REFRIGERATED TRAILER: ELECTRICITY OR DIESEL

Bachelor Thesis

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Acknowledgements

I am indebted of E. Noomen and J. Schreurs from Nomad Power for their initial idea for this study and help during the process. Also I would like to thank L. Van der Lugt for her efforts and feedback through the process. Specially, I would like to thank all the transporters and producers who answered the questionnaire. At last I would like to thank the people of Transfrigoroute with their help of finding all the sources.

Abstract

The refrigerated transport sector, for a great part, makes up the transportation industry. Refrigerated trailers are powered by a diesel generator, which converts mechanical energy to electrical energy. The refrigerated trailers can also be powered with electricity from the grid.

Nomad Power is a company that places electricity connections at parking lots near the highways. Powering the refrigerated trailer with electricity is more cost efficient than using a diesel generator as power source. Drivers can power their trailer with electricity when they are on a break. Since drivers are permitted by law to drive only 9 hours per day, the difference could become quite significant.

This report makes a comparison between these two methods of cooling in order to estimate the difference in costs. The report is divided in six sub questions that investigate different factors that affect the cost.

Firstly, the costs of cooling a trailer are discussed, which consist of the operating , maintenance and switching cost. When switching to electricity a cost reduction of 39% per operating hour is realized. A cost reduction in maintenance of 40% is realized when switching to electricity, whereas the cost of switching are only 80 euro's.

Secondly, the effect of the inside temperature has on the cost is investigated. The inside temperature affects the consumption of power strongly. Types of cargo that need a low inside temperature for transportation have a more significant effect on the cost reduction.

Thirdly, the effect of the outside temperature on the consumption of power is discussed. The outside temperature has an effect on the consumption of power; when the outside temperature is low the consumption of power also decreases.

Fourthly, the amount of time that a loaded truck stands still near the highways (stop rate) is investigated by interviewing multiple transporters. Three different stop rate clusters are identified: short, medium and long transportation distances. The short transportation distances have an average stop rate of 0%, the medium transportation distances have an average stop rate of 10% and the long transportation distances have an average stop rate of 44%.

As fifth, the effect that prices have in different west-European countries on the cost is investigated. This effect is estimated by calculating the break-even point and the potential benefit in five years for all west-European countries. Of all investigated European countries The Netherlands have the lowest break-even point of 39,93 operating hours and the cost-benefit in five years for long distances is €21.684 and short distances is €4.866, followed by The United Kingdom, Belgium, Italy, Germany and Spain.

At last it is investigated if the cost reduction has a significant impact on the total cost of transportation. Multiple transport companies were interviewed and ask how large the share of the cost of energy are in comparison with the total cost of transportation for all types of cargo. It was founded that when the inside temperature increases, the percentage of total costs decreases in value. A cost reduction of 0,68% on the total cost of transportation for long transportation distances is created when using electricity from the grid.

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1. Introduction

"Today it's so easy for us to forget about seasons when we eat"

George Metaljan

In the past people were only consuming the goods that were locally produced and available in the season. Modern food processing and worldwide distribution of food make food available year-round, and grocery stores shelves look much the same in December as they do in July (Mateljan, 2007). It is likely that the white fish from your grocery store comes from Vietnam, your apple from Chili and your oranges from Spain. The food market has become a global market and transportation plays a key role in this development. Food must be refrigerated during transport, because otherwise it will spoil. The global refrigerated transport market is growing at a considerable rate. In North America and Europe, refrigerated trucks, vans, and trailers are also experiencing a considerable growth in demand as they provide flexibility in the delivery of goods; they cater for transport to multiple locations at flexible times (Markets and Markets, 2014). Chilled, frozen, and deep-frozen are the different temperature ranges through which products are stored and transported. In Europe the most commonly used mode is the refrigerated trailer. The Refrigerated trailer has a cooling unit attached to it which can cool the trailer to whatever temperature is necessary for the specific transported cargo. A generator that is installed under the trailer and runs on diesel powers the cooling unit of the truck. The cooling unit could however also be powered directly with electricity from the grid.

In 2012 two Dutch entrepreneurs saw potential benefits in the option of cooling with electricity and found the company Nomad Power. Their ambition was to have a sustainable impact on the European refrigerated road transport industry. Nomad Power delivers an electrical power supply system that contributes to sustainable temperature controlled road transport. Their goal is to install electric charging points along the European highways. When drivers rest, they can use these power points to cool their cargo electrically instead of using the diesel generator, currently the only available method for cooling cargo. The intention of using this device is to reduce the costs transportation companies incur, reduce the emission of harmful substances to the environment and to reduce noise pollution.

In the past years various research has been conducted on the potential benefits that occur when using electricity to cool the trailer instead of the diesel generator. Those studies where mostly focused on examining the effects on energy consumption, emissions and noise. The researches were very technical and made a lot of assumptions about the refrigerated market that weren't backed by further research. The transportation companies were not involved in the investigations, leaving an incomplete picture of the actual benefits that arise in real life. The goal of this thesis is to update and enhance existing research with the information that can be obtained from the transporters, shippers and producers of this massive industry. The amount of time that a refrigerated trailer stands still near the highway has not yet been investigated. Further, the effect that a cost reduction, when switching to electricity instead of diesel, has on the total cost of transportation has never been evaluated at all.

Because of the time and effort that is needed to investigate these topics it was decided to split the research in two parts, the second part is conducted by Bernice Vogelzang. The combined research question for these studies is as follows:

Is there demand for electric cooling of freight trucks during rest periods?

In order to divide the thesis in two parts, a distinction is made between the behavioral issues and the costs issues associated with changing the cooling mechanism in freight trucks. This specific study will focus on the cost aspect of the implementation of the facilities of Nomad Power. The research question of this report will be the following:

What are the effects on the cost of refrigerated trailers when using electricity instead of the diesel as power source during rest moments?

To answer this question it is divided into sub question in order to get a clearer picture of the various factors affecting the costs. The first step that should be made is assessing the costs of cooling a trailer by answering the following sub question:

1. *What are the costs of cooling a trailer with both diesel and electricity?*

The focus will be on the costs of cooling a trailer that are associated with using the refrigerated unit. The costs of cooling a trailer consist of power consumption, maintenance, depreciation and switching costs. In 2014 Nomad Power instructed Van der Beek, Commandeur, Khajehzadeh, & Overbeek who were conducting their bachelor thesis for the TU Delft, to examine the effects that occur when using electricity instead of a diesel generator as power source in the road transportation market. They conducted experiments to measure fuel consumption and compared it to cooling with electricity. The fuel consumption they found can be used as starting point for assessing the costs of cooling a trailer. Maintenance costs are all the costs that arises when maintaining the refrigeration unit and the diesel generator. When using the facilities of Nomadpower electricity is used from the grid and thus the diesel generator is not needed. The diesel generator is still needed but runs less frequently than in a situation where only the diesel generator is used as power source. Nomadpower has asked to investigate if the use of electricity as power source has effect on the economic lifetime of the diesel generator. When the diesel generator has a longer economic lifetime the depreciation cost a year will decrease. If the depreciation costs of the diesel generator decreases then this will be an extra motivation for transporters to use the facilities of Nomadpower. Further research is needed to investigate if this assumption is correct. At last the switching cost will be mentioned. Switching cost are the that arises when a transporter decided to use the facilities of nomad for the first time, are there any investments needed?

Energy consumption is a very important cost factor of cooled cargo. Does the energy consumption changes as different cargo is transported? This is a factor that needs to be examined further in order to gain a more complete understanding of the issue at hand. The cargo of the refrigerated transport sector is often of a fragile nature and can easily decay when it is not being transported in precisely the right temperature. It sounds logical to state that the consumptions of energy differs as the inside temperature of the trailer needs to be adjusted, either higher or lower, for the optimum transportation temperature inherit to the goods being transported. To assess this the following sub question is used:

2. *Does the required inside temperature of the trailer effects the consumption of energy when cooling the trailer?*

To fully estimate if different temperatures have effect on the consumption of energy, the outside temperature should also be considered as factor of influence. There are two existing researches that already have done experiments on this topic. One is conducted in the area of New York and the second one in Germany. Both of these studies will be used to obtain a more precise and complete understanding of the given problem. The studies will allow a better understanding of the third and following sub question:

3. *Does the outside temperature have influence on the consumption of energy when cooling the trailer?*

The effect that cooling with electricity instead of cooling with a diesel generator has on the cost of transportation is very important. But the actual time that a loaded truck uses this option is perhaps equally important. In order to use the facilities of Nomad Power a truck needs to stop at parking lots next to the highways and plug in the cable to power the cooling unit. In most of the existing studies that have been conducted this percentage is about 50 percent of the total time of transportation (Transfrigoroute Deutschland (td) e.V., 2014). To examine if this is a good assessment of the time that trucks actually stand still at these parking lots the following sub question is used:

4. *What is the average amount of time that loaded trailers stand still at parking lots near the highway?*

Refrigerated transport is global business and cargo is frequently crossing borders before reaching their destination. Because taxes and regulations differ in countries the prices of electricity and diesel also change when crossing borders. Nomad Power has energy supply systems at different locations in West-Europe. These different prices should be considered when estimating the benefits of using the facilities of Nomad Power. To estimate this correctly the following Sub question will be used:

5. *Do the costs remain the same when transporting cooled freight through different countries in West-Europe?*

The West European countries that will be considered are the ones where Nomad Power already has facilities, or were they are currently being built. In the Netherlands, Germany, Italy and Belgium the facilities are already there. In The United Kingdom and Spain they are being built at this moment or in the upcoming three months. Before going on to the last sub question all the cost factors that were conducted in the first five sub questions will be combined to calculate the following parts:

- The break-even point, the point where the extra cost of using the Nomad Power facilities are being outweighed by the benefits
- The potential cost-benefit that one refrigerated trailer delivers for the coming five years when using electricity during stand still.

Nomad Power states that the potential cost benefits can be significant when using their facilities, but is this really an accurate statement to make? The cost reductions associated with cooling the trailer with electricity need to have a significant effect on the total cost of transportation. Otherwise it is not interesting or cost efficient for transporters to use Nomad Power's facilities. In order to investigate this issue the following sub question is formulated:

6. *Does the cost reduction have a significant impact on the total cost of transportation?*

To give a reliable answer on this question multiple transport companies need to be interviewed to ask how large the share of the cost of energy are in comparison with the total cost of transportation. To give a good representation of the total market all different inside temperatures of the trailers should be considered. At the end the goal will be to estimate if switching to electricity as power source during rest moments results in a significant decrease of the total cost of transportation.

This thesis will start with the theoretical framework were the refrigerated transport sector will be described. All the factors that affect the total cost of transportation will be mentioned and shortly described. The theoretical framework will also contain background information, legislations that applies to the sector and the different types of trailers that are used in transport.

The costs of cooling a trailer that are already known will be given in the theoretical framework, this would be the consumption values and the switching costs. The costs of cooling a unit that need further investigation are the maintenance and depreciation costs, which will be investigated by interviewing the producers.

The effect that the required inside temperature has on the consumption of power will be estimated by using the consumption measurements from Van der Beek and colleagues as basis. The percentage differences in consumption level for diesel and electricity from the grid will then be given in the first part of the data section.

The effect that the outside temperature has on the consumption of energy will be given in the theoretical framework section, because this is based on the study that was conducted by Shurepower in the area of New York. Shurepower, a company that delivers the same product as Nomadpower, investigated the possible opportunities that can arise when transporting perishable cargo.

In order to investigate what the actual amount of time is that trailers stand still near the highways, multiple transporters will be asked to estimate the percentage of time that a loaded truck stand still near the highways (Stop rate). The most interesting part will be to assess if the transporters' given answers will clusters together in groups.

In order to assess the effect of different prices in the different countries of west-Europe, the break-even point and cost benefit in coming five years will be calculated for all countries where Nomadpower is active. The break-even point will be calculated by dividing the switching cost by the cost difference, which is created when switching to electricity, per operating hour. The cost-benefit in five years will be calculated by comparing the potential cost for the coming five years when using the refrigeration unit with both diesel and electricity.

To assess if the cost reduction has a significant impact on the total cost of transportation, the percentage that the use of the diesel generator has on the total cost of transportation(percentage of total cost) will be estimated. Transporters will be asked to give an estimation of the percentage of total cost per type of transported cargo.

It sounds logical to state that the consumption of energy increases when a lower inside temperature is needed in the trailer. Thus, it can be expected that the percentage of total cost increases when the required inside temperature decreases. With the help of SPSS this statement will be tested to assess if correlation occurs between the two variables: percentage of total cost and the required inside temperature.

In order to give an answer on the question if the cost reduction has a significant impact on the total cost of transportation, the stop-rate, the cost difference(when switching to electricity and the percentage of total cost will be combined. With the help of these three values the effect that the cost reduction, of switching to electricity as power source, has on the total cost of transportation can be calculated and given in a percentage.

2. Theoretical framework

The refrigerated transport sector

The refrigerated transport sector is part of the so-called ‘cold chain’. A cold chain is a temperature-controlled supply chain for perishable food products, pharmaceuticals, and chemicals that allows the products to maintain their required quality and increase the shelf life. Cold chain infrastructure consists of precooling facilities, refrigerated storage, refrigerated transport, packaging, and information management systems. Globally, the meat and seafood market has the largest share of the entire transportation market, by application, followed by dairy and frozen desserts, and fruits and vegetables (Markets and Markets, 2014). The consumption of these perishable foods is increasing globally, thereby increasing the inter-trading of perishable foods among different countries. The increasing use of home delivery services and the increased quality demands of consumers increase pressure on the refrigerated transport sector to reduce the energy consumption. Quality and operation requirements are stricter for road transport refrigeration equipment than stationary refrigeration equipment, partly because the operations conditions are harsher. Due to the wide range of operating conditions and constraints imposed by available size and weight, transport refrigeration equipment have lower efficiencies than stationary systems (Tassou, De-Lille, & Lewis, 2012).

When a shipper wants to transport its (perishable) goods it uses a transporter who facilitates the transportation. The transporter can use multiple modes of transportation such as, Sea transport (reefer), RoRo (Roll on Roll off), road Transport (refrigerated trailer), rail transport and air transport. In the refrigerated transport sector the most common used are road and sea transport (Tassou, De-Lille, & Lewis, 2012). This study will focus on refrigerated transport that is been done by road, this is because the facilities of Nomadpower can only be used with a refrigerated trailer that travels by road.

Cost of cooling a trailer		**Impacting factors**		
fixed costs	Refrigeration unit (depreciation)	price of machine		
		life time		
variable costs	Energy	level of use	required inside temperature	type of cargo
			outside temperature	season
				country
		time of use	stand still duration(stop-rate)	length of trip
				legislation
				way of organising
		price of energy	global oil price	
	Maintenance	use of machine	stand still duration(stop-rate)	see above
			planning of the transporter	
		wear rate	quality of machine	
		maintenance schedule	quality of machine/maintenance philosophy	
	Switching cost	cost of a cable	only in the first year	
Total cost of transportation				
Fixed costs	truck costs(including trailer)	truck type		
		costs of truck	depreciation, rent of financing	
		economic life time		
variable costs	Fuel	fuel use	length of trip	
			time of use diesel generator	aflicted by the stop-rate
		fuel price	fuel price in particular country	
	Labor	labor use	driving hours	
			office personnel	
			garage personnel	
	Garage	Rent of garage		
		Equipment		
	Office expenses	Rent of office		
		IT-facilities		
	Maintenance	See the cost of cooling section		
	Other costs	Insurance, taxes and tollways		

Table 1: Overview of the costs

A transport company usually has multiple trucks, trailers and employees on contract which are all cost factors that affect the total cost of transportation, which can be seen in table 1. The largest cost factor for transporters are the labor costs, in some market segments their share of the total cost is more than half. The labor cost relate mainly to labor costs for the drivers, in addition it concerns the labor cost of workshop staff and other personnel. Secondly there are the fuel cost for driving the truck from point A to B. Both the truck and trailer need maintenance, such as MOT tests, standard maintenance, leak tests, settings checks and new tires. Insurance, taxes and tollways are also factors that affect the total cost of transportation. All the large materials such as the truck, trailer and the refrigeration unit (which is needed for cooling) need to be amortized, and thus this creates depreciation costs. Usually most of the invested capital is (partly) borrowed, therefore rent is also a factor affecting the total cost of transportation. At last there are office expenses such as, telephone bills, computers, internet, etc (Niwo, 2014). For example the total cost of transportation for one truck + trailer when transporting frozen foods from Rotterdam to the north of United Kingdom are about €216.000 a year[1].

In order to transport perishable goods the trailer needs to be equipped with a refrigeration unit. A refrigeration unit can cool the truck to create the perfect conditions that are needed for the transported cargo. A refrigeration unit can reach temperatures far below zero, until minus 25 degrees Celsius. Every cargo has its own optimal temperature for transportation. For example frozen foods is cooled at minus 18 degrees Celsius and fresh flowers at 2 degrees Celsius. All the different required inside temperatures for all types of cargo can be found in figure 2.

In general the refrigeration unit is powered by a diesel generator which is also mounted on the trailer as can be seen in figure 1. A diesel generator is the combination of a diesel engine with an electric

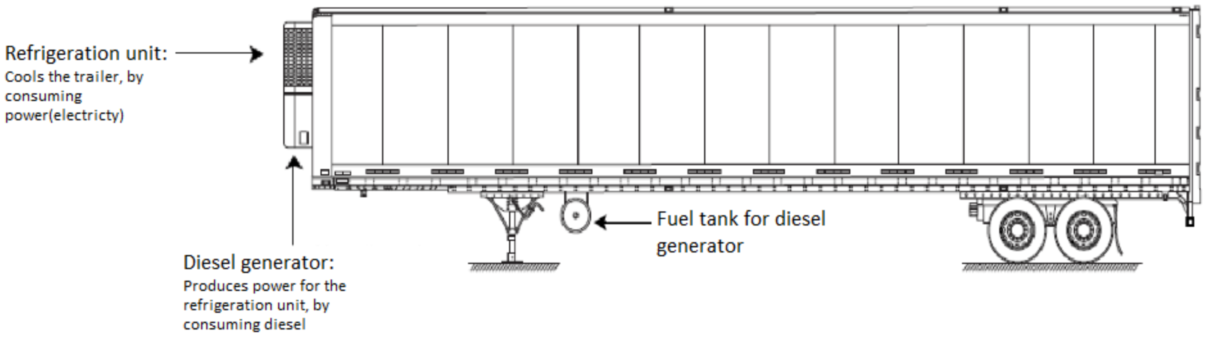


Figure 1: Technical drawing of diesel generated refrigeration unit (Mcguire, 2014)

generator to generate electrical energy, which in this case powers the refrigeration unit.

However, the refrigerated trailers could also be powered with electricity from the grid. Nomad Power is a company that places electricity connections at parking lots near highways. Drivers can power their loaded trailer with electricity when they are on a break. Note here that the difference between powering the loaded trailer and charging is an important distinction. The refrigerated trailers are never charged with electricity, only powered when the trailer is connected to the grid while the driver rests (Green truck Partnership, 2013).

Three companies dominate the market of refrigerated units: Thermoking located in Minneapolis (Minnesota, USA), Carrier Corporation in Farmington (Connecticut, USA) and Frigroblock in Essen

[1] Estimation of a transport company, located in the area of Rotterdam. (120.000 km * €1,8)

(Germany). These companies produce the refrigeration units and the diesel generators that are required for the refrigerated trailers. They also facilitate the maintenance that is necessary on the refrigerating unit and the generator.

The costs of cooling a trailer

The costs of cooling a trailer are the costs that are associated with using the refrigeration unit and its diesel generator. The first cost of cooling a trailer is the consumption of power. The consumption of both diesel and electricity is needed to make a comparison. The second cost of cooling a trailer are the maintenance costs of both the refrigeration unit and the diesel generator and will be investigated by interviewing the producers: Thermoking, Carrier and Frigoblock. The third cost of cooling a trailer are the depreciation costs of the refrigeration unit and the diesel generator. The depreciation costs will also be investigated by interviewing the producers. At last the switching cost will be given, these are the cost of investment that is needed if a transporters wants to use the facilities of Nomadpower.

Consumption of diesel

Van der Beek, Commandeur, Khajehzadeh, & Overbeek distinguish two different definitions of consumption per hour. The first definition is the consumption per hour, which is when the diesel generator operates continuously for 60 minutes. The second one is the consumption per hour per set point temperature, which includes the warming up period. The trailer cooled down to -15°C. Then the cooling system shuts down and the trailer warms up because of the surrounding temperature. Once the trailer reaches a temperature outside of the target range, the cooling system starts cooling again. The temperature and times at which these instances (cooling down period and the cool down period with the warming up period included) occurred were noted. In order to attain a reliable average cooling down time, these measurements were repeated for multiple cooling down cycles. The average consumption per hour when the diesel generator would operate continuously is 2.675 liter. When the start stop system is on and the warm up times are also included, the average consumption per hour is 1.368 liter (see table 13) (Van der Beek, Commandeur, Khajehzadeh, & Overbeek, 2014).

The same measurements were performed at a set point temperature of -5°C. At this temperature it shows that the average consumption is 2.483 liter per hour when the generator works continuously. With the start stop system and the warm up times included, the average consumption is 1.044 liter per hour (see table 14) (Van der Beek, Commandeur, Khajehzadeh, & Overbeek, 2014).

The price of diesel is primarily dependent on the oil price. Brent Crude is a major trading classification of crude oil that serves as a major benchmark price for purchases of oil worldwide. It is used to price two thirds of the world's internationally traded crude oil supplies. Goldman Sachs, an American multinational investment bank, has cut its long-term crude oil price forecasts and raised its projection for the average Brent crude oil price in the year 2015 to $58. Goldman Sachs has predicted that the Brent oil price assumption will increase to $60-$65 for 2016-2019, falling to $55 for 2020. These assumption made by Goldman Sachs will be used in the remainder of this study.

Consumption of electricity

Furthermore, besides the diesel consumption, the electric consumption was also estimated in the experiment by Van der Beek, Commandeur, Khajehzadeh, & Overbeek. The same two methods mentioned for the consumption of diesel were used to estimate the consumption of electricity. For the desired temperature of -15°C this resulted in 7.81 kWh per operating hour when operating continue. When the start stop system is on and the warm up times would also be included, the average consumption per hour is 3,133 Kw(see table 13) (Van der Beek, Commandeur, Khajehzadeh, & Overbeek, 2014).

This process was the same for the desired temperature of -5°C. The time to cool to the set point was shorter, this is logical because the difference between the target temperature and surrounding temperature was smaller, and this indicated that less heat was transferred through the insulation of the container. Therefore, there were fewer cycles in one hour than for a temperature of -15°C. The total measurement took 2 hours and 15 minutes and resulted in a use of 3 Kw total. Hence, the average use per hour when the warm up times would be included was 1,332 Kw. Unfortunately the measured consumption at -5°C from the TU Delft was not conducted correctly due to different warm up times of the trailers (Van der Beek, Commandeur, Khajehzadeh, & Overbeek, 2014), therefore these calculations are not of use when estimating the costs of cooling a trailer.

Switching Cost

Switching costs are the costs that arise when a vehicle needs to be made ready for the use of electricity to power the cooling unit. Thus when a transporter switches from a diesel generator to an electrically powered unit certain costs are incurred. The only equipment needed for a cooling unit to use the facilities of Nomad power is a cable. A 32A plug-in 5-pole (see figure 2) is needed to connect the cooling unit with the charging facilities of Nomad Power that are located at parking lots near the highways in West Europe. A 4-pole plug-in which is used for reefers is also possible to connect to the Nomad Power facilities, however an extra converter is needed which can be seen in figure 3. The switching costs are therefore very low.

Figure 2: 32A plug-in 5-pole (NomadPower)

Figure 3: 4-pole to 5-pole plug in converter (NomadPower)

Types of trailers

The majority of refrigerated road transportation is carried out using semitrailers. A semi-trailer is a trailer without a front axle; a tractor unit supports a large proportion of its weight. Semi-trailers are more popular for transport than full trailers, which have both front and rear axles(Van der Beek, Commandeur, Khajehzadeh, & Overbeek, 2014).

Another way of transporting cooled cargo is using a reefer. Just as refrigerated trailer reefer containers are used to transport goods requiring temperature-controlled conditions in transit, such as fruit, vegetables, dairy products and meat. A reefer on the other hand is mostly used when transporting overseas. A reefer is a container with a cooling unit built inside the container, which is connected to the carrying ship's electrical power supply (Container concepts, 2015).

Even though the reefer is not the subject of this study, studies that have investigated reefers in the past can still offer valuable insight to the current study. Therefore, studies that focus on reefers instead of trailers are not entirely excluded from the sources used in the theoretical framework.

Legislation

If a driver carries perishable food products abroad in an insulated refrigerated vehicle or container, many countries require drivers to comply with the Agreement on the International Carriage of Perishable Foodstuffs (ATP) and special equipment to be used for such cargo. The different areas of legislation include temperature, insulation and rest-time legislation.

Temperature legislation

The European union legislation covers temperature control requirements during the storage and transport of perishable foods. The regulations have been revised in early 2006 and regulation EC No 852/2004 on the hygiene of food products requires manufacturers to have suitable temperature controlled handling and storage facilities that can maintain food at appropriate temperatures and enable these temperatures to be monitored, controlled and recorded (Tassou, De-Lille, & Lewis, 2012). There are also specific temperature requirements for certain categories of food. Examples of specific temperature requirements for chilled and frozen food products are given in figure 2. The EU has also implemented specific chill temperature control requirements for food products not covered by EC No 853/2004. These requirements apply to food that is likely to support the growth of pathogenic microorganisms or the formation of toxins. Such food must be kept below 8 Celsius. The transport of perishable food products and the equipment used for the carriage of these products is governed by an agreement drawn up by the Inland Transport Committee of the United-Nations economic committee for Europe. The aim is to facilitate international traffic by setting common internationally recognized standards. The agreement is known as the ATP agreement and was adopted in Europe in 1980. It provides common standards for temperature controlled transport vehicles such as road vehicles, railway wagons and sea containers (Tassou, De-Lille, & Lewis, 2012). With regard to these international legislation laws it is important for transportation companies to be

Chilled products	Temperature (°C)
Fresh fish (in ice), crustaceans and shellfish (excluding live ones)	+2
Cooked dishes and prepared foods, pastry creams, fresh pastries, sweet dishes and egg products	+3
Meat and cooked meats pre-packaged for consumer use	+3
Offal	+3
Poultry, rabbit and gane	+4
Non-sterilized, untreated, unpasteurised or fermented milk, fresh cream, cottage cheese and curd	+3
Milk for industrial processing	+6
Cooked meats other than those which have been salted, smoked, dried or sterilized	+6
Frozen Products	**Temperature (°C)**
Ice and ice cream	-25
Deep frozen foods	-18
Fishery products	-18
Butter and edible fats, including cream to be used for butter making	-14
Egg products, offal, rabbit, poultry and game	-12
Meat	-10

Figure 4: Required inside temperature per type of cargo

aware of the proposed rules with regard to refrigerated transportation.

Insulation legislation

Insulation decreased the amount of energy needed to maintain a set temperature inside a transportation unit. Therefore, insulation plays a key role in the refrigerated transport sector. Because of its relative importance the international market has come up with a set of rules that transportation companies must comply with in order to operate in this sector. Insulation is measured using the K coefficient. A low K coefficient indicates high insulation efficiency. ATP regulations state that for frozen transport the thermal insulation of the refrigerated compartment should have a K-coefficient of heat transfer of ≤0.4W/m2K, and for chilled transport a value of ≤0.7W/m2K (World Health Organization, 2014). Normally the trucks in the Netherlands have an isolation coefficient of 0.4, which makes them very efficient to use. Insulation is one of the most important factors that can directly affect the costs and energy consumption of the truck (Van der Beek, Commandeur, Khajehzadeh, & Overbeek, 2014). In order to make a correct comparison all of the refrigerated trailers that are mentioned in this report will have a K-coefficient of 0,4 (Tassou, De-Lille, & Lewis, 2012) studies with a K-coefficient outside this scope will be treated as incompatible with the existing data and problem set. A coefficient of 0.4 is used because this value is the most commonly used value in West Europe.

Rest time legislation

The EU regulation (EC) 561/2006 provides a common set of rules for maximum daily and fortnightly driving times, as well as daily and weekly minimum rest periods for all drivers of road haulage and passenger transport vehicles. The scope of operations regulated is tremendously diverse, it includes: passenger transport and road haulage operations, international and national, long and short distance, drivers for own account and for hire and reward, employees and self-employed. The aim of this set of rules is to avoid distortion of competition, improve road safety and ensure drivers' good working conditions within the European Union (European Commission, 2006).

- A driver is not allowed to drive more than 4,5 hours non-stop and not more than 9 hours a day, with an exemption of twice a week when it can be extended to 10 hours. Between these periods of 4,5 hour he has to rest at least 45min.
- Total weekly driving time may not exceed 56 hours and the total fortnightly driving time may not exceed 90 hours.

The compliance with these provisions is subject to continuous monitoring and control, which are carried out on national and international level via checking tachographs records at the road side and at the premises of undertakings (European Commission, 2006).

Finally, the refrigerated transportation market must comply with a set of strict legislative rules. New ways of refrigerated transport, including electric power supplies must also adhere to these stringent rules. In order to be competitive legislative measures must first be met. Therefore, the legislative rules form a solid base for this investigation.

Effect outside temperatures

The rate at which cargo warms up is strongly determined by the outside temperatures. Therefore, it is likely that outside temperatures impact the consumption of energy and thereby influencing the costs of refrigerated transport. The company Shurepower is involved in the same line of business as NomadPower. Shurepower investigated the possible opportunities that can arise when transporting perishable cargo. Throughout the course of one year, several reefer trailers were analyzed and their diesel and electricity power consumption were recorded. All these reefers were equipped with a Vector cooling unit, which is made by Carrier Corporation, one of the previously mentioned producers for temperature controlled cooling units. The raw diesel fuel consumption data was collected by on-site maintenance personnel and transmitted to a Shurepower team for analysis. The maintenance personnel collected the data by connecting the cooling unit to a fuel database system and downloading the monthly fuel data set. Shurepower used a control fleet and a test fleet in order to analyze the impact of outside temperatures. On a monthly basis, the average fuel consumption was expressed in gallons per hour. Once calculated, the values were compared to the other test and control trailer data for that month. After all data was collected and analyzed for outliers, the average fuel consumption was plotted against several different variables, such as the outside temperature. These plots permitted the identification of any underlying trends that may exist in the data. When plotting the outside temperatures and consumption levels a correlation between the two variables can be graphically observed. Other factors could contribute to fuel consumption of the reefer trailer. For example solar gain, the proportionate increase in temperature due to the sun's radiation, could also contribute to the warming up of the trailer. However, the researchers of Shurepower considered this and other similar factors to be too difficult to quantify. Therefore, Shurepower assumed that outside temperature is an adequate indicator of the environmental exposure and can be used to identify these impacts on the fuel consumption of the reefer trailer (Shurepower, 2007). Figure 5 illustrates the direct correlation between the average monthly fuel use of the trailers and the average temperature of the month. Gallons and Fahrenheit, which were used by Shurepower, were

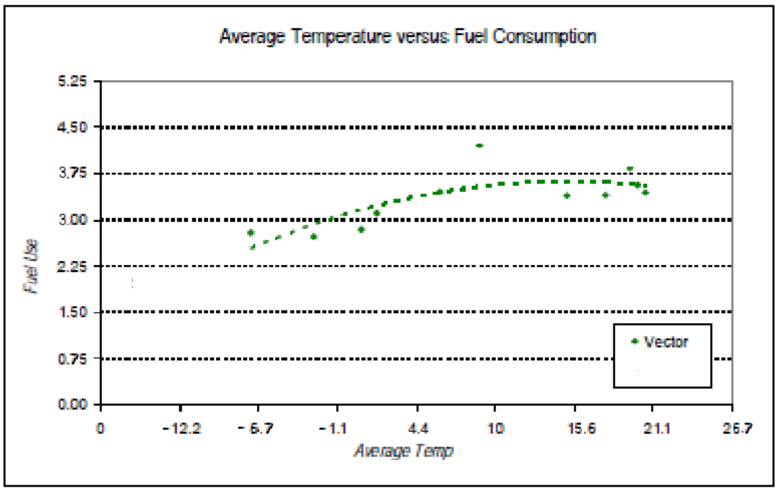


Figure 5: Average outside temperature versus fuel consumption (Shurepower, 2007)

converted into Liters and Celsius in order to made the data accessible to the European market and current problem set. The original figure of Shurepower can be found in appendix II.

3. Research Methodology

The costs of cooling a trailer

In order to estimate the costs of cooling a trailer when using both diesel and electricity the research by the TU Delft is used. Although their research lacks in some areas, the research done by Van der Beek and his colleagues is to time-consuming and technical to reproduce for the current study. Van der Beek and his colleagues conducted research that assessed two different types of consumption of power. The steps of their investigation are addressed under costs of cooling a trailer in the theoretical framework. For the current study, the first step is to estimate what consumption values are going to be used for further calculation. The measured consumption at -5ºC from the TU Delft was not carried out correctly due to different warm up times from the two trailers. The consumption values at -15ºC, however, can be used for further calculation. Because the maintenance cost is calculated by looking at the operating hours of the refrigerated unit the consumption per hour at -15 will be used for further calculation, which is when the diesel generator operates continuously for 60 minutes.

Secondly the maintenance and depreciation costs need to be investigated. The most important question about the maintenance costs will be if less maintenance is needed when using electricity from the grid during rest moments. During rest moments electricity can be used from the grid, which results in less operating hours for the diesel generator. In order to estimate the maintenance and depreciation cost the producers of the refrigeration units will be interviewed. The producers can give a good insight in the maintenance cost, frequency and amount of parts that need maintenance. The producers will be asked if less operating hours for the diesel generators also lead to less maintenance cost for the diesel generator.

Finally, the depreciation costs will be discussed, in particular the question whether these costs change when using electricity instead of diesel. The goal is to investigate if the use of electricity as power source has effect on the economic lifetime of the diesel generator. When the diesel generator has a longer economic lifetime the depreciation cost a year will decrease. During the interview the producers will be asked if the economic lifetime of the diesel generator changes when it runs less operating hours. The most important aspect will be if a diesel generator can/is being reused when the refrigeration unit is amortized.

The big producers Carrier, Thermoking and Frigroblock produce and maintain both the refrigerating unit and the diesel generator and, therefore they should be able to provide the required information. The producers will be asked to give an estimation based on the most common used units in west-Europe, for Thermkoking this would be the SMX 300 and for Carrier the Vector 1350.

Stop rate

Secondly, the time that loaded refrigerated trailers actually stand still near the highways needs to be estimated. In order to estimate this it is necessary to interview multiple transporters to get a reliable answer. The data that is collected will then be used to estimate if the values cluster to each other, form multiple smaller clusters or give a random plot of values by looking at a simple dot plot. It is suspected that the data will form multiple smaller clusters. This is because some transporters will only travel a short distance thereby foregoing the need to rest, other transporters will travel up to 9 hours and thus will have to rest twice for 45 minutes, while another group of transporters transport cargo over large distances and will need to stop after 9 hours before continuing the next day with their transport.

Bernice Vogelzang is conducting her thesis on the behavioral issues that arise when switching to an electric power source. She also requires information from the transporters. Hence questions that require answering from the transporters are combined into one questionnaire . Transporters were asked to assess the average amount of time that loaded trailers stand still at parking lots near the highway. In the period between the 5th of May and the 16th of June sixty-nine transport companies in the Netherlands were contacted and asked to answer the combined questions found in appendix. From these companies 25 responded and gave answers to all our questions. Some of them gave a percentage but others just mentioned the amount of time. The amount of time the trailers stand still a day is than converted into a percentage.

Prices west-Europe

When driving through Europe the fuel prices differ when passing the borders. In order to assess this effect the website globalpetrolprices.com will be used to estimate the different diesel prices in west-Europe. The average price of diesel for the Netherlands, Belgium, Germany, Italy, the United Kingdom and Spain will be given for the period from 30-May-2015 to 06-July-2015. A set period is chosen because it offers a more realistic average diesel price in West Europe. Specifically this period is used because it was the only period available on both globalpetrolprices.com and other sources. For comparison, the average price of diesel in the world for this period is 1.14 euro's.

NomadPower charges a set price per kilowatt that the transporters use to power the cooling unit. The cost of powering the cooling unit electrically is therefore equal to the price that Nomad Power charges for the use of its facilities. For the Netherlands, Belgium and Italy the real prices of Nomad Power prices will be used. The prices of the United Kingdom and Spain will be estimated on predictions that Nomad Power itself has given.

Break-even point and cost-benefit

The information till this point will be combined and used to calculate the break-even point and the potential cost-benefit that one refrigerated trailer delivers for the coming five years when using electricity during stand still. The break-even point will be estimated by calculating how much operating hours there are needed to compensate the cost that were made for switching to electricity from the grid. Firstly, the consumption of energy at -15 Celsius, as found by van der Beek and his colleagues, will be used as starting point because this data is considered to be most reliable out of the different set of measurements conducted by the researchers at TU Delft. Hereafter, the diesel price per liter is added to the consumption level. This will provide a consumption price per operation hour. Thereafter, the maintenance per operation hour will be added to the consumption price this gives the variable cost per operating hour. In order to arrive at the break-even point the difference in variable cost is divided by the switching cost.

In order to calculate the potential cost-benefit in five years some assumptions have to be made. Firstly, West-European diesel prices are primarily affected by the Brent oil price. Thus the Brent Crude price predictions can be used to estimate the price fluctuations for the coming five years. NomadPower had stated that they will use the price of oil (Brent Crude price) to estimate the price per kilowatt, which they charge for the use of their facilities. They have chosen to adopt this pricing strategy so that the transporters will maintain a cost benefit as oil prices rise and fall. Secondly, Goldman's Sachs prediction for the Brent Crude price (see theoretical framework) is used to estimate the diesel price for the coming five years. For simplicity this study will assume that the Brent price will rise with 5% in 2016 and 2017 reaching a peak price of 64 dollar per barrel in 2017. This study will also assume that the thereafter the Brent price will decrease with 5% per year in 2018 and 2019. Hence in 2020 the Brent price will fall to 55 dollars per barrel. Thirdly, the yearly use of the trailer is needed to calculate the amount of cost savings that are being achieved per refrigerated trailer a year. In a situation where the refrigerated trailer, the driver and the truck are held together constantly the yearly use could be calculated by taking the rest time regulation in consideration. In this case the yearly use of a trailer would be approximately 275 days. This however is not a good representation of reality. Transfrigoroute Deutschland, an association that unites companies involved in temperature-controlled transportation, carried out a cost prediction for the coming five years. They found that a refrigerated trailer is being used on average about 200 days a year. Which means that a refrigerated trailer is operating only 55% of the year on average (Transfrigoroute Deutschland (td) e.V., 2014). Finally is it assumed that switching costs, which is only the cost of one cable, are only incurred in the first year of switching to NomadPower's facilities. Using these assumptions, the cost benefit for the medium and long distance transports are calculated. The potential cost-benefit is calculated by quantifying the yearly use of the trailer in hours, multiplied by the variable cost per operating hour. The variable cost is correctly yearly to the Brent price assumption stated earlier.

The break-even point and potential cost-benefit in five years will be estimated separately for the different countries in West Europe including The Netherlands, Germany, Belgium, Italy, Spain and the United Kingdom.

Percentage of total cost

Additionally, to examine if the cost reduction has a significant effect on the total cost of transportation the questionnaire that will be conducted also includes questions about the total cost of transportation. Each transporter has different types of cargo (e.g. frozen fish, flowers, etc) that require different types of inside temperatures, therefore the percentage of each type of cargo that is transported is asked. The inside temperature values will be placed on the horizontal axes and the percentage of total cost on the vertical.

In the introduction it was stated that the share of the generator costs on the total costs of transportation increases when the required inside temperature decreases. To test this statement the Pearson product-moment correlation coefficient will be used to estimate if correlation is occurring between two variables *percentage of total cost* and *inside temperature*, giving a value between +1 and −1 inclusive, where 1 is total positive correlation, 0 is no correlation, and −1 is total negative correlation.

The continuous variables *inside temperature* and *percentage of total cost* are used to estimate if correlation occurs with the help of the Pearson's Product-Moment Correlation coefficient. When analyzing the data by using the Pearson's correlation, part of the process involves checking to make sure that the data that is being analyzed can actually be analyzed using Pearson's correlation. This is necessary because it is only appropriate to use Pearson's correlation if the data "passes" four assumptions that are required for Pearson's correlation to give a valid result.

The first assumption is that the two variables should be continuous (Laerd Statistics, 2013). The two variables *percentage of total cost* and *inside temperature* are both continuous variables and both passes the first assumption.
Secondly there needs to be a linear relationship between the two variables. In order to assess a linear relationship the dependent variable(percentage of total cost) is plotted against the independent variable(inside temperature), and then visually inspected for linearity.

The third assumption is that here should be no significant outliers. Outliers are simply single data points within the data that do not follow the usual pattern. An outlier may indicate bad data. For example, the data may have been coded incorrectly or an experiment may not have been run correctly. In some cases, it may not be possible to determine if an outlying point is bad data.

The fourth assumption is that variables should be approximately normally distributed. The Shapiro-Wilk test is used to estimate if the used variables are normally distributed. The Shapiro-Wilk Test is more appropriate for small sample sizes (< 50 samples), but can also handle sample sizes as large as 2000. For this reason, the Shapiro-Wilk test would be used as the numerical means of assessing normality. If the Sig. value of the Shapiro-Wilk Test is greater than 0.05, the data is normal. If it is below 0.05, the data is significantly deviate from a normal distribution (Laerd Statistics, 2013).

For the last part the effect that the cost reduction of switching to electricity has on the total cost of transportation will be calculated. In order to do this the different stop-rates, the cost difference per operating hour (when switching to electricity) and the percentage of total cost will be combined.

Two different stop-rates will be used for calculation: medium transportation distances and long transportation distances. The cost difference per operating hour is the percentage difference of the variable costs per operating hour for diesel and the variable costs per operating hour for electricity. The consumption values that were used for the calculation of the variable cost per operating hour are based on measurements with an inside temperature of minus 15 degrees Celsius. Thus, it would be necessary to only use values that are conducted with an required inside temperature of minus 15 degrees Celsius. The percentage of total cost value that is used for the calculation of the impact on the total cost of transportation will need to have an inside temperature of minus 15 degrees Celsius. This value can be found on the trend line, which is created in the scatterplot of the two variables *inside temperature* and *percentage of total cost.*

The impact that the cost reduction has on the total cost of transportation will be given in the form of a percentage. This percentage will be made absolute with the use of the total transportation costs example given in the theoretical framework.

During the questionnaire The transporters will be asked to estimate what the share of the generator cost is in relation to the total cost of transportation. Some transporters gave multiple answers to our questions others just gave one percentage of one type of cargo. During the period between the 5th of May and the 16th of June, 25 transporters were questioned which resulted in a dataset of 43 values as can be seen in the appendix.

4. Research data

The costs of cooling a trailer

In order to assess the costs of cooling a trailer, the consumption levels of diesel and electricity are needed. The consumption per operating hour and the consumption per hour including warm-up times for both diesel and electricity are given in table 1. The consumption values of diesel change when looking at different inside temperatures. Per operating hour the consumption of diesel is 8% higher when the inside temperature is -15 °C instead of -5 °C. This percentage is even higher when looking at the per hour consumption including warm-up times, which is 31% higher.

Power Consumption		-15°C	-5°C	Difference
Per operating hour	Diesel	2,675 L	2,483 L	8%
	Electricty	7,810 Kw	-	
Per hour including warm-up times	Diesel	1,368 L	1,044 L	31%
	Electricity	3,133 Kw	1,332 Kw	135%

Table 2: Consumption values of both diesel and electricity

Secondly the costs related to maintenance are given in table 2. The frequency of maintenance differed between the 1500 operating hours and 3000. But the amount of variable cost per operating hour that the producers had were almost all the same. A rule of thumb, that producers use, for maintenance is that the cost of maintenance is between the €1 and €0,75 per operating hour. The maintenance of the generator mostly consist of oil refill and the renewal of diesel filters and thus do not occur when cooling with electricity. However, most of the costs of maintenance of diesel and electricity overlap each other, such as a leak inspection, MOT test and the cool technical settings. While conducting the interviews it was found that the overlapping part is about 60% of the total cost of maintenance, which means that only 40% cost reduction is created when switching to electricity. The producers argued that depreciation does not play a role in the costs of cooling a trailer at all, because a refrigerated unit does not have a longer economic or technical lifetime when using electricity. The diesel generator is not needed when using electricity, but this does not mean that the depreciation can be decreased. This is due to the fact that a diesel generator almost never leaves the trailer or the refrigeration unit were it is mounted on. Thus, the economic lifetime of a diesel generator does not become longer when it runs less operating hours. The diesel generator is not reused when the refrigeration unit or trailer is amortized. so, When the diesel generator runs less operating hours this has no effect on the economic lifetime of the generator. Hence, the deprecation cost do not differ when cooling with electricity instead of diesel. The costs that arise when switching to electricity as power source consist only of the cost of a cable which cost 80 euro(figure 3).

	Diesel	Electricty	Cost overlap
Maintenance per operating hour (€)	1 - 0,75	0,4 - 0,3	60%
Depreciation (€)	-	-	
Switching cost (€)	0	80	0%

Table 3: Maintenance cost, Depreciation and Switching cost

Stop rate

Because some transporters only wanted to cooperate when their answers would stay anonymous, it was decided to keep all the data anonymous. The average percentage of total transportation time that loaded trucks stand still near the highways of 25 transporters is given in figure 6.

With the dot plot three different clusters can be observed: blue, green and yellow. When taking the rest time regulations into consideration, these percentages can be interpreted as different distances.

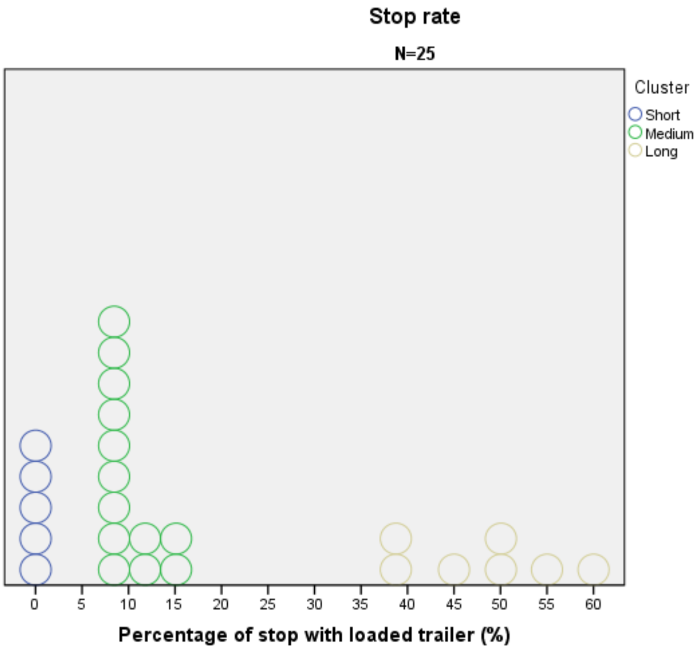


Figure 6: Rate of Stop

The blue cluster can be interpreted as a short distance transport that does not exceed 4,5 hours of transportation time. As the rest time is zero hours, the percentage of stop is also zero. The green cluster can be interpreted as a medium distance transport that does not exceed 9 hours of transportation time and include at least 45 minutes of stoppage time. This can be observed from the fact that 45 minutes of rest equals around 10% of the total travel time. The yellow cluster can be interpreted as a long distance transport that exceeds 9 hours of transportation time and thus the truck needs to stop the remaining part of the day.

The mean of every cluster is indicated with the mean stop-rate and is been given in table 3 and can be used for further calculations. The amount of transporters that are within these three clusters are indicated with N. The amount of transporters in each clusters is also converted into a percentage of total transport. Medium distances are the most common with a share of 52% of all the distances followed by long and short.

Distance:	Amount(N)	Share of total transport	Mean Stop-Rate
Short	5	20%	0%
Medium	13	52%	10%
Long	7	28%	44%

Table 4: Additional information stop rate

Prices west-Europe

In order to calculate the effect of prices in other countries in West-Europe, the prices of both diesel and Kw are needed. Both the Diesel and Kw prices are given for the countries Netherlands, Germany, Belgium, Italy, Spain and the United Kingdom in table 4. The price difference in the Netherlands with 489% between Kw and diesel is the most significant followed by Belgium(439%) and the United Kingdom(423%). Spain has the lowest relative price difference of all the studied countries in West-Europe.

	Diesel Price (€)	Kw prices (€)	Difference Kw -> Diesel
Netherlands	1,37	0,28	489%
Germany	1,23	0,35	351%
Belgium	1,23	0,28	439%
Italy	1,49	0,39	382%
Spain	1,21	0,4	303%
UK	1,69	0,4	423%

Table 5: Prices in West-Europe (Global Petrol Prices, 2015)

Break-even point and cost-benefit

In order to estimate the break-even point and the potential cost-benefit in five years, information that was gathered in the previous sub questions are combined. Firstly the break-even point was calculated by multiplying the consumption per operating hour by the price of the power source, resulting in the consumption price per operating hour. This was done for both diesel an electricity. The maintenance costs are added to the consumption per operating hour, which results in the variable cost per operating hour. To calculate the break-even point the switching cost are then divided by the variable cost per operating hour. Secondly the cost benefit in five years is calculated for both long and medium distances. In order to calculate the cost benefit in five years, the yearly use of the trailer in hours is multiplied by the variable cost per operating hour. The variable cost of both diesel and electricity is corrected yearly to the Brent price assumption stated in the research methodology. The break-even point and the cost benefit in five years when taking the prices of the Netherlands in consideration is given in table 5. The figure gives a comprehensive view of the calculation that have been done. The complete calculation can be found in the appendix.

	Diesel		Electricity	
Consumption per operating hour	2,675	L	7,810	Kw
Price Netherlands	1,370	€	0,280	€
Consumption price per operating hour	3,665	€	2,187	€
Maintenance per operating hour	0,875	€	0,350	€
Variable cost per operating hour	4,540	€	2,537	€
Switching cost			80	€
Break even Point			**39,93**	Hour
Cost benefit in five years: Medium distance			**4866,57**	€
Long distance			**21684,89**	€

Table 6: Break-even point and the Cost-benefit in five years (Netherlands)

The consumption price per operating hour for electricity is 39% lower than the consumption price per operating hour for diesel. The variable cost per operating hour for electricity is 44% lower than the variable cost per operating hour for diesel.

After 39,93 operating hours the break-even point in the Netherlands is reached. For medium distances the cost benefit for five years when taking the prices of the Netherlands in consideration is 4.866 euro's. The long distance cost-benefit in the Netherlands is 21.684 euro's after five years.

The calculations for the other West-European countries were done almost the same way, only the prices were adjusted. Because most of the calculations stay the same the outcomes of the break-even point and cost benefit in five years are given in figures without the calculations.

The break-even point and the potential cost-benefit in five years for Germany are given in table 6. The break-even point of Germany is reached after 73,92 operating hours. The potential cost-benefit in five years for medium and long distances are respectively 2.569 and 11.577 euro's.

Germany	Diesel	Electricity
Variable cost per operating hour	4,166 €	3,084 €
Break-even point		73,92 Hour
Cost benefit in five years: Medium distance		2569,387 €
Long distance		11577,304 €

Table 7: Break-even point and the Cost-benefit in five years (Germany)

The break-even point and the potential cost-benefit in five years for Belgium are given in table 7. The break-even point of Belgium is reached after 73,92 operating hours. The potential cost-benefit in five years for medium and long distances are respectively 3.932 and 17.575 euro's.

Belgium	Diesel	Electricity
Variable cost per operating hour	4,166 €	2,537 €
Break even point		49,11 Hour
Cost benefit in five years: Medium distance		3932,61 €
Long distance		17575,47 €

Table 8: Break-even point and the Cost-benefit in five years (Belgium)

The break-even point and the potential cost-benefit in five years for Italy are given in table 8. The break-even point of Italy is reached after 54,59 operating hours. The potential cost-benefit in five years for medium and long distances are respectively 3.524 and 15.781 euro's.

Italy	Diesel	Electricity
Variable cost per operating hour	4,861 €	3,396 €
Break even point		54,59 Hour
Cost benefit in five years: Medium distance		3524,90 €
Long distance		15781,55 €

Table 9: Break-even point and the Cost-benefit in five years (Italy)

The break-even point and the potential cost-benefit in five years for Spain are given in table 9. The break-even point of Spain is reached after 125,36 operating hours. The potential cost-benefit in five years for medium and long distances are respectively 1.462 and 6.705 euro's. Out of all countries, Spain, followed by Germany, has the lowest cost-benefit outcome for both the medium and long distances compared to the other West European countries.

Spain	Diesel	Electricity
Variable cost per operating hour	4,112 €	3,474 €
Break even point		125,36 Hour
Cost benefit in five years: Medium distance		1462,24 €
Long distance		6705,84 €

Table 10: Break-even point and the Cost-benefit in five years (Spain)

The break-even point and the potential cost-benefit in five years for the United Kingdom are given in table 10. The break-even point of The United Kingdom is reached after 41,62 operating hours. The potential cost-benefit in five years for medium and long distances are respectively 4.664 and 20.795 euro's. Out of all countries, Spain has the lowest cost-benefit outcome for both the medium and long distances compared to the other West European countries.

United Kingdom	Diesel	Electricity
Variable cost per operating hour	5,396 €	3,474 €
Break even point		41,62 Hour
Cost benefit in five years: Medium distance		4664,38 €
Long distance		20795,26 €

Table 11: Break-even point and the Cost-benefit in five years (Spain)

Out of all countries, the Netherlands, followed by United Kingdom has the highest cost-benefit outcome for both the medium and long distances compared to the other West European countries.

Percentage of total cost

In order to estimate what the share of the generator's cost is in relation to the total cost of transportation, transporters were questioned. Some transporters gave multiple answers to our questions others just gave one percentage of one type of cargo. In the introduction it was stated that the share of the generator costs on the total costs of transportation increases when the required inside temperature decreases. To test this statement the Pearson product-moment correlation coefficient will be used to estimate if correlation is occurring between two variables *percentage of total cost* and *inside temperature.* Note that the data is based on estimations from transporters and thus it is not a precise reflection of the values in reality. The correlation test is used to prove that there is relation between the required *inside temperature* and *the percentage of total cost*.

In order to the use Pearson's correlation coefficient the data needs to "pass" the four assumptions: variables should be continuous(already proven in methodology section), there should be a linear relationship between the two variables, there should be no significant outliers and the data needs to be normally distributed.

Using SPSS a scatterplot is generated and a trend line is estimated by analyzing the available data in figure 7. Figure 7 helps to support the second assumption, the data must be approximately linear.

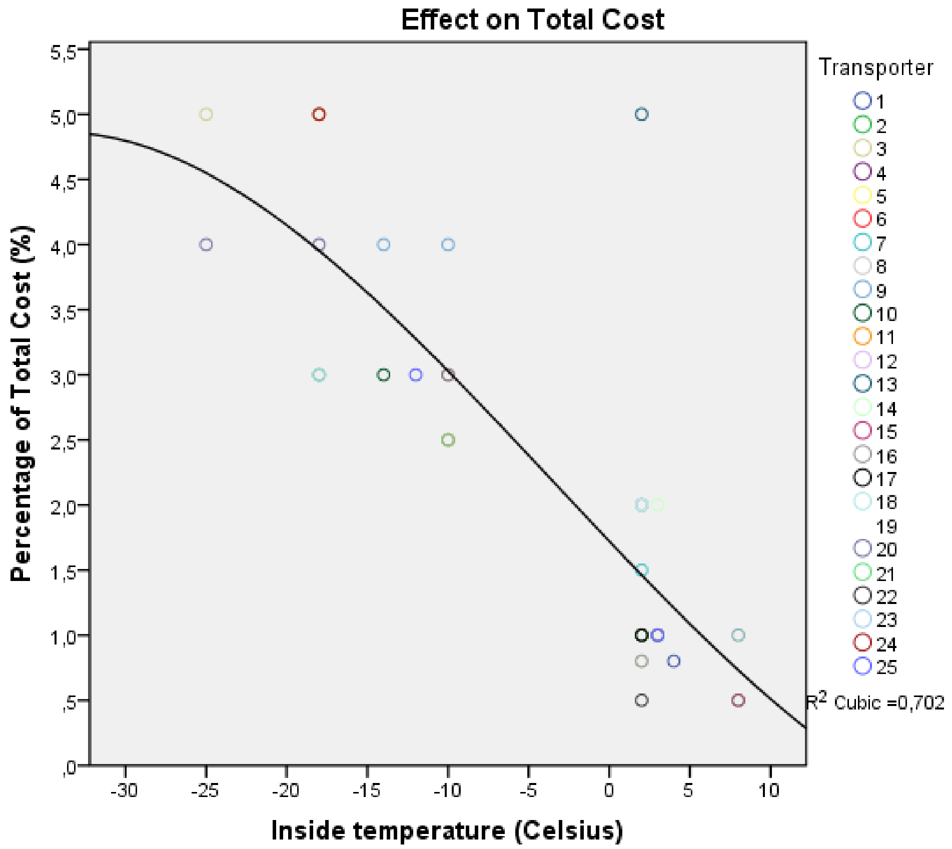
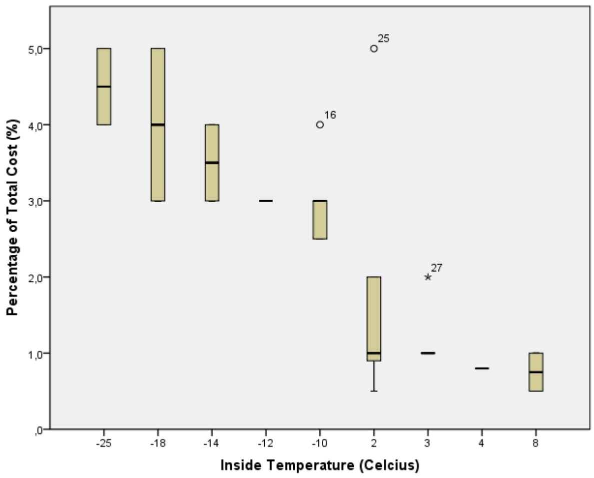


Figure 7: The share of the generator cost on the total cost of transportation

In figure 7 the R-square is given on lower-right corner and has an value of 0,702. The value R-square is a fraction between 0.0 and 1.0, and has no units. An R-square value of 0.0 means that knowing X does not help you predict Y. There is no linear relationship between X and Y, and the best-fit line is a horizontal line going through the mean of all Y values. When R-square equals 1.0, all points lie exactly on a straight line with no scatter. Knowing X lets you predict Y perfectly (Graph Pad Software, 2014).

In figure 8 a boxplot is given with the inside temperature values placed on the horizontal axes and the percentage of total cost on the vertical. This boxplot helps to identify outliers, the third assumption states that no outliers should be present in the data set. In this research a percentage of total cost is asked from the transporters. Values can differ because cost structures of transporters differ between each other. Different percentages of total cost may differ because transporters have different ways of managing their cost. A very high percentage doesn't mean it is bad data, therefore outliers are not excluded out of the dataset and extreme values are interpreted as normal good data.



Now the Shapiro test is applied in order to test the fourth assumption; if the variables are approximately normally distributed. As can be seen in table x the variables *percentage of total cost* and *inside temperature* have a Sig. value of respectively 0,001 and 0,000. Therefore it can be assumed that the data of both variables are normally distributed.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Percentage_of_Total_Cost	,205	43	,000	,887	43	,001
Inside_temperature	,328	43	,000	,836	43	,000

a. Lilliefors Significance Correction

Figure 8: Boxplot

Table 12: Tests for Normality

Now that all the assumptions are "passed" the Pearson coefficient can be used to estimate if correlation occurs between the two variables. In table 12 the Pearson correlation coefficient gives a value of minus 0,837, which indicates a negative correlation between the variables. This means that as the inside temperature increases in value, the percentage of total costs decreases in value. In table 12 the Sig. (2-Tailed) has a value of 0.000. This value is less than 0.05. Because of this, we can conclude that there is a statistically significant negative correlation between the inside temperature of a trailer and the percentage of total cost. Thus, the share of the generator costs on the total costs of transportation increases when the required inside temperature decreases.

Correlations

		Inside_temperature	Percentage_of_Total_Cost
Inside_temperature	Pearson Correlation	1	-,837**
	Sig. (2-tailed)		,000
	N	43	43
Percentage_of_Total_Cost	Pearson Correlation	-,837**	1
	Sig. (2-tailed)	,000	
	N	43	43

**. Correlation is significant at the 0.01 level (2-tailed).

Table 13: Spearman's Rank-Order Correlation using SPSS

In order to calculate the impact that use of electricity during rest moments has on the total costs of transportation the following three values are needed: the percentage of total cost, the stop-rate and the percentage change of the variable cost per operating hour when switching to electricity. The consumption values that were used for the calculation of the variable cost per operating hour (table 5) are based on measurements with an inside temperature of minus 15 degrees Celsius. In figure 7 it can be seen that when the trailer has an inside temperature of minus 15 degrees Celsius the percentage of total cost has a value of 3,5%. The medium and long transportation distances have a stop-rate of respectively 10% and 44%. The variable cost per operating hour for electricity is 44% lower than the variable cost per operating hour for diesel (see table 5). When multiplying these three values the impact, of using the facilities of Nomadpower, on the total cost of transportation are calculated for the medium and long transportation distances. A cost reduction of 0,68% on the total cost of transportation for long transportation distances is created when using electricity from the grid. For long transportation distances this would be a cost reduction of approximately €1470 a year per refrigerated trailer + truck. A cost reduction of 0,15% on the total cost of transportation for medium transportation distances is created when using electricity from the grid.

	Impact on the total cost of transportation (%)
Long transportation distances	-0,68%
Short transportation distances	-0,15%

Table 14: Impact on the total cost of transportation

5. Conclusion

This study has attempted to find a comprehensive answer to the following question:

What are the effects on the cost of refrigerated trailers when using electricity instead of the diesel as power source during rest moments?

To answer this question several sub questions were constructed in order to obtain a clearer understanding of the various factors affecting the costs.

The costs of cooling a trailer

The costs of cooling a trailer with both diesel and electricity consist of the consumption of power, maintenance, depreciation and switching cost. The price per operating hour for diesel and electricity are respectively 3,665 and 2,187 euro's, thus when switching to electricity a cost reduction of 39% per operating hour is realized.

The maintenance costs for a refrigeration unit and its generator are between the 1 and 0,90 euro per operating hour. The maintenance cost decreases between the 0,30 and 0,40 euro per operating hour when switching to electricity. 60% of the maintenance costs do not change when using electricity instead of diesel as power source. Thus a cost reduction in maintenance of 40% is realized when switching to electricity. The depreciation cost do not play a role in the costs of cooling the trailer at all, because a diesel generator does not have a longer economic or technical lifetime when using electricity.

The costs that arise when switching to electricity instead of diesel are called the switching costs. The switching costs consist only of purchasing a new cable, which cost 80 euro.

Inside temperature

The inside temperature of the trailer effects the consumption of energy when cooling the trailer. Per operating hour the consumption of diesel is 8% higher when the inside temperature is -15 °C instead of -5 °C. This percentage is even higher when looking at the per hour consumption including warm-up times. The per hour consumption including warm-up times of diesel is 31% higher when the outside temperature is -15°C instead of -5°C. Further research is needed to investigate the precise consumption values for all used inside temperature in the refrigerated transport sector. Still it can be stated that the inside temperature of a trailer effects the consumption of power. When the inside temperatures goes further below zero degree Celsius the consumption of power increases.

Outside temperature

The outside temperature has influence on the consumption of energy when cooling the trailer. The company Shurepower found a direct correlation between the average monthly fuel use of the trailer and the average temperature of the month. The average fuel use decreases when the outside temperature decreases, hence there is a positive correlation. Note that this only occurs when the outside temperature falls below approximately 15 degrees Celsius. The significance of this effect however cannot be estimated, because these test results discussed in this study are conducted with the use of reefer trailers. It would be incorrect to assume that the exact same effects holds for refrigerated trailers.

Stop rate

The average amount of time that loaded trailers stand still at parking lots near the highway differs depending on the transportation distance. With the dot plot(figure 6), three different transportation distances were observed: short, medium and long distances. Short transportation distances do not stop at all and thus have a stop rate of zero percentage. Medium transportation distances have an average stop rate of 10% and are the most common distances with a market share of 52%. Long transportation distances generally exceeds 9 hours of transportation time and thus the truck needs to stop the remaining part of the day, which results in an average stop rate of 44%. For longer transportation distances the stop rate is higher and therefore their cost-benefit can reach higher values than shorter transportation distances.

Prices West-Europe

The costs do not remain constant when transporting cooled freight through different countries in West-Europe. Different prices in the west European countries result in different break-even points and a different cost-benefit analysis. Of all European countries The Netherlands have the lowest break-even point of 39,93 operating hours and the cost-benefit in five years for long distances is €21.684 and short distances is €4.866, followed by The United Kingdom, Belgium, Italy, Germany and Spain. For comparison, Spain has the highest break-even point of 125,36 operating hours, the cost benefit in five years for long distances is €6.705 and short distances is €1.462. Spain's break-even point is 3,14 times higher than the break-even point of the Netherlands. Spain's cost-benefit in five years is even 59% lower than the cost-benefit in five years from The Netherlands. Overall it can be stated that the cost-benefits outweighs the switching cost after a relative small amount of operating hours, for instance in the Netherlands only 40 operating hours are needed. All west-European countries that were investigated reached a positive cost-benefit in five years , however the amount of cost-benefits differ strongly between the different countries. The North-West European countries including The Netherlands, The United Kingdom and Belgium have the highest cost-benefit in five years and can be described as the most promising countries for cooling with electricity instead of diesel. On the other hand the South-West European countries Spain and Italy in general have high outside temperatures and can therefore compensate their relatively lower diesel and higher Kw price.

Percentage of total cost

The cost reduction has a significant impact on the total cost of transportation, but this does not hold for all types of cargo. Multiple transport companies were interviewed and asked how large the share of the cost of energy are in comparison with the total cost of transportation for all types of cargo. It was found that when the inside temperature decreases, the percentage of total costs increases. When the required inside temperature is -15 a cost reduction of 0,68% on the total cost of transportation is realized for long transportation distances, which can represent 1.500 euros cost reduction on a yearly base. When looking at short transportation distances this percentage drops to 0,15. Overall it can be stated that when looking at inside temperatures under the zero degrees Celsius the cost reduction can have a significant effect on the total cost of transportation. Therefore, cargoes that need a low inside temperature can benefit the most from the cost reduction, such as frozen meat, frozen fish, ice(cream), egg products, offal and other deep frozen foods. When a higher inside temperature is needed this still leads to a cost reduction, but it is not as significant as the cost reduction of cargoes with lower inside temperatures.

6. Discussion

Consumption values

Due to time and technical constraints, this investigation has taken other studies into consideration during the data analysis part. The consumption values of, both, diesel and electricity used in calculations carried out in this study, were taken from research conducted at the TU Delft by Van der Beek and his colleagues. It is easier to find points of criticism in studies conducted by others, nonetheless the data of the current study is based on values obtained by another study, therefore one needs to be critical towards the source of this data. There are some points of critique that need to be discussed considering the consumption values found by van der Beek and his colleagues. Their research made a distinction between two ways of measuring the consumption of energy. The first one was the energy consumption of an unloaded truck per operating hour. The second was the consumption of an unloaded truck per hour per set point temperature, which includes the warming up period. These two power consumption measurements approach the values that would occur in reality. However, there is still room for improvement in the approximation of these values. In order to estimate the consumption values correctly, the values of a loaded truck should be measured including warm-up times.

Different types of cargoes can result in different warm-up times, because some cargo can warm-up faster than other types of cargo. The research of Van der Beek and colleagues only did consumption measurements for -5 and -15 Celsius. However, a significant part of the global refrigerated transport sector consist of cargo, like flowers and fresh foods, that are transported with a set point temperature of higher than zero Celsius. In order to make a good estimation of the reality, warm-up times and set point temperature of different types of cargo should be included in the research.

Sometimes the outside temperature becomes lower than the inside temperature of the refrigerated trailer. In these circumstances the refrigeration unit will need to warm-up the trailer instead of cooling it. Consumption values for warming-up the trailer are fully excluded in all the researches that have been done until now, including this thesis. In order to get a more comprehensive view of reality, warming-up consumption values should be included in the research.

Finally, it could also be interesting to investigate if other power sources, such as red diesel, can and are being used. Red diesel fuel is chemically seen, only slightly different from regular automotive diesel fuel, but there can be a significant difference in cost. The red diesel fuel can do the same work as the more expensive automotive diesel fuel. In order to ensure that red diesel, which is minimally taxed, is not used as diesel fuel, which can be heavily taxed, regulation require these type of fuel to receive a special red dye. This liquid red dye can be detected in even the smallest samples taken for examination (Wisegeek, 2015). While red diesel is an interesting fuel option, it can be debated whether its use in a generator used for transport vehicles is legal in The Netherlands. Additionally legislation on this fuel type differs among the different European countries. Therefore, there it could be interesting to explore alternative power sources.

Effect outside temperatures

The effect of the outside temperatures on the consumption of power was investigated by Shurepower in the area around New York. Their research was done with the use of a reefer trailer, which are different than the refrigerated trailers in West-Europe. The research of Shurepower was very useful for this research, but their measurements cannot be used for further calculations. A reefer trailer has different kind of characteristics and is cooled with other refrigeration units than a refrigerated trailer. These different kind of characteristics can have an impact on the consumption values. It would lead to wrongfully formed conclusions when combining the Shurepower measurements in combination with the consumption values of the trailer, from Van der Beek and colleagues, for calculation.

In order to make a correct estimation of the consumption values with different outside temperatures, all factors of influence should be the same. The consumption values should by measured by taking both the inside as outside temperature in consideration. In an ideal situation all consumption values of power with different inside temperatures are measured for all possible outside temperatures. The measurements should be taken with the use of identical trailers that are being cooled with the same refrigeration unit.

Assumptions

In this thesis some assumptions have been made in order to make a forecast of the potential benefits of switching to electricity instead of diesel as power source. The Brent crude oil price was used as basis to estimate the prices for the potential cost-benefit in five years. The price of diesel is dependent on the oil price, therefore is it very hard to make a correct prediction of the prices for the coming years. In the absence of a better option the Brent crude predictions from Goldman Sachs were interpreted and transformed into a yearly increase/decrease percentage (see the appendix). It was also considered to use the diesel price from the last ten years as basis for the yearly growth rate. However, there is a big peak up and down around 2008 when the financial crisis hit and that would lead to a distorted growth rate. Summarizing, it is very hard to assess a good prediction method for the price of oil and there is no perfect way to estimate it. The Goldman Sachs predictions were used because it was the best option that came up after research and was recently confirmed by Royal Dutch shell its predictions (Royal Dutch Shell, 2015).

The yearly use of the trailer of 200 days was used to calculate the cost-benefit for the coming years. Transfrigoroute Germany did research on this matter and found that 200 days was a good presentation of how much the trailers were used in reality. However it is unclear on what this assumption is based and if the refrigerated trailer, the driver and the truck are held together constantly. In order to make a good estimation of the reality, the yearly use of a trailer should be investigated and in particular if the trailer, the truck and the driver stay together constantly. Further, it would be interested to investigate if the use of a trailer differs when looking at different types of cargo and transportation distances.

In this thesis only the costs and benefits of one type of refrigerated trailer are given. This particular trailer is the most used mode of refrigerated transport, but it is not the only one that is used in the refrigerated transport sector. Smaller trucks and trailer are excluded from this research, but are also part of the industry. In order to make a comprehensive overview of the cost and benefits that are created when switching to electricity, smaller types of trucks and trailer should also be included in the research.

The most important task for Nomad Power would be to facilitate enough energy supply points near highways. The calculated costs-benefits in five years assumes that Nomad Power's energy supply systems are situated at every stop near the highway. This would be nearly impossible for Nomad Power to achieve, but they can place their facilities at the most common used stop places for trucks.

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Appendix I: Theoretical framework

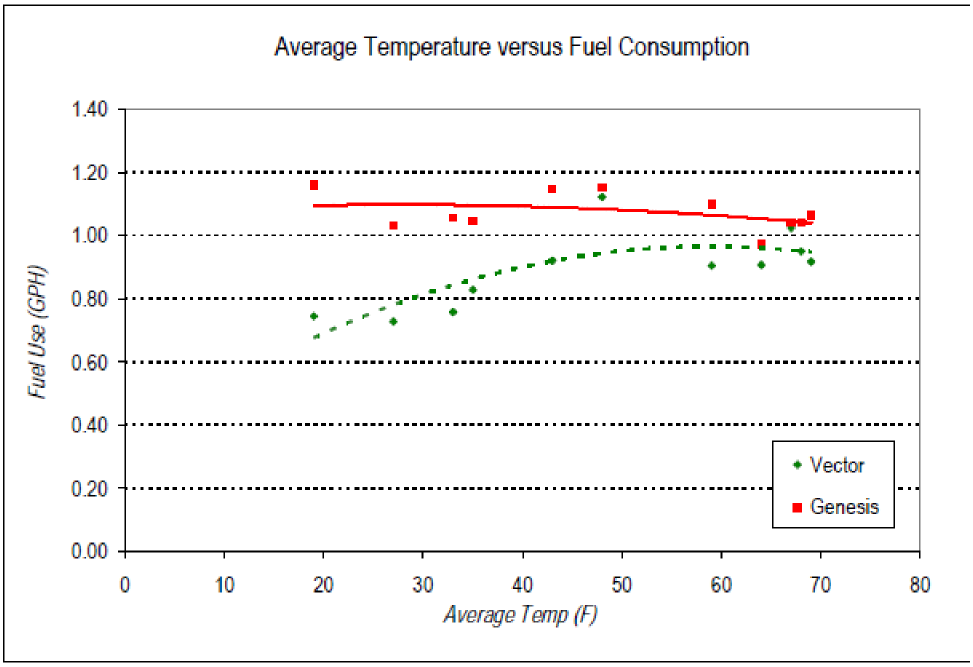

Figure 9: Original figure of the Average Ambient Temperature versus Fuel Consumption (Shurepower, 2007)

Verbruik:	2.52.22	uren	9	kWh
Gemiddeld verbruik:	1	uren	3.133	kWh
Uitstoot: CO2	415	gram	1	kWh
	1300.2	gram	3.133	kWh
SO2	65	miligram	1	kWh
1 uur	203.6	miligram	3.133	kWh
NOx	254	miligram	1	kWh
	795.8	miligram	3.133	kWh

Gemiddeld verbruik:	1	uren	1.3683	liter
Gemiddeld verbruik(η=100%):	1	uren	13.683	kWh
Gemiddeld verbruik(η=22,9%):	1	uren	3.133	kWh
Uitstoot: CO2	1153	gram	1	kWh
	3612.3	gram	3.133	kWh
SO2	3.7	miligram	1	kWh
1 uur	11.5	miligram	3.133	kWh
NOx	523.7	miligram	1	kWh
	1640.9	miligram	3.133	kWh

Table 15: Consumption values at -15 degrees Celsius (Van der Beek, Commandeur, Khajehzadeh, & Overbeek, 2014)

Appendix II: Data

Electrisch bij -5				
Verbruik:	2.15.07	uren	3	kWh
Gemiddeld verbruik:	1	uren	1.332	kWh
Uitstoot: CO2	415	gram	1	kWh
	522.86	gram	1.332	kWh
SO2	60	miligram	1	kWh
	79.93	miligram	1.332	kWh
NOx	254	miligram	1	kWh
	338.3	miligram	1.332	kWh

Diesel bij -5 Uitstoot en rendement is niet representatief omdat de opwarmtijden tussen de trailers grote verschillen vertonen				
Gemiddeld verbruik:	1	uren	1.0440	liter
Gemiddeld verbruik(η=100%):	1	uren	10.440	kWh
Gemiddeld verbruik(η=12,8%):	1	uren	1.332	kWh
Uitstoot: CO2	2069	gram	1	kWh
	2756	gram	1.332	kWh
SO2	6.6	miligram	1	kWh
	8.8	miligram	1.332	kWh
NOx	430.5	miligram	1	kWh
	573.5	miligram	1.332	kWh

Table 16: Consumption values at -5 degrees Celsius (Van der Beek, Commandeur, Khajehzadeh, & Overbeek, 2014)

Cargo(in dutch)	Temperature	% percentage of total cost	Stop Rate %
Bloemen	2	1	7,5
Poultry	4	0,8	
aardappelen	8	0,5	7
Bevroren vis	-18	3	
ijs	-25	5	10
verse vis	2	0,8	
Bloemen, groente, fruit	2	2	10
Bloemen, groente, fruit	2	1	40
medicijnen	8	1	
Vlees	-10	2,5	8
levensmiddelen	3	1	
verse vis	2	1,5	15
diepvries Vis	-18	4	40
Vis bevroren	-18	5	45
ei producten	-14	4	
vlees	-10	4	
verse vis	2	2	
aardappelen	8	1	
koel	3	1	0
diepvries levensmiddeln	-14	3	
groenten	2	1	
vries	-10	3	8
vries	-18	5	
bloemen en fruit	2	2	37,5
Groente en fruit	2	5	50
Bloemen en planten	2	2	0
levensmiddelen	3	2	
medicijnen	8	0,5	8
Groente en fruit, bloemen e	2	0,8	12
vers	2	1	10
Bloemen en planten	2	2	0
bloemen	2	0,5	2
ijs	-25	4	15
Vis bevroren	-18	4	
vlees brevroren	-10	3	
Bevroren vis	-18	3	10
vlees brevroren	-10	2,5	
verse producten	2	0,5	50
Bevroren voedsel	-18	3	7
vers	3	1	
bevroen voedsel	-18	5	45
koel	3	1	1
ei producten	-12	3	

Table 17: Data from questionnaire

Questionnaire(in dutch) for the combined research with Bernice Vogelzang.

1. Wat voor soort vracht vervoert u voornamelijk?

2. Hoe groot is het aandeel(procentueel) van het gebruik van de diesel aggregator op de totale transportkosten per soort vracht?

3. Op een schaal van 1 tot 10, geef aan hoe belangrijk de milieuvriendelijkheid van de aggregator is. (1= zeer onbelangrijk, 5= neutraal, 10= zeer belangrijk)

4. Op een schaal van 1 tot 10, geef aan hoe bereid u zou zijn om uw chauffeurs te laten omrijden, eerder te laten stoppen of langer door te laten rijden om deze voorziening van Nomad Power te kunnen gebruiken. (1= Helemaal niet bereid, 5= neutraal, 10= zeer bereid).

5. Hoe veel procent van de tijd schat u dat uw chauffeurs gemiddeld beladen stilstaan naast de snelweg?

6. Indien er een beslissing moet worden genomen over het gebruik van de voorzieningen van Nomad Power, heeft de chauffeur in vaste dienst hier dan invloed op?

7. Indien er een beslissing moet worden genomen over het gebruik van de voorzieningen van Nomad Power, heeft de eigen rijder hier dan invloed op?

8. Indien uw klant het belangrijk vind dat u milieuvriendelijk handelt, bent u dan bereid om over te stappen op de voorziening van Nomad Power?

9. Tenslotte, bent u bereid om een digitale enquete door te sturen naar uw chauffeurs? op deze manier hopen we om ook hun mening over deze mogelijkheid te weten te komen. De chauffeurs kunnen de enquete invullen via de volgende link: https://nl.surveymonkey.com/s/Q2XKW9M

Appendix III: Data calculation

Costs of cooling a trailer:

Per operating hour difference = (Power consumption at -15 / Power consumption -5) -1

Maintenance per operating hour(electricity) = maintenance per operating hour(diesel) * 0,4

Stop Rate:

Share of total transport = Amount N of the transportation distance(short, medium or long)/ Total amount N of all transportation distances

Mean stop rate = Sum of all the values of the particular clusters(short, medium or long)/ Amount of values of the particular cluster

Prices West-Europe

Differences in prices = Price Diesel/ price Kw

Break-even point and cost benefit in five years

Consumption price per operating hour = Consumption per operating hour * Price of Energy(Kw/diesel) per country

Variable cost per operating hour = Consumption price per operating hour + Maintenance per operating hour

Break-even Point = Switching cost / Variable cost per operating hour

Interpretation of the forecast from Goldman Sachs:

year	price adjustment(absolute)	Price adjustment (percentage)
2015	58	
2016	60,9	0,05
2017	63,945	0,05
2018	60,74775	-0,05
2019	57,710363	-0,05

Variable cost per operating hour when calculating five year cost-benefit:

Consumption per operating hour *Price of power*(1+Price adjustment in that year(percentage)) + maintenance per operating hour

Cost per year (electricity and diesel):

yearly use of the trailer(200 days)*24(hours of one day)*variable cost per operating hour(for that specific year)* Medium or Long distance stop rate(0,10 or 0,44 stop rate) – Switching cost(only in the first year

Cost benefit in five years:

(Cost per year 2015 for diesel – cost per year 2015 for electricity) + (Cost per year 2016 for diesel – cost per year 2016 for electricity) + same for 2017 + same for 2018 + same for 2019

Percentage of total cost

Impact on the total cost of transportation (%)

For the long distances

3,5% * 0,44 * 0,44 = 0,68% reduction of the total cost of transportation

For the short distances

3,5% * 0,44 * 0,10 = 0,15% reduction of the total cost of transportation