 127 080	10 127 080	10 127 080	10 127 080	10 127 080	10 127 080
CAPEX Wagons	NOK	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086	2 151 086
Total Maintenance Wagons	NOK	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487
Energy Cost	NOK	14 209 394	14 385 092	14 558 669	14 730 202	14 899 760	15 067 410	15 233 215
Staff	NOK	5 040 310	5 040 310	5 040 310	5 040 310	5 040 310	5 040 310	5 040 310
Infrastructure cost	NOK	0	0	0	0	0	0	0
Sum	NOK	45 587 377	45 763 075	45 936 653	46 108 186	46 277 744	46 445 394	46 611 199
Cost per unit	NOK/TEU	1 140	1 090	1 044	1 002	964	929	896

General info	**Units**	**LNGCase**	**LNGCase**	**LNGCase**	**LNGCase**
Volume (TEU)	**TEU**	**27 000**	**28 000**	**29 000**	**30 000**
Train utilization per year	days	313	313	313	313
Average velocity	km/h	50	50	50	50
Max train length Nordland Line	m	390	390	390	390
Distance Bodø - Trondheim	km	729	729	729	729
Trains per day and direction	-	2	2	2	2
Train slots per day	-	4	4	4	4
Volume per day	TEU/day	43,1	44,7	46,3	47,9
Loop time	hours	48	48	48	48

Locomotives	Units	LNGCase	LNGCase	LNGCase	LNGCase
Main haul engine	-	Euro4000	Euro4000	Euro4000	Euro4000
Operational engines	units	2	2	2	2
Engines including reserve	units	2,5	2,5	2,5	2,5
Investments per engine	NOK/engine	42 616 010	42 616 010	42 616 010	42 616 010
Interest rate	%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30
Train distance	km/year	912 708	912 708	912 708	912 708
Train utilization per year	hours/year	10 016	10 016	10 016	10 016
Pulling capacity	tonnes	1 400	1 400	1 400	1 400
Load weight	tonnes	690	716	741	767
Tare weight	tonnes	516	516	516	516
Total train weight	tonnes	1 206	1 232	1 257	1 283
CAPEX including reserve	NOK	6 366 021	6 366 021	6 366 021	6 366 021
Fix maintenance	NOK	1 000 000	1 000 000	1 000 000	1 000 000
Var maintenance	NOK	9 127 080	9 127 080	9 127 080	9 127 080
Total maintenance	NOK	10 127 080	10 127 080	10 127 080	10 127 080
Energy consumption	liters	5 132 412	5 186 508	5 240 047	5 293 044
Diesel price	NOK/liter	-	-	-	-
LNG price	NOK/liter	3,00	3,00	3,00	3,00
Energy cost	NOK	15 397 235	15 559 525	15 720 141	15 879 132

Wagons	Units	LNGCase	LNGCase	LNGCase	LNGCase
Wagon model	-	Sggmrss104	Sggmrss104	Sggmrss104	Sggmrss104
Loop time	hours	48	48	48	48
Number of train sets	units	2	2	2	2
No of wagons (including reserve)	units	31	31	31	31
Investment costs per wagon	NOK/wagon	1 200 000	1 200 000	1 200 000	1 200 000
Wagon distance	km/year	912 708	912 708	912 708	912 708
Interest rate	%	4,5%	4,5%	4,5%	4,5%
Depreciation period	years	30	30	30	30
CAPEX Wagons	NOK	71 703	71 703	71 703	71 703
CAPEX including reserve	NOK	2 151 086	2 151 086	2 151 086	2 151 086
Fix maintenance	NOK	620 000	620 000	620 000	620 000
Var maintenance	NOK	7 073 487	7 073 487	7 073 487	7 073 487
Total maintenance	NOK	7 693 487	7 693 487	7 693 487	7 693 487

Staff	Units	LNGCase	LNGCase	LNGCase	LNGCase
Total staff cost	NOK	5 040 310	5 040 310	5 040 310	5 040 310

Total operating cost	Units	LNGCase	LNGCase	LNGCase	LNGCase
CAPEX Locomotive	NOK	6 366 021	6 366 021	6 366 021	6 366 021
Total Maintenance Locomotive	NOK	10 127 080	10 127 080	10 127 080	10 127 080
CAPEX Wagons	NOK	2 151 086	2 151 086	2 151 086	2 151 086
Total Maintenance Wagons	NOK	7 693 487	7 693 487	7 693 487	7 693 487
Energy Cost	NOK	15 397 235	15 559 525	15 720 141	15 879 132
Staff	NOK	5 040 310	5 040 310	5 040 310	5 040 310
Infrastructure cost	NOK	0	0	0	0
Sum	NOK	46 775 218	46 937 509	47 098 125	47 257 115
Cost per unit	NOK/TEU	866	838	812	788

Appendix 8: Diesel and LNG Emissions (own display)

Emissions	CO_2	NO_X	PM_{10}	SO_X
Fuel	Diesel	Diesel	Diesel	Diesel
Annual demand for diesel, liters	3 064 627	3 064 627	3 064 627	3 064 627
Emission factor, g /l diesel	2 538	17	0,42	0,41
Annual emissions, kg	7 778 022	52 099	1 287	1 256
Shadow price, NOK/kg emissions	0,21	50	440	25
Environmental costs, NOK/year	1 633 385	2 604 933	566 343	31 412
Fuel	LNG emits 30% less CO_2	LNG emits 70% less NO_X	LNG emits 100% less PM_{10}	LNG emits 100% less SO_X
Environmental costs, NOK/year	1 143 369	781 480	0	0
Total environmental costs for diesel, NOK/year	**4 836 073**			
Total environmental costs for LNG, NOK/year	**1 924 849**			
Total cost difference, NOK/year	**2 911 224**			

Appendix 9: CBA Analysis results (own display)

Year	Units	0	1	2	3	4	5	6	7
Base Case									
Projected Costs for Diesel Loco									
Investments	NOK	68 944 000	0	0	0	0	0	0	0
Maintenance costs	NOK	0	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310
Fuel costs	NOK	0	14 219 868	14 219 868	14 219 868	14 219 868	14 219 868	14 219 868	14 219 868
Social economic costs	NOK	0	4 836 073	4 836 073	4 836 073	4 836 073	4 836 073	4 836 073	4 836 073
Total costs	NOK	68 944 000	26 501 251	26 501 251	26 501 251	26 501 251	26 501 251	26 501 251	26 501 251
Projected Revenues	NOK	0	0	0	0	0	0	0	0
Cash Flow	NOK	-68 944 000	-26 501 251	-26 501 251	-26 501 251	-26 501 251	-26 501 251	-26 501 251	-26 501 251
Discounted Cash Flow	NOK	-68 944 000	-25 481 972	-24 501 896	-23 559 515	-22 653 380	-21 782 096	-20 944 323	-20 138 772
NPV (4,0%)	NOK	**-527 204 507**							
Alternative Project									
Projected Costs for LNG Loco									
Investments	NOK	85 232 020	0	0	0	0	0	0	0
Maintenance costs	NOK	0	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487
Fuel costs	NOK	0	15 879 132	15 879 132	15 879 132	15 879 132	15 879 132	15 879 132	15 879 132
Social economic costs	NOK	0	1 924 849	1 924 849	1 924 849	1 924 849	1 924 849	1 924 849	1 924 849
Total costs	NOK	85 232 020	25 497 468	25 497 468	25 497 468	25 497 468	25 497 468	25 497 468	25 497 468
Projected Revenues	NOK	0	0	0	0	0	0	0	0
Cash Flow	NOK	-85 232 020	-25 497 468	-25 497 468	-25 497 468	-25 497 468	-25 497 468	-25 497 468	-25 497 468
Discounted Cash Flow	NOK	-85 232 020	-24 516 796	-23 573 842	-22 667 156	-21 795 342	-20 957 060	-20 151 019	-19 375 980
NPV (4,0%)	NOK	**-526 135 083**							
Financial Metrics									
Reduction in OPEX costs	*%*		*3,8%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*
Benefits Cash Flow	*NOK*	*-16 288 020*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*
Discounted Benefits Cash Flow	*NOK*	-16 288 020	*965 176*	*928 054*	*892 359*	*858 038*	*825 036*	*793 304*	*762 792*
Cumulative Discounted Benefits Cash Flow	*NOK*	-16 288 020	-15 322 844	-14 394 791	-13 502 432	-12 644 394	-11 819 358	-11 026 054	-10 263 261
Net Present Value (4,0%)	*NOK*	**1 069 424**							
Economic Rate of Return	*%*	***1%***							
Breakeven	years	***26,7***							

Year	Units	8	9	10	11	12	13	14	15
Base Case									
Projected Costs for Diesel Loco									
Investments	NOK	0	0	0	0	0	0	0	0
Maintenance costs	NOK	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310
Fuel costs	NOK	14 219 868	14 219 868	14 219 868	14 219 868	14 219 868	14 219 868	14 219 868	14 219 868
Social economic costs	NOK	4 836 073	4 836 073	4 836 073	4 836 073	4 836 073	4 836 073	4 836 073	4 836 073
Total costs	NOK	26 501 251	26 501 251	26 501 251	26 501 251	26 501 251	26 501 251	26 501 251	26 501 251
Projected Revenues	NOK	0	0	0	0	0	0	0	0
Cash Flow	NOK	-26 501 251	-26 501 251	-26 501 251	-26 501 251	-26 501 251	-26 501 251	-26 501 251	-26 501 251
Discounted Cash Flow	NOK	-19 364 204	-18 619 427	-17 903 295	-17 214 707	-16 552 603	-15 915 964	-15 303 812	-14 715 204
Alternative Project									
Projected Costs for LNG Loco									
Investments	NOK	0	0	0	0	0	0	0	0
Maintenance costs	NOK	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487
Fuel costs	NOK	15 879 132	15 879 132	15 879 132	15 879 132	15 879 132	15 879 132	15 879 132	15 879 132
Social economic costs	NOK	1 924 849	1 924 849	1 924 849	1 924 849	1 924 849	1 924 849	1 924 849	1 924 849
Total costs	NOK	25 497 468	25 497 468	25 497 468	25 497 468	25 497 468	25 497 468	25 497 468	25 497 468
Projected Revenues	NOK	0	0	0	0	0	0	0	0
Cash Flow	NOK	-25 497 468	-25 497 468	-25 497 468	-25 497 468	-25 497 468	-25 497 468	-25 497 468	-25 497 468
Discounted Cash Flow	NOK	-18 630 750	-17 914 183	-17 225 176	-16 562 669	-15 925 643	-15 313 118	-14 724 152	-14 157 839
Financial Metrics									
Reduction in OPEX costs	*%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*
Benefits Cash Flow	*NOK*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*
Discounted Benefits Cash Flow	*NOK*	*733 454*	*705 244*	*678 120*	*652 038*	*626 960*	*602 846*	*579 660*	*557 365*
Cumulative Discounted Benefits Cash Flow	*NOK*	-9 529 807	-8 824 563	-8 146 443	-7 494 405	-6 867 445	-6 264 599	-5 684 940	-5 127 575

Year	Units	16	17	18	19	20	21	22	23
Base Case									
Projected Costs for Diesel Loco									
Investments	NOK	0	0	0	0	0	0	0	0
Maintenance costs	NOK	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310
Fuel costs	NOK	14 219 868	14 219 868	14 219 868	14 219 868	14 219 868	14 219 868	14 219 868	14 219 868
Social economic costs	NOK	4 836 073	4 836 073	4 836 073	4 836 073	4 836 073	4 836 073	4 836 073	4 836 073
Total costs	NOK	26 501 251	26 501 251	26 501 251	26 501 251	26 501 251	26 501 251	26 501 251	26 501 251
Projected Revenues	NOK	0	0	0	0	0	0	0	0
Cash Flow	NOK	-26 501 251	-26 501 251	-26 501 251	-26 501 251	-26 501 251	-26 501 251	-26 501 251	-26 501 251
Discounted Cash Flow	NOK	-14 149 234	-13 605 033	-13 081 763	-12 578 618	-12 094 825	-11 629 639	-11 182 345	-10 752 255
Alternative Project									
Projected Costs for LNG Loco									
Investments	NOK	0	0	0	0	0	0	0	0
Maintenance costs	NOK	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487
Fuel costs	NOK	15 879 132	15 879 132	15 879 132	15 879 132	15 879 132	15 879 132	15 879 132	15 879 132
Social economic costs	NOK	1 924 849	1 924 849	1 924 849	1 924 849	1 924 849	1 924 849	1 924 849	1 924 849
Total costs	NOK	25 497 468	25 497 468	25 497 468	25 497 468	25 497 468	25 497 468	25 497 468	25 497 468
Projected Revenues	NOK	0	0	0	0	0	0	0	0
Cash Flow	NOK	-25 497 468	-25 497 468	-25 497 468	-25 497 468	-25 497 468	-25 497 468	-25 497 468	-25 497 468
Discounted Cash Flow	NOK	-13 613 307	-13 089 718	-12 586 267	-12 102 180	-11 636 711	-11 189 146	-10 758 794	-10 344 994
Financial Metrics									
Reduction in OPEX costs	*%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*
Benefits Cash Flow	*NOK*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*
Discounted Benefits Cash Flow	*NOK*	*535 928*	*515 315*	*495 495*	*476 438*	*458 113*	*440 494*	*423 552*	*407 261*
Cumulative Discounted Benefits Cash Flow	*NOK*	-4 591 647	-4 076 332	-3 580 837	-3 104 399	-2 646 285	-2 205 792	-1 782 240	-1 374 979

Year	**Units**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**Total Budget**
Base Case									
Projected Costs for Diesel Loco									
Investments	NOK	0	0	0	0	0	0	0	**68 944 000**
Maintenance costs	NOK	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310	7 445 310	**223 359 300**
Fuel costs	NOK	14 219 868	14 219 868	14 219 868	14 219 868	14 219 868	14 219 868	14 219 868	**426 596 032**
Social economic costs	NOK	4 836 073	4 836 073	4 836 073	4 836 073	4 836 073	4 836 073	4 836 073	**145 082 184**
Total costs	NOK	26 501 251	26 501 251	26 501 251	26 501 251	26 501 251	26 501 251	26 501 251	**863 981 516**
Projected Revenues	NOK	0	0	0	0	0	0	0	**0**
Cash Flow	NOK	-26 501 251	-26 501 251	-26 501 251	-26 501 251	-26 501 251	-26 501 251	-26 501 251	**-863 981 516**
Discounted Cash Flow	NOK	-10 338 707	-9 941 064	-9 558 716	-9 191 073	-8 837 570	-8 497 663	-8 170 830	**-527 204 507**
Alternative Project									
Projected Costs for LNG Loco									
Investments	NOK	0	0	0	0	0	0	0	**85 232 020**
Maintenance costs	NOK	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487	7 693 487	**230 804 610**
Fuel costs	NOK	15 879 132	15 879 132	15 879 132	15 879 132	15 879 132	15 879 132	15 879 132	**476 373 952**
Social economic costs	NOK	1 924 849	1 924 849	1 924 849	1 924 849	1 924 849	1 924 849	1 924 849	**57 745 473**
Total costs	NOK	25 497 468	25 497 468	25 497 468	25 497 468	25 497 468	25 497 468	25 497 468	**850 156 055**
Projected Revenues	NOK	0	0	0	0	0	0	0	**0**
Cash Flow	NOK	-25 497 468	-25 497 468	-25 497 468	-25 497 468	-25 497 468	-25 497 468	-25 497 468	**-850 156 055**
Discounted Cash Flow	NOK	-9 947 110	-9 564 529	-9 196 662	-8 842 944	-8 502 831	-8 175 799	-7 861 345	**-526 135 083**
Financial Metrics									
Reduction in OPEX costs	*%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*	*3,8%*	
Benefits Cash Flow	*NOK*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*	*1 003 783*	***13 825 461***
Discounted Benefits Cash Flow	*NOK*	*391 597*	*376 536*	*362 054*	*348 128*	*334 739*	*321 864*	*309 485*	***1 069 424***
Cumulative Discounted Benefits Cash Flow	*NOK*	-983 382	-606 846	-244 793	103 336	438 075	759 939	1 069 424	