Electrical trailer cooling during rest periods

Analysis of emissions and costs

Co-financed by the European Union
Trans-European Transport Network (TEN-T)

CE Delft

Committed to the Environment

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Summary

NomadPower is developing a power supply network at parking places for temperature controlled transport. This power supply network allows drivers to run the cool units of their trailers on electricity instead of diesel.
For the development of this network, NomadPower is supported by the European transport network (TEN-T) Programme for improving transport infrastructure across Europe. In context of the TEN-T programme, NomadPower has asked CE Delft to assess the costs benefits and environmental impact of the NomadPower concept.

The most important market for NomadPower are transport haulage operators on international long distance routes. The transports in this market are often multiple days and require an overnight stop. This means a resting period of nine hours or more in which it would be possible to connect to electricity if this service is present on the location. For these transports the potential of NomadPower is high.

In this report we examined the potential use of NomadPower on parking places in long haul refrigerated transport. For Europe as a whole we found that 50–100 million hours of diesel consumption at parking places can be replaced by electricity consumption. This substitution would save 130-260 million litres of diesel, 290-580 kton of CO_2, which equals the yearly emissions of 2,700-5,400 new long haul trucks. Depending on the electricity prices set by NomadPower, this fuel reduction would save transport operators €180 per year per transport refrigeration unit (TRU). Furthermore, it would also significantly reduce air pollutant emissions: 2.36- 4.73 kton of NO_x emission and 280-560 tonnes of PM_{10} emission per year. This equals the yearly NO_x emissions of 5,000-20,000 Euro-V trucks or 35,000-70,000 Euro-VI trucks and the yearly PM_{10} emissions of 110,000-220,000 Euro-V trucks or 220,000-440,000 Euro-VI trucks, respectively. Especially the PM_{10} reduction potential is high. The annual potential PM_{10} reduction of the TRU during resting periods equals the annual PM_{10} emission of a Euro-VI truck or 50% of the emission of a Euro-V truck. The potential emission reductions are relatively high as currently there are no emission standards for TRU diesel aggregates as there are for truck engines.

The potential emission reduction and cost savings for transport operators may vary depending on the characteristics of the transport. Ambient temperature, operation mode, and the type of product are important parameters that determine the potential environmental and costs benefits of the Nomad Power concept. The influence of different parameters has been illustrated by different cases for an overnight resting period in France and Poland.
From the cases it can be concluded that when switching from diesel to electricity, CO_2 emission will be reduced by 32-91%, NO_x emission by 73-98% and PM_{10} by 85-99%. On average costs will be reduced. The investigated cases reveal cost savings up to € 0.50 per gross operating hour switched to electricity. For chilled products, however, switching to electricity in cases with a relatively high electricity and low and diesel price lead to extra costs up to € 0.20 gross operating hour.

1 Introduction

1.1 NomadPower concept

NomadPower is developing a power supply network at parking places for temperature controlled transport. This power supply network allows drivers to run the cool units of their trailers on electricity instead of diesel.

Cool trailers normally operate on a diesel aggregate mounted to the trailer. The vast majority (ca. 95%) of cool trailers are also equipped with an electric standby refrigeration option. In the electric mode the cool system is driven by an electromotor connected to the grid, to maintain the internal temperature of the trailer. A reason of this high share is the requirement for trailers on ferries to use the electrical standby mode. However, usually the electric standby unit is used during extended stops at loading docks where power supply is present. Power supply at parking places will increase the potential to use electric standby mode instead of the diesel mode.
The NomadPower initiative thus has the potential to eliminate tailpipe emissions, reduce noise and reduce operational and maintenance costs associated with running a diesel engine. In particular the tailpipe emission reduction potential is relatively high as the diesel aggregates are not subject to any EU emission regulations yet and emissions are relatively high as compared to, for instance, the regulated truck engines.

1.2 Scope

NomadPower is taking part in the European transport network (TEN-T) Programme for improving transport infrastructure across Europe. In context of the TEN-T programme NomadPower has asked CE Delft to assess the costs benefits and environmental impact of the NomadPower concept.

Transport haulage operators on international long distance routes are the most important target group for NomadPower. The trips in this market are often multiple days and require an overnight stop. This means a resting period of nine hours or more in which it would be possible to connect to electricity if this service is present on the location. For these transports the potential of NomadPower is high.
In this study we therefore focus on the possible cost savings and environmental benefits of NomadPower services for long distance cool transport. This focus includes typical trailers and transport refrigeration units (TRU) used in this market.

Different long distance transport scenarios will be evaluated. These scenarios will highlight the different influences on potential emissions and cost reductions. Important factors are temperature (inside trailer and outside trailer), resting time, and operation mode (continuous/start-stop).

1.3 Method

The study has been performed by means of interviews and literature research. Interviews haven been performed with both transporters and manufactures of the cool systems. Whereas the interviews with transport companies focussed on information on fuel consumption, costs and resting hours from practice, interviews with manufacturers focussed on the way the cooling systems works, test results on fuel consumption and also costs. Table 31 in Annex B lists the interviewed persons and organisations.

Besides the information that resulted from the interviews, literature research provided information to build the theoretical framework on energy consumption and emissions during cooling (either in the electrically plugged-in or in diesel mode). An overview of literature used for this report can be found in Chapter 8.

2 Framework for assessment

2.1 Refrigeration system

The most common transport refrigeration unit (TRU) in use for refrigerated food transport applications today is the vapour compression system (Tassou, et al., 2008). Mechanical refrigeration with the vapour compression cycle offers a wide range of options for compressor drive methods.

The two most commonly used compressor drive methods (90% of market) are:
1. Auxiliary diesel engines with direct drive to compressor and fans.
2. Auxiliary diesel engines which drives a generator that electrically powers compressor and fans.

The two most important suppliers of these systems for trailers (> 90% of market) are Thermoking (Method 1) and Carrier (Method 2). For both types the diesel engine can run in two modes (engine speeds): high speed and low speed. The high speed mode delivers a higher cooling capacity (removed heat per hour), needed when the temperature offset is high. In low speed mode the systems deliver a lower cooling capacity, sufficient to maintain the temperature constant.
The majority of systems (95%) also have an electrical standby that is normally used at the terminal and for example on ferries. This electrical standby can be used for NomadPower services. To use NomadPower only a connecting plug of circa € 80 is needed (source NomadPower). The cooling capacity in the electric standby mode is comparable to that of the low speed mode of the diesel engine. Table 1 illustrates the maximum cooling capacity in different modes for four systems of Thermoking (SLXemodels) and Carrier (VECTOR model). In this study we will use these types as exemplary for the long distance cool transport.

Table 1 Cooling capacities in different modes at two cooling temperatures for four refrigeration systems

Maximum refrigeration capacity	Cooling mode	Type 1	Type 2	Type 3	Type 4
At 0°C (W)	Diesel high speed capacity	13,400	15,000	17,400	18,800
	Diesel low speed capacity	Comparable to electrical standby			14,140
	Electrical standby capacity	9,600	11,700	12,500	15,400
At -20°C (W)	Diesel high speed capacity	7,800	8,100	9,300	10,100
	Diesel low speed capacity	Comparable to electrical standby			8,810
	Electrical standby capacity	5,900	6,100	6,900	9,100

Source: Data on SLXe models of Thermoking and VECTOR models of Carrier. The associated maximum refrigeration capacities are based on the ATP-test data from their respective websites.

Besides auxiliary engines there are also TRU systems that do not have a separate engine to drive the TRU, but that make use of the main truck engine power instead. The main engine is connected to a generator to electrically power the compressor and fans. Examples of this type of systems are the TRUs of Frigoblock and TRS. At this moment the market share of these systems in long distance transport is still very limited (according to these manufacturers). However, NomadPower services for these systems might be of special interest as these systems require the truck engine to be turned on during resting periods when it is not possible to electrically connect. The possibility to plug in to NomadPower makes it possible to turn off the truck engine preventing a lot of diesel consumption noise disturbance, even more than for the auxiliary engines. Other types of TRUs are cryogenic refrigerant systems (cooling with liquid CO_2 or Nitrogen), eutectic systems or hybrid systems. These systems, however, are all still very much operating in a niche market and are not included in this study.

2.2 Methodological framework

The goal of this study is to assess the financial and environmental effects of the use of NomadPower services during resting periods. Both costs and environmental effects depend on the amount of diesel consumption by the TRU that can be avoided and the amount of electricity consumed instead. For costs also maintenance of the TRU plays an important role. The difference in costs per year can be expresses as follows:

$$\Delta costs = HoursNP \times (ElectrC * ElectrP - DieselC \times DieselP) + HoursNP \times (MTcostE - MTcostsD)$$

With:
- HoursNP = Yearly hours at parking places to use NomadPower (hour/year).
- ElectrC = Average hourly electricity consumption per hour (kW).
- ElectrP = Electricity price (euro/kWh).
- DieselC = Average hourly diesel consumption (litre/hour).
- DieselP = Diesel price (euro/litre).
- MTcost = Maintenance costs.

The difference in emissions per year can be expressed as:

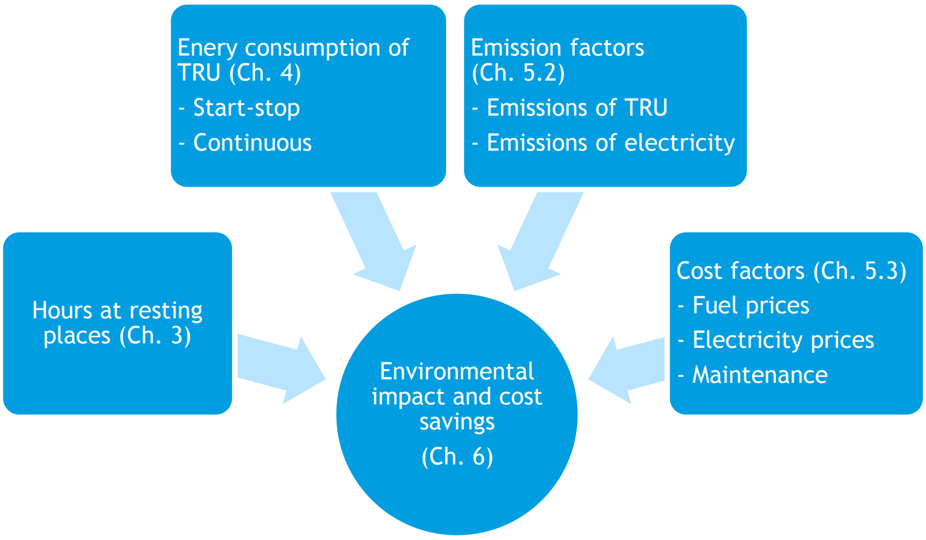
$$\Delta Emissions = HoursNP \times (ElectrC * ElectrEF - DieselC \times DieselEF)$$

With:
- EF = Emissions factor of specific emittant.

The following key elements in the expressions above will be assessed in the following paragraphs:
- yearly hours at parking places: Chapter 3;
- diesel and electricity consumption per hour at parking places: Chapter 4;
- emission factors of diesel and electricity: Paragraph 5.2;
- TRU cost factors: Paragraph 5.4.

The relation between the chapters in this report is schematically depicted in Figure 1.

Figure 1 Relation between the chapters in this report



In Chapter 6 the findings of Chapters 3-5 are combined to estimate the potential emission and cost effects of NomadPower for Europe (EU-28) in long distance transport. For individual transport companies the emission and financial effects of using NomadPower services depend very much on the logistical characteristics. This is illustrated by several cases in Chapter 6. Chapter 7, finally, gives the conclusion and outlook for other markets that could benefit from NomadPower services.

3 Potential of hours to run on NomadPower

3.1 Introduction

The electrical standby of TRUs can be used when the truck is not driving. Normally, the TRUs are plugged-in at distribution centres and warehouses where goods are loaded and unloaded if electricity supply is available.
The NomadPower concept, however, offers the possibility to plug in at parking places along the road as well, during short resting periods (45 minutes) or overnight resting periods or, occasionally, during weekends waiting for Monday to unload.

Talking about operational hours of transport refrigeration units we distinguish between net and gross operational hours.

- The gross operational hours are the hours that the system is turned on to keep the temperature at the set temperature. It depends, however, on the operating mode (start-stop/continuous) whether the system will actually be working all the time.
- The net operational hours are the hours that the compressor is actually operational (consuming energy and generating refrigeration capacity).

In continuous mode the net operational hours equal the gross operational hours. In start-stop-mode, however, the operational hours are only a percentage of the gross operational hours. In start-mode the system, the system will be turned off when the temperature is within a certain offset from the set temperature.

In this chapter the (range of) total operational hours of TRUs in long distance transport and the potential hours to use NomadPower services will be assessed.

3.2 Net operational TRU hours per year

In interviews, transport operators reported net operational TRU hours of 500–2,300 h/year. The TRU manufacturers stated that 1,500 hours is about average for TRUs.

The yearly operating hours of a TRU depend on the number of transport days and the operating time per day.
For a truck driver the maximum operating days per year are 260 days (see textbox on EU regulation).
The operational hours per day depend on the trip characteristics.
On loaded trips of maximum one day driving, the TRU might be operational up to 9-10 hours a day (see textbox), whereas on trips of multiple days the operational time might be up to 24 hours a day. On empty return trips the TRU will be turned off. On average it is assumed that 75% of trips in cool transport are loaded (average for food operations, source STREAM, 2011).
The net operating hours, moreover, depend also on the operating mode: start-stop or continuous.

The upper value for the net operating hours that are reported in the interviews of 2,300 operating hours might corresponds to an average of 9 net operating hours per day for 260 days.

The average of 1,500 operating hours per year can be thought of as the operation of the TRU for 180 days average according to Transifigoroute Deutsland (TD) e.V, (2014) with almost nine net operating hours per day.

EU regulation on driving time and rest periods
In the European Union there is a regulation that covers the truck drivers' working hours (Regulation (EC) 561/2006). These rules regulate the 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. According to the regulation, the daily driving time shall not exceed 9 hours. Total weekly driving time may not exceed 56 hours. In addition to this, a driver cannot exceed 90 hours driving in a fortnight. Breaks of at least 45 minutes (separable into 15 minutes followed by 30 minutes) should be taken after 4.5 hours driving at the latest. Finally, the daily rest period shall be at least 11 hours.

Assuming a daily driving time of 9 hours and a break of 45 minutes per day, this leaves 14 hours and 15 minutes of resting per day for trips of multiple days.
According to the regulation a truck driver can drive ten days of nine hours as a maximum in a fortnight. Per year this would mean 260 operating days for the TRU, if the truck driver always operates the same truck-trailer.

3.3 Potential of hours to switch to NomadPower services for long distance transports

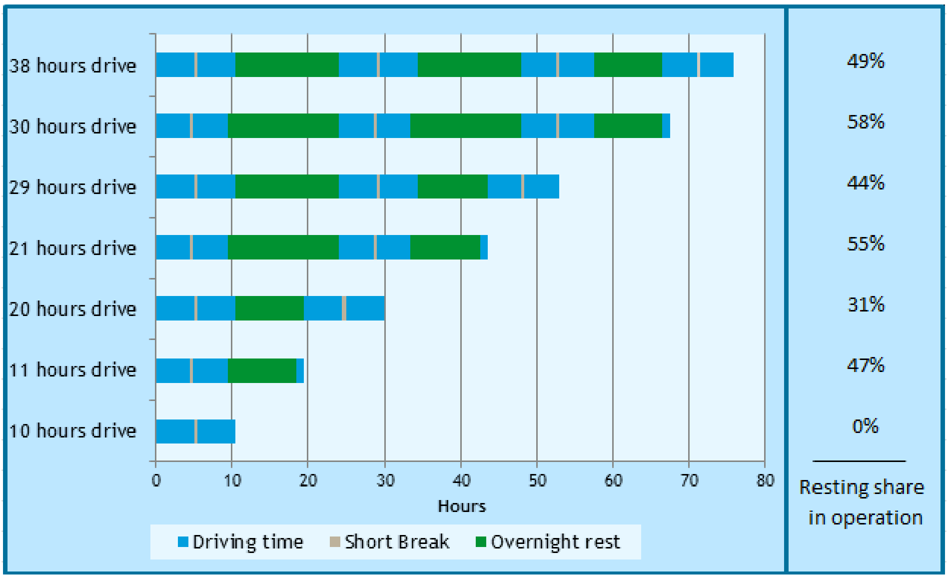
In the interviews all transport operators (operators in long distance transport) stated that their routes most often require an overnight resting period which is eligible for using the electrical standby mode (if present). For the resting periods during the day (of 45 minutes) some interviewees stated that it is not worth the effort to plug in the TRU.
Based on this information we assume the potential hours to be replaced are restricted to the nightly resting periods.

According to the interviewed transport operators, the potential to replace diesel by electric is about 10-15% of the total operating hours.

The potential for electric standby depends on the share of resting hours in the operating hours. In Figure 2 for different trip lengths the theoretical overnight resting hours as a share of the total TRU operating hours are given.
In the given cases it is assumed that the ratio between driving and resting is periods is dependent on the EU regulation for driving time and resting periods (see box above)[1] and the total driving time. Driving hours are chosen in such a way that they just fit or exceed the maximum driving hours per day (or multiple days) thereby representing best and worst cases.

[1] Based on information from interviews it is assumed that there is only one truck driver. Truck operation times are therefore assumed to follow the driving time and resting period regulation.

Figure 2 Share of resting hours in total operation hours for different trip lengths (in hours)



The analysis shows that the potential to switch to electric standby mode is about 30-60% for long distance trips. Only trips to locations that can be reached within 10 hours do not require an overnight resting period.
Based on this theoretical analysis we assume that in potential 30% of the diesel operational hours can be switched electric standby is realistic for long distance transport, at least on the longer term when electricity for TRUs is fully available at parking places. For the shorter term we assume that 15% of diesel operation can be switched to electric standby.

Conclusion

Based on the interview results the net operational hours are estimated on 500-2,300 hours per year and 1,500 hours per year on average (See Table 2). Considering the legislative framework and average operational profiles these estimations seem reasonable. Transport operators believe that about 15% of the hours can be switched to electricity making use of power supply during stops. On the longer term we think this share can grow to 30% on average. This results in a range of 75–690 hours on a yearly basis. On average 225 hours per year seem to be realistic to switch from diesel to electricity during stops in the short term. On the longer term we believe 450 hours per year is feasible.

Table 2 Potential hours to replace diesel by electric

Net operational hours per year	15% replaced (Short term)	30% replaced (Long term)
500 hours	75	150
1,500 hours	225	450
2,300 hours	345	690

4 Energy consumption of transport refrigeration units

4.1 Introduction

In this chapter the most important variables and their influence on the energy consumption of transport refrigeration units will be identified.
More specifically, the diesel consumption and the ratio between electricity and diesel consumption during stops at parking places are rationalized.

The energy consumption of TRUs depends on many factors, such as outside and cool temperature, isolation of the trailer unit, the loaded product and efficiency of the cool system. In general, the fuel consumption is dependent on the cooling demand. Roughly two situations can be distinguished in the operation of a TRU:
- The temperature offset in the trailer is high, for example when doors have been opened. The TRU will be working in high speed mode (pull down mode), having a relatively high fuel consumption.
- The inside temperature is near the set temperature. The system will work in low speed mode, maintaining the set temperature.

In this chapter we will focus on the energy consumption during stops. It is assumed that normally, during a stop, the inside temperature is near the set temperature. For this situation it is important to distinguish between:
1. TRUs operating in the start-stop mode and.
2. TRUs operating in the continuous mode.

The start-stop mode is often applied when the trailer contains products that do not require continuous ventilation, as in the stop periods the ventilation is also stopped. This mode is often applied for frozen products. The continuous mode is mostly applied for chilled products, such as fruit and vegetables. During overnight periods, drivers might prefer continuous mode, as the repeated starting of the aggregate during the night is loud and wakes up the driver.

The fuel consumption in start-stop mode and continuous mode differs and is also modelled in a different way. In Paragraph 4.2 the theoretical energy consumption in start-stop mode is assessed. Paragraph 4.3 is on the energy consumption in continuous mode. In Paragraph 4.4 the theoretical derived energy consumptions are compared to actual energy consumption data.
In Paragraph 4.5 conclusions are drawn on the energy consumption of a TRU on parking places.

4.2 Start-stop mode

In start-stop mode the TRU is running when the temperature in the trailer is above (or under) a certain threshold value. When the temperature is within a range set by an upper and under threshold value around the set temperature, the system is turned off. In the start-stop mode the energy consumption is directly related to cooling demand and the efficiency of the TRU.

4.2.1 Cooling demand

The transport refrigeration system keeps the temperature of the refrigerated space at the required level by removing heat from the interior of the trailer. The amount of heat that needs to be removed is the cooling demand of the trailer and depends on different influences.

(Brunel University, 2009) based on (ASHRAE, 2006) distinguish five main sources of heat flow into the refrigerated area (thermal load) that influence the cooling demand:

- Transmission load, which is heat transferred into the refrigerated space through its surface. Solar radiation increases significantly the refrigeration load of a trailer. The cooling demand of stationary vehicles has been found to increase by 20% when exposed to sunlight for several hours.
- Product load, which is heat produced by the products brought and kept in the refrigerated space. Fruits and vegetables continue to respire after harvest, producing CO_2, moisture and heat. Highly perishable products tend to generate more respiratory heat and the respiration rate increases with an increase in produce temperature.
- Infiltration air load, which is heat gain associated with air entering the refrigerated space (during door openings). The heat gain from air infiltration during door openings is considerable in the case of delivery vehicles.
- Precooling load (insulated body), which is heat removed from the vehicle to bring its interior surfaces to the planned thermostat settings before loading it with the product to be carried.
- Other loads: Internal load, which is heat produced by internal sources, and equipment-related load (fan motors if forced-air circulation is used, heat from defrosting). According to (Brunel University, 2009) this load is marginal compared to the other loads. For this study other loads will be neglected.

In the context of long haulage operations and the refrigeration during resting periods mainly transmission load and, for some kinds of chilled transport (fruits and vegetables), product load are contributing to the total cooling demand. The quantification of these two contributions is discussed below. Infiltration air load and precooling load are not expected to contribute during resting periods. The effect of the latter two loads on the total cooling demand are discussed by different kind of transport operation patterns in which the effect of infiltration air load is varied.

Transmission load

The transmission load is the heat flow into the refrigerated trailer which is caused by the temperature difference between the refrigerated space and the ambient. The transmission load is defined as the amount of energy that is transferred per second and can be calculated via the following formula (Tassou, et al., 2008):

$$Q_w = K \cdot S \cdot \Delta T$$

Where:

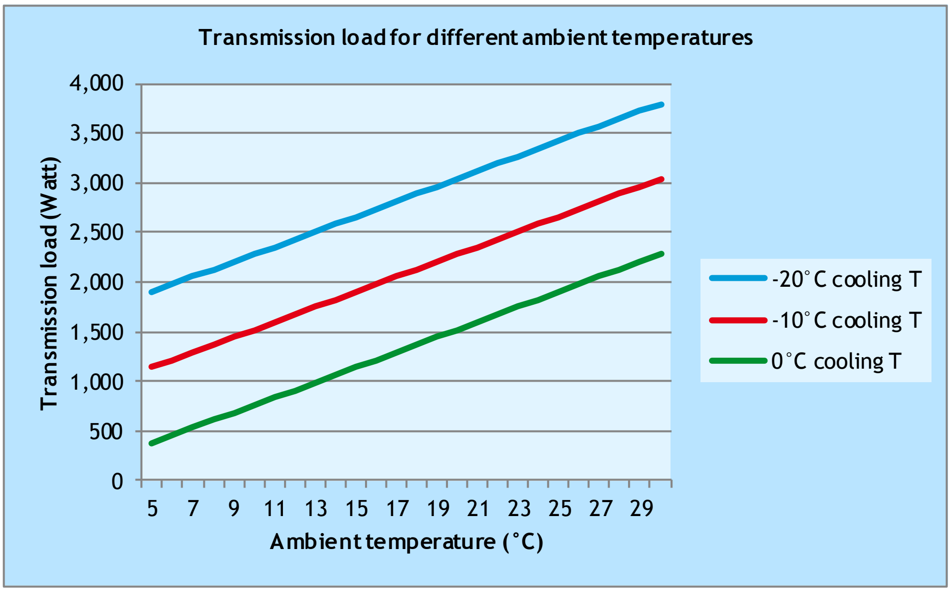
Q = Heat transfer rate (W).
K = Overall heat transfer coefficient (W/m^2 K), or isolation coefficient.
S = Heat transfer surface area (m^2), calculated as the geometric mean of the inside surface area S_i and the outside surface area S_e of the body: $S = \sqrt{S_i \cdot S_e}$.
ΔT = Difference in temperature between the inside of the trailer and the ambient temperature.

This means that the cooling demand for the refrigeration unit is mainly dependent on the size of the trailer (because of S), the isolation value of the trailer, the ambient temperature (dependent on season, location and time of day) and the interior temperature (dependent on product).

In general the surface area of the trailer is standard around 150 m^2, because of the standard size of the trailers in the EU (see Appendix A.1).
The required isolation coefficient for a new trailer is 0.4 (ATP, 2015). However, the isolation will decrease about 5% per year (Tassou, et al., 2008). With an average TRU lifetime of 7 years (Appendix A.2) this means that at the end of the lifetime the heat loss will be 40% higher. For an average TRU (Age 3.5 years) we therefore estimate the average isolation coefficient to be 0.5.

Applying the 150 m^2 surface area and an isolation coefficient of 0.5, Figure 3 shows the relation between cooling temperature and ambient temperature on the one hand and fuel consumption on the other hand.

Figure 3 **Relation between transmission load and ambient temperature for different cooling temperatures (k=0.5 and S = 150)**



Product load

Some chilled products such as fruits and vegetables continue to respire after harvest, producing CO_2, moisture and heat. Highly perishable products tend to generate more respiratory heat. According to (Brunel University, 2009), for long haul transport, the product load will increase the cooling demand for chilled products by around 20%.

Product load due to insufficient precooling of product

The products should be at storage temperature when they are loaded into the truck, or else there must be heat removed to bring the products to storage temperature. We have learned from interviews (Annex B) that improperly precooled products will bring such a considerable extra heat load to be removed from the refrigerated space that it is impossible for the TRU to reach the set temperature. This means that the TRU will continuously operate in 'pull-down' mode at full speed and with the highest possible fuel consumption. This is highly undesirable (evidently also for the product quality), but in practice may sometimes occur. This causes a difference between the actual measured energy consumption and the theoretical energy consumption in which perfect circumstances are assumed. The energy consumption of continuous high speed mode is discussed in Paragraph 4.3.

Cooling demand for different types of operation

While in this study the focus is on the fuel consumption during resting periods, the fuel consumption will be different for other types of operation, due to the other sources of heat. (Brunel University, 2009) distinguish between four types of operation: Long haulage operations, long hours and deliveries, delivery rounds and short deliveries. Based on specific activities during the day and corresponding thermal loads (door openings, precooling, product loads, transmission loads) the average thermal load per hour were derived for both chilled and frozen products. The ambient temperature used in the calculations was 20°C.

Table 3 Variation in the thermal load due to different types of operation at 20°C ambient temperature (Brunel University, 2009)

Temperature	Type of operation	Total thermal load (W)
Chilled (+2°C)	Long haulage operations	1,600
	Long hours and deliveries	2,830
	Delivery rounds	4,040
	Short deliveries	2,900
Frozen (-18°C)	Long haulage operations	2,670
	Long hours and deliveries	7,540
	Delivery rounds	11,640
	Short deliveries	6,410

Table 3 shows that the thermal load can be up to five times as high due to the type of operation. The cooling load for long haulage is expected to be representative for the cooling load during resting periods.

Conclusion on cooling demand
The required cooling demand during resting periods is mainly based on transmission load and varies between 400 and 3,800 W (see Figure 3) depending on the temperature difference. The product load can increase the cooling demand by 20%. In other types of operation the cooling demand can be up to five times higher due to additional loads.

4.2.2 Efficiency of refrigeration systems

The energy consumption in the start-stop mode can be calculated from the cooling demand if the efficiency of the TRU is known.

The energy efficiency can be expressed as the amount of energy (fuel or electricity) that the TRU uses to provide a certain amount of cooling.
In the literature this is referred to as the coefficient of performance (COP).
The COP is expressed in:
- litre diesel/kiloWatthour$_{refrigeration}$ (L/kWh$_r$); for the TRU in diesel mode;
- kiloWatthour$_{electricity}$/kiloWatthour$_{refrigeration}$ (kWh$_e$/kWh$_r$); for the TRU in electric mode.

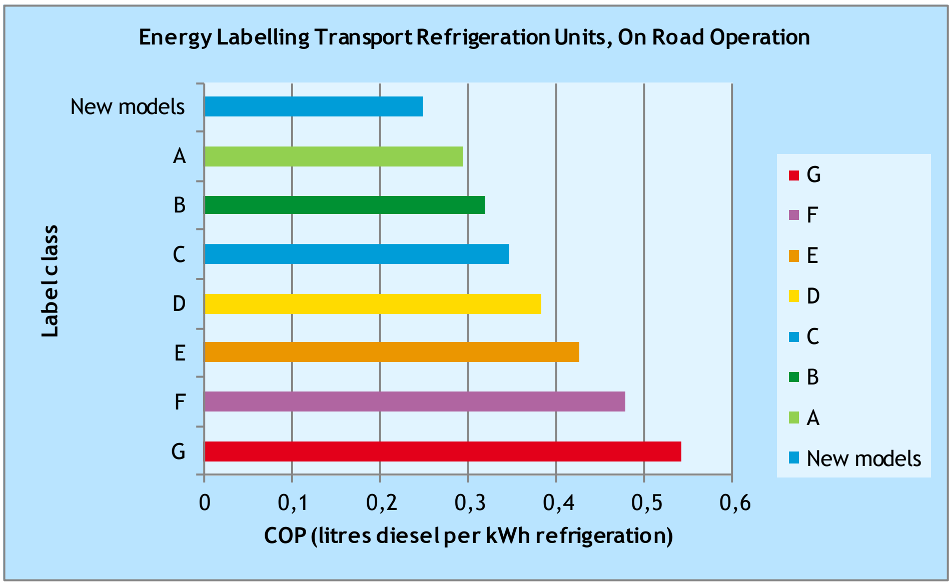
The efficiency varies amongst different refrigeration systems and also depends on operation speed and the cooling temperature. In so called ATP tests, for type approval of refrigeration units, COP values are measured under standardised conditions. In the following section the ATP test values for the

diesel mode are assessed. The efficiency in the electric mode is assessed by the ratio between diesel and electric refrigeration.
This ratio is important to quantify the possible reductions in costs and emissions for switching from diesel to electricity.

ATP measurements

All TRU types are tested via the ATP efficiency test procedures on cooling temperatures of 0°C and -20°C at an ambient temperature of 30°C.
In this test procedure the COP (coefficient of performance) is also measured. The COP values in the ATP test give the energy demand of the refrigeration unit at a specified temperature at maximum cooling capacity.
On base of ATP test values, the German Federal Environment Agency UBA has proposed an energy efficiency classification of transport refrigeration systems in 2007. The classes more or less represent the values of actual systems in use measured in ATP tests (UBA, 2008). The average UBA values for diesel consumption are shown Figure 4. Based on COP values reported for new TRU systems of Thermoking and Carrier (see Table 26, Annex A.4) a value of 0.26 litre/kWh$_r$ for new models has been added to the UBA values.

Figure 4 **Planned Energy Labelling (UBA proposal): litres diesel/kWh$_r$**



We assume that the Label B value of 0.32 l/kWh$_r$ is average for the current systems in use. Based on the ATP test results from new TRU systems (see Table 26, Annex A.4), the value will be 15% lower (chilled products) or higher (frozen product) depending on the cooling temperature.

Conclusion efficiency in diesel mode:
The average COP value of TRUs in diesel mode is 0.32 litre diesel/kWh$_r$. The value will be around 0.27 litre diesel/kWh$_r$ for transport of chilled products and 0.37 litre diesel/kWh$_r$ for transport of frozen products.

The ratio between diesel and electric refrigeration

The electricity consumption during resting periods is assessed by relating it to the diesel consumption. From different sources the exchange ratio of electricity consumption (kWh_e/kWh_r) and diesel consumption ($litre/kWh_r$) are summarised in Table 4 giving values expressed in kWh_e/litre:

– The values from the interview are based on information from transport companies on the electricity consumption and diesel consumption over the net operational hours. As the diesel consumption is partly based on periods of pull down, with high fuel consumption per hour, the values are an underestimation of the values during resting periods.
– The ATP test figures are representative for new TRUs. Based on the UBA figures they probably overestimate the average ratio.
– TU Delft (TU Delft, 2014) did an experiment with two empty trailers (see Annex A.4).
  The data are an example of real world energy consumption. The results are, however, not straight forward (see Annex A.4).
– The ratios based on the values of UBA labels for diesel and electricity. For the ratio between electricity and diesel a fixed ratio has been used.
– In a recent study (Dearman, 2015) a ratio of 3.6 is calculated from the COP values from electric and diesel TRUs.
– In a report on on-shore power supply (TU Delft, 2011), the TU Delft reported on the ratio electricity-diesel for 13 different electricity generators (powers in range 10-80 kW).

Based on the values in Table 4 we propose an average value for de electricity-diesel ratio of 3.2 kWh_e/litre. Based on the ATP figures in Table 4 we assume that for frozen transport the value is 7% lower (3.0 kWh_e/litre) and for chilled transport the value is 7% higher (3.4 kWh_e/litre).

Table 4 Ratios (kWh_e/litre) for electricity consumption (kWh_e/kWh_r) and diesel consumption ($litre/kWh_r$)

Source	Diesel mode in comparison	Cool temperature (°C)	Ratio (kWh_e litre)	Commentary
Interview 1	*Average*	-	*2.3*	Under estimation
Interview 2	*Average*	-	*1.25*	Under estimation
Interview 3	*Average*	-	*2.0-3.4*	Under estimation
ATP test figures (Table 26, Annex A.4)	*Low speed*	*0*	*4.0-4.5*	Over estimation
	Low speed	*-20*	*3.4-3.9*	
Experiment TU Delft (Table 27, *Annex A.4)*	*Low speed*	*-5*	*1.4-3.8*	Test result/not unambiguous Table 27, *Annex A.4)*
	Low speed	*-15*	*2.3-3.2*	
Transfrigoroute Deutschland (td) e.V. (2014).	-	*-25*	*2.7*	-
UBA 2007	-	-	*2.6*	Fixed ratio for different labels
(Dearman, 2015)	-	-	3.6	Calculated from COP values in this study
(TU Delft, 2014)			3.2*	Diesel electricity ratio for electricity generators on diesel10-80 kW on inland waterways ships

* Deduced from average fuel consumption of 260 gram diesel/kWh. Average value of 13 generator types in for engines load of 60-100%.

When these ratios are applied to the diesel consumption values the average electricity efficiency (COP value) is estimated at 1.0 kWh_e/kWh_r varying from 0.9 kWh_e/kWh_r for chilled transport to 1.1 kWh_e/kWh_r for frozen transport.

Conclusion
For replacing 1 litre of diesel during resting periods, 3.0 kWh electricity is needed in frozen transport (-20°C) and 3.4 kWh in chilled transport (0°C), on average 3.2 kWh.
The COP value in electric mode is estimated at 1.0 kWh_e/kWh_r varying from 0.9 kWh_e/kWh_r for chilled transport to 1.1 kWh_e/kWh_r for frozen transport.

4.2.3 Conclusion

The gross[2] fuel consumption per hour in the start-stop mode is the product of the cooling demand (4.2.1) and the efficiency (COP) of the TRU (4.2.2). Based on the figures in the previous paragraphs the diesel and electricity consumption during resting periods are summarised in Table 5.

Table 5 Diesel and electricity consumption for different type of transport in start-stop mode during resting periods

	Diesel (l/hour)	Electricity (kWh/hour)
Chilled transport *	0.11-0.63	0.37-2.14
Chilled transport including product load *	0.13-0.75	0.45-2.57
Frozen transport *	0.66-1.40	1.97-4.16

* Range based on of 5-30°C ambient temperature.

The net[2] fuel consumption in start-stop mode resembles the fuel consumption in the continuous mode and the values will be discussed in the following paragraph.

4.3 Continuous mode

In most TRU systems the ventilation can only function with the cooling system turned on[3]. For some products (such as fruit or flowers) it is important that the ventilation remains running all the time and therefore the TRU needs to be set to the continuous mode. Also during resting periods it might be favoured to have the system turned on continuously as the repeated starting of the diesel aggregate is causing more nuisance during sleep time (statement from interviews).

In continuous mode the engine will operate in low speed mode when the refrigeration temperature is reached. Generally, the system will modulate between warming and cooling modus, with the ventilation turned on, giving a homogenous temperature throughout the trailer. Manufacturers have indicated that new technologies make it possible to accomplish a lower fuel consumption for the low speed mode, by ‘squeezing’ the refrigeration capacity.
According to the manufacturers the energy consumption of the TRU in continuous mode will be around 20-25% lower than the fuel consumption in low speed mode at full capacity.

2 Gross refers to the fact that the fuel consumption includes the off-period where the system is turned off as opposed to the net consumption that only takes on periods into account.

3 For some systems the ventilation can be turned on separately in the electric mode.

Based on ATP test result for various new TRUs (see Annex A.5, Table 30), the energy consumption figures of average aged TRUs have been estimated (see Annex A.5) resulting in the values in Table 6. The values are valid when the TRU is working at full capacity and are representative for the net fuel consumption in the start-stop mode.

Table 6 **Energy consumption per net operating hour based on ATP tests values of TRUs**

Operating mode	0°C	-20°C
Diesel high speed (l/h)	5.4 l/h (±15%)	3.8 l/h (±25%)
Diesel low speed (l/h)	3.2 l/h (±20%)	2.4 l/h (±15%)

Taking into account a 20% reduction in fuel consumption in the continuous as compared to the low speed mode results in the energy consumption values as depicted in Table 7.

Table 7 **Energy consumption in continuous mode**

Operating mode	0°C	-20°C
Diesel continuous (l/h)	2.5 l/h (±20%)	1.9 l/h (±15%)
Electric standby continuous (kWh/h)	9.8 kWh/h (±25%)	6.3 kWh/h (±15%)

The energy consumption in electric standby continuous mode is based on the ratio between diesel and electric found in 4.2.2). Notably, the energy consumption at 0°C is higher than at -20°C. However, also the refrigeration capacity at 0°C is higher than at -20°C.

4.4 Comparison with actual fuel consumption of transport refrigeration units

In this paragraph we will compare the consumption rates in start-stop mode and continuous mode, representative for resting periods, to actual fuel consumption rates that were found in literature, tests and interviews.
In general, interviewed transport operators did not have a clear insight in the fuel consumption of the TRU in specific situations. In many cases they could give a general estimate of the fuel consumption, but the impact of for example ambient temperature, cooling temperature and insulation could not be quantified. Table 8 gives an overview of the estimates from the interviews and observed values that were found in literature study.

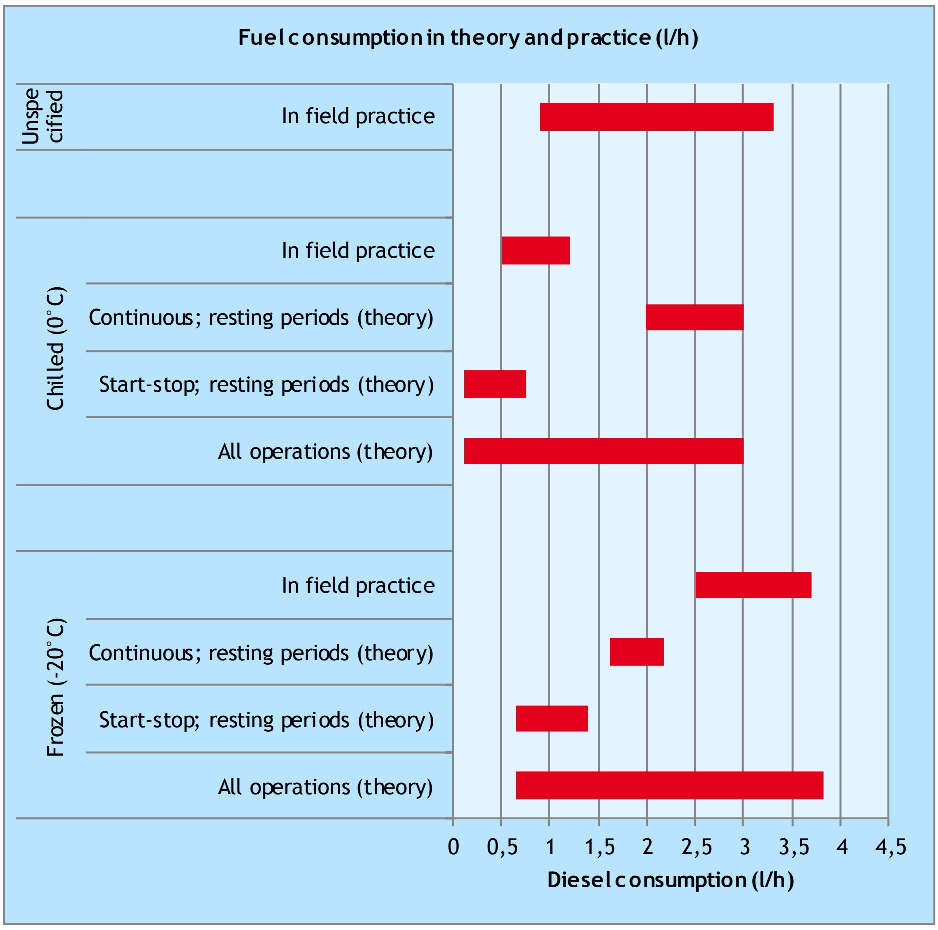
Table 8 Fuel consumption according to transport operator experiences, interviews and literature

Source	In-field fuel consumption per gross operational hour* (l/h)
(Tassou, et al., 2008) (+3°C)	0.5-1.0
(Tassou, et al., 2008) (-20°C)	2.5-3.0
GTP (+2°C)	1.2
(Shurpower, 2005) (-18°C)	2.8-3.7
ING trailer market analysis (average)	1.2 (30 l/day)
GIZ 2015 (South Africa) (average)	2.0-2.5
Thermoking (interview)	1.8
Carrier (interview)	1.7
Transport operator 1 (interview)	1.7-3.3
Transport operator 2 (interview)	0.9
Transport operator 3 (interview)	2.8
Transport operator 4 (interview)	2.0-2.5
TU Delft (experiment) (-15ºC - -5ºC	1.0-1.4

* The mode of operation is unknown.

The gross consumption rates that were found for in-field fuel consumption are between 0.5-1.2 l/h for chilled and between 2.5-3.7 l/h for frozen products. For the total average fuel consumption (cooling temperature and operation mode unspecified) values of 0.9-3.3 l/h were reported.
The found ranges for in field fuel consumption are summarised in Figure 5 and compared to the theoretical values found in previous paragraphs.

Figure 5 Net fuel consumption in practice compared to theory

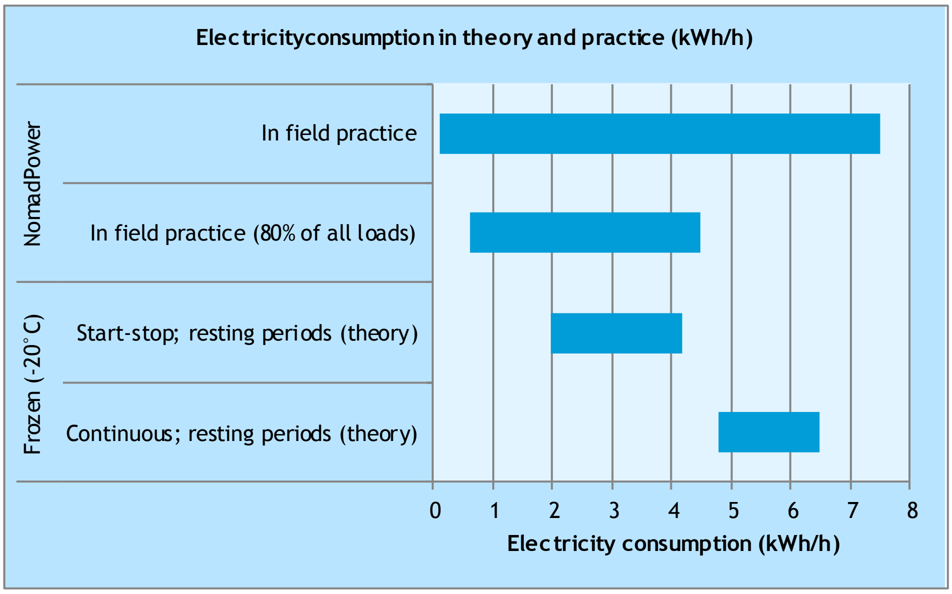


As can be seen from the figure, the real-world fuel consumption estimates (in field practise) for chilled transport (0°C) are within the range of the theoretical fuel consumption values for all types of operation (with many or little door openings). The theoretical start-stop values during resting periods are lower than average, as expected. In continuous mode, however, the values are higher than the average values. The theoretical values for fuel consumption of chilled transport seem to be in line with values found in practise, assuming a relatively low share of the continuous mode.

The real-world fuel consumption estimates for frozen transport (-20°C) are within the range of all types of operation, on the high side. The relatively high real world values might be due to the pronounced effect of door openings in frozen transport. The theoretical values for fuel consumption during resting period, both in start-stop mode and continuous mode are lower than the average in field values, as would be expected. The proposed fuel consumption values during stops therefore might well be in line with the real world values from interviews and literature.

Similarly, we compared our assumptions and theoretical framework to actual available electricity consumption data that NomadPower was able to provide us with (see Figure 6). The data in the first bar of the Figure cover all the times that the service of NomadPower was used by one company during the course of one year. This company transported mostly frozen products (ice-cream and chicken-products). The second bar represents the 80% loads that occurred most frequently.

Figure 6 Net electricity consumption in practice compared to theory



The theoretical values (bar 3 and 4) fit well within the bandwidth of the real world values (in field practise). The share of continuous mode seems the be small for the specific company. Overall it can be concluded that the theoretical values for the resting periods are within the bandwidth found in practise during stops.

4.5 Conclusion

The fuel consumption rates in start-stop mode and continuous mode that were calculated in Paragraph 4.2 and 4.3 are in line with actual fuel consumption data. The fuel consumption values from the analysis in this chapter are summarised in Table 9 for different possible operation modes of the TRU during resting periods. The table differentiates between gross fuel consumption and net fuel consumption. For the continuous mode the net and gross fuel consumption are the same. For the start-stop mode the gross fuel consumption includes off-times and is lower than the net fuel consumption that excludes off-times.
In the start-stop mode, the gross fuel consumption (the on time) depends heavily on the ambient temperature. A range of fuel consumption values is given for ambient temperatures between 5 and 30°C.

Table 9 Proposed gross and net fuel consumption values for different modes during stops

Mode	Cooling temperature	Ambient temperature	Gross fuel consumption (l/h)	Net fuel consumption (l/h)
Continuous	-20°C	-	1.9	1.9
Start-stop	-20°C	5-30°C	0.66-1.4	2.4
Continuous	0°C	-	2.5	2.5
Start-stop	0°C	5-30°C	0.11-0.75	3.2

The distribution of the different operating modes is unknown. From the interviews it appears that the use of the TRU in practice is diverse. However, the net fuel consumption per operating hour seems to lie around 2.5 l/h.
For the average net fuel consumption this value is assumed.

In this chapter also the ratio between electricity and diesel consumption have been examined. For replacing 1 litre of diesel during resting periods, 3.3 kWh electricity is needed in frozen transport (-20°C) and 3.9 kWh in chilled transport (0°C), on average 3.6 kWh.

5 Emission and cost factors

5.1 Introduction

This chapter describes the emission and cost factors for electricity and diesel consumption. With these factors it is possible to convert diesel and electricity consumption into values for NO_x and PM_{10} emissions and costs. The difference in noise production between electric and diesel mode are addressed as well.
In Paragraph 5.2 the emission factors for electricity are presented for different countries. Average diesel emission factors are presented based on EU and US regulation. Paragraph 5.4 describes the noise difference between diesel and electric mode. Finally, Paragraph 5.4 gives energy cost and maintenance cost factors.

5.2 Emission factors

Switching from diesel to electricity tailpipe emission of diesel are avoided. The emissions of the TRU on electricity are zero on location. The TRU in electric mode could be referred to as zero emissions refrigeration, similar as for electric vehicles. However, electricity generation, does generate emissions, depending on the electricity source. In this study we apply a well-to-wheel approach for CO_2 emissions. This means that tailpipe emissions as well as emission during winning and transport of the fuel are taken into account. For the air pollution tailpipe emissions of the aggregate are compared to emissions during electricity production.

5.2.1 Emission factors electricity per country

The emission factors of electricity are different per country and depend on the electricity mix in a country. Coal fired power plants have higher emissions than gas fired power plant and electricity generation emissions from wind, water and solar power are zero.
In addition, the emission factor also depend on the method to determine the mix. Shares of power sources can be determined on base of the electricity generation in a country (production mix), but can also be determined on base of the sold electricity mix in a country, based on guarantees of origin (supply mix). The supply mix in a country can, for example, include a large amount of hydropower from Norway, backed up by imported guarantees of origin.

Emissions factors for the two described methods and for four different countries and the EU are listed in Table 10. The data are based on the electricity mix according to (RE-DISS II, 2014) and the emission factors for the different fuels according to (EC, 2015).
The Supply mix figures for the EU, France and Poland are applied in Chapter 6.

Table 10 **Emission factor electricity generation 2013**

		NO_x (g/kWh)	PM (g/kWh)	CO_2 (g/kWh)
DE	Production mix	0.42	0.014	559
	Supply mix	0.21	0.007	239
FR	Production mix	0.09	0.007	50
	Supply mix	0.09	0.007	51
NL	Production mix	0.21	0.004	437
	Supply mix	0.16	0.004	329
PL	Production mix	1.33	0.084	847
	Supply mix	1.33	0.083	842
EU	Production mix	0.39	0.027	332

5.2.2 Emission factors diesel: EU and US regulation

In the EU, TRUs do not have to fulfil any regulations because the non-road mobile machinery directive only applies to engines above 19 kW. European emission standards ranging from Stage I (from 1999) to Stage IIIb (from 2011-2013) have been gradually been implemented for new engines with net power of 19-560 kW. These stage regulations were specified by Directive 97/68/EC and five amending Directives adopted from 2002 to 2012. However, the emission standards only apply on engines above 19 kW, thereby excluding the transport refrigeration units that normally have powers below 19 kW.

On September 25, 2014, the European Commission proposed Stage V emission regulations, replacing Directive 97/68/EC and its amendments. The proposal widens of the scope of regulated engines below 19 kW and above 560 kW and would become effective in 2019. The proposal for Stage V is aligned with the American Tier 4 standard.

In two interviews with the major manufacturers of TRUs, it was reported that the newest TRUs that will be produced as from 2016, will already comply with the Stage V emission standards. It was estimated that the current engines in the market should at this moment comply with the US Tier II standards for one manufacturer and Stage IIIA (> 19kW) for the other. The US Tier II standard also regulates engines below 19 kW.

Table 11 **EU Emission Standards for Non-road Diesel Engines, g/kWh**

Stage/Net power	Date	CO	HC	NO_x	PM
Stage II: 18-37 kW	2001	5.5	1.5	8.0	0.8
Stage IIIA: 19-37 kW	2007	5.5	7.5*		0.6
Proposed Stage V: 8-19 kW	2019	6.6	7.5*		0.4
Proposed Stage V: 19-37 kW	2019	5	4,7*		0.015

* HC+ NO_x. For NO_x only a value of 6.0 is assumed for Stage IIIa.

Table 12 **US EPA Tier 1-3 Non-road Diesel Engine Emission Standards, g/kWh**

Stage/Net power	Date	CO	HC+ NO_x	PM
Tier 1: 8-19 kW	2000	6.6	9.5	0.8
Tier 2: 8-19 kW	2005	6.6	7.5	0.8
Tier 4: 8-19 kW	2008	6.6	7.5	0.4

Source: TRS analyses.

Based on the interviews it is assumed that the average NO_xemissions of the TRU in diesel mode amount to 6 gram/kWh and the PM emission to 0.7 gram/kWh on average.
It is notable that the emissions standard for Euro-VI trucks are much stricter than for the non-road mobile machinery. The PM_{10} (PM) emissions standard is 98% lower (0.01 g/kWh) whereas the NO_x emissions standard is 95% lower (0.4 g/kwh (EU Regulation 595/2009).

CO_2 content of diesel
The CO_2 emission of diesel exist of exhaust emissions (2.58 kg CO_2/litre) and emissions during the production and transport of diesel (0.62 kilo CO_2/litre). The total well-to-wheel emissions amount to 3.2 kilo CO_2/litre (CE Delft, 2014).

5.3 Effect on noise

The TRU generates less noise when working on electricity. In the experiment by the TU Delft (TU Delft, 2014) noise levels were measured as well. Whereas for the electric mode maximum noise levels of 66.7-68.7 were reported, in diesel mode the levels were 71.0-72.3, about 4 dB higher.[4] This indicates that the noise caused by the diesel aggregate is somewhat higher (ca. 70 dB) than the noise stemming from the compressor. A 4 dB difference is not easily distinguishable, but in the truck cabin, where the truck driver is sleeping, the noise difference might be larger. Moreover, the largest noise source is eliminated in electric mode. For TRUs with lower compressor noise the difference might be bigger.

For the driver, besides the noise, also the vibrations felt within the truck, caused by the engine, can be of importance during sleeping periods.
These vibrations are also reduced in electric mode.

5.4 Cost factors

Switching from electric to diesel mode the following costs will be affected:
– maintenance costs; and
– depreciation costs;
– energy consumption costs.

The cost categories will be elaborated in the following paragraphs.

5.4.1 Maintenance
Due to the reduced use of the diesel engine, the maintenance costs are expected to be lower when the operation is switched to electrical standby more often.

Interviews
From interviews with transport operators it seems that the conditions for maintenance are slightly different. All interviewees reported that once a year a periodical technical inspection (PTI) is combined with a leakage test of the refrigerant and that also at the same time often maintenance of the transport refrigeration unit is scheduled.

[4] Measurements were at 7.5 metre distance from the TRU at 3 metre height from the pavement.

50% of the transport operators reported maintenance to be scheduled once a year, and 50% reported that this was scheduled twice a year. Manufacturers state that they use the number of operating hours to determine maintenance frequency (one every 1,500 hours, another every 3,000 hours) with a minimum of once every year.

The maintenance costs vary according to the transport operators on average between € 0.75 to 1.50 per hour. For an average year of operation, with about 1,500 operating hours, the cost would be € 1,500. Manufacturers also reported that the maintenance costs will be on average around € 1 for every net operating hour of the TRU. One manufacturer only bills diesel operating hours, while another manufacturer charges € 0.50 for electric operating hours and € 1.50 for diesel operating hours.
The TRU keeps a record of the number of net operational hours for diesel and electric standby use separately.

The possible savings on maintenance costs reported from the interviews with manufacturers are 20, 25 and 67%. (Shurpower, 2005) assumes a range of 30-40% reduction in maintenance costs.

In Chapter 6 (cases) we have assumed that per hours switched from diesel to electricity, € 0.30 per net operating hour can be saved, based on average maintenance costs of € 1 per net operating hour and 30% reduction in costs.

5.4.2 Depreciation costs

The transport refrigeration units requires an investment of around € 20,000. The economic life time of the units is estimated at 7 years on average (Appendix A.2) When the use of electricity as power source has effect on the economic lifetime of the diesel generator this could mean that the depreciation costs decrease when using electricity instead of diesel.

Some studies (TU Delft, 2014) have indicated that the lifetime of the TRU can be extended if more use is made of the electrical system, or that the end-of-life value will increase.
However, from interviews, Baartmans (TU Delft, 2015) concludes that the depreciation costs do not play a role in the costs of cooling the trailer at all. He found that the producers argued that depreciation does not play a role in the costs of cooling a trailer at all, because the diesel generator is not replaced during the lifetime of the trailer or the refrigeration unit were it is mounted on. Therefore, the economic lifetime of the generator is not influenced by the operating hours of the diesel generator.

From our interviews, we arrived at the same conclusion and therefore will not take any cost savings from depreciation costs into account.

5.4.3 Fuel price/electricity price

Diesel

The transport operators have also been asked which price they pay for their diesel fuel. One operator reported that he uses red diesel (very low excise duty) whenever possible (only for sale in Belgium). All other operators have reported to use the same diesel as for the truck engine. The transport operators often get a discount as they have sales contracts with the fuel suppliers. At the moment fuel price for diesel are reported around € 0.95-1.05 per litre. The red diesel costs € 0.76 per litre.

For a more structural view, the prices over a longer period should be observed. CE Delft has constructed a fuel price database for T&E based on the Oil Bulletin that is published by the EU. The fuel prices for trucks are ex VAT and include a discount that transport companies usually stipulate with their fuel suppliers. In France and Spain transport companies can get some of the excise back. With all these factors included, and after correcting the prices to the price level in 2014 (with the consumer price index), the real diesel prices for trucks in the last 5 years are show in Table 13.

Table 13 **Diesel prices over the last 5 years for trucks (€/1000 litre, ex. VAT, including discounts)**

Country	2010	2011	2012	2013	2014	5 year average
France	949	1.057	1.084	1.037	971	1.019
Germany	1.051	1.174	1.225	1.158	1.075	1.137
Italy	1.034	1.177	1.208	1.100	1.037	1.111
Netherlands	1.025	1.148	1.175	1.133	1.093	1.115
Poland	945	1.088	1.150	1.105	1.004	1.058
Spain	920	1.034	1.094	1.043	983	1.015
EU-28	1.016	1.136	1.183	1.122	1.056	1.103

From this data it becomes clear that there are some variations in the diesel price over the years and between the countries. Based on these numbers we will use € 1.10 per litre diesel as an average price for the EU-28 and also perform a sensitivity analysis for prices between € 1.00 and 1.20 per litre.

Electricity

The electricity costs are determined by the electricity prices set by NomadPower and differ per country. In the Netherlands and Belgium the electricity prices are the lowest (€ 0.28/kWh) and in Spain the prices is the highest (€ 0.40/kWh). The differences in prices have an impact on the cost savings per litre of diesel that is replaced. Different prices per country for diesel and electricity are listed in Table 14. The effect of the prices on the operational costs are depended on the exchange ratio between diesel and electricity. For the electricity-diesel ratios found in Paragraph 4.2.2 the cost consequences are shown in the last three columns of Table 14.

Table 14 **Cost savings per litre diesel replaced by electricity**

Country	Diesel price (€/l ex. VAT)	Electricity price (€/kWh)	Ratio 3.0 kWh/l (€/l replaced)	Ratio 3.2 kWh/l (€/l replaced)	Ratio 3.4 kWh/l (€/l replaced)
Netherlands	€ 1.12	€ 0.28	€ 0.28	€ 0.22	€ 0.17
Germany	€ 1.14	€ 0.35	€ 0.09	€ 0.02	€ -0.05
Belgium	€ 1.02	€ 0.28	€ 0.18	€ 0.12	€ 0.07
Italy	€ 1.11	€ 0.39	€ -0.06	€ -0.14	€ -0.22
Spain	€ 1.02	€ 0.40	€ -0.18	€ -0.26	€ -0.34
France	€ 1.02	€ 0.35	€ -0.03	€ -0.10	€ -0.17

Based on these electricity prices, there are in most cases no cost savings for energy consumption. The charged electricity price is crucial. Especially in Spain, where the diesel price is relatively low, cost savings are unlikely. However, NomadPower can adjust the price. Their aim is to deliver a 20% cost saving on fuel cost per operating hour. This means a price between € 0.26 and 0.29 depending on COP values of systems and the diesel prices (1 litre diesel is replaced by 3.0-3.4 kWh electricity).

6 Environmental impacts and cost savings for EU average and specific cases

6.1 Introduction

In this chapter the findings of Chapters 3-5 are combined to estimate the potential emission and cost effects of NomadPower for Europe in long distance transport. The dependency of logistical characteristics on the reduction potential are illustrated by cases for overnights in France and Poland..

6.2 EU average and aggregated

In this chapter we estimate the total environmental and financial impact when all long distance transports will make use of electricity at parking places during resting periods.
Based on the previous chapters the calculation for Europe is based on the following assumptions:

1. **The number of TRUs for long haul operations:**
   According to (Dearman, 2015) the number of (semi-)trailers in the EU-28 is 234,344.
2. **Number of net operating hours during resting periods that can be replaced by electric standby:**
   On average 1,500 net operating hours per year per truck with 15% potential to switch to electricity on the short and 30% on the long term.
3. **Diesel consumption per net hour op operation:**
   From our analysis, the conclusion is that the diesel consumption during resting periods will depend on temperatures and operation mode. For the average yearly operation we assume 2.5 litre/net operating hour.
4. **Ratio of energy consumption between diesel/electric mode:**
   The ratio of energy consumption between diesel/electric mode will be between 3.0 and 3.4 depending on the cooling temperature. We will use 3.2 for the average yearly operation.

For the calculation of the emission and cost savings per hour, the main assumptions are summarised in Table 15. The results per net operating hour are given in Table 16 and the total effects per TRU per year are depicted in Table 17 and Table 18.

Table 15 Assumption calculation per hour

Parameter	Diesel	Electricity
Fuel consumption	2.5 l/h	8 kWh_e/h
Energy price	€ 1.10/litre	€ 0.28/kWh_e
Maintenance costs/h	€ 1.00	€ 0.70
CO_2 (g/kWh_e)	1077	313
NO_x (g/kWh_e)	6.0	0.4
PM_{10} (g/kWh_e)	0.7	0.03

As depicted in Table 16, hourly cost saving amount to € 0.81 per operating hour, of which 63% results from fuel costs and 37% from maintenance costs. CO_2 emission reductions amount 5.5 kilogram per hour.

Table 16 Cost savings and emission reductions per net operating hour

Per operating hour	Savings (€/h or g/hour)	Savings (%)
Cost savings fuel (€/h)	€ 0.51	19%
Maintenance savings (€/h)	€ 0.30	30%
Total cost savings (€/h)	€ 0.81	22%
CO_2 reduction (%)	5,496	69%
NO_x reduction (%)	45	93%
PM reduction (%)	5.4	96%

The cost savings and the environmental effects translated to the total effects per TRU per year are given in Table 17 and Table 18. Both the effects on the short term (potentially 15% of the operating hours are replaced) and the long term (potentially 30% of the operation hours replaced) are shown.

Table 17 Cost savings per TRU per year

Per year	Short term (15% replaced)	Long term (30% replaced)
Operating hours/year	1,500	1,500
Hours replaced	225	450
Cost saving fuel (€/year)	€ 115	€ 230
Maintenance savings (€/year)	€ 68	€ 135
Total cost savings (€/year)	€ 182	€ 365
Litres diesel saved	563	1,125

The cost savings per year are higher than the investment costs per TRU (of € 80 for a plug). To match these costs only 7% of the hours needs to be replaced (instead of 15%).

The diesel price has a large impact on the total cost savings per year. For a diesel price of € 1.00 the total fuel cost savings are much smaller (€ 59), while the cost savings are 50% higher (€ 171) with a diesel price of € 1.20. The total cost savings per TRU per year are € 126-239 for this fuel price range. Table 18 shows the environmental effects per TRU per year.

Table 18 Environmental effects per TRU per year

Emission reduction per year	Short term (15% replaced)	Long term (30% replaced)
CO_2 (kg)	1,237	2,473
NO_x (kg)	10.1	20.2
PM (kg)	1.2	2.4

Table 19 shows the total potential environmental effects for the EU per year taking into account the total number of TRU trailers.

Table 19 **Total potential environmental effects EU per year**

Total potential Europe	Short term (15% replaced)	Long term (30% replaced)
TRUs trailer/semi-trailer	234,344	234,344
Potential hours electric	52,727,400	105,454,800
CO_2 (tonnes)	289,790	579,580
NO_x (tonnes)	2,362	4,724
PM (tonnes)	283	567

The total potential on the short term (when 15% of the net operating hours are replaced) are 130 million saved litres of diesel, 290 kilotonnes of CO_2, 2.36 kilotonnes of NO_x and 280 tonnes of PM.

The total reduction, assuming 15% of the hours switched to electricity, equals the NO_x exhaust emissions of 5,000-10,000 Euro-V trucks or 30,000 Euro-VI trucks. The PM savings are comparable to the yearly PM_{10} emissions of 110,000 Euro-V trucks or 220,000 Euro-VI trucks (see Table 20). Particularly the emission the PM_{10} reduction is very high as compared to the yearly emission of a Euro-V (48%) or Euro-VI (94%) truck.

Table 20 **TRU emission reduction (15% of hours replaced) expressed in relation to truck emissions**

	NO_x	PM_{10}	CO_2
TRU emissions reduction (kg/year)	10	1,2	1.237
TRU emission reduction expressed as % of Euro-V Truck emission	2-4%	48%	1,1%
TRU emission reduction expressed as % of Euro-VI Truck emission	14%	94%	1,1%
TRU emission reduction expressed in number of Euro-V trucks causing the same emission on yearly base	4,654-9,465	113,159	2,692
TRU emission reduction expressed in number of Euro-VI trucks causing the same emission on yearly base	31,930	219,738	2,692
Truck Euro-V emission (kg/year)*	250-508	2.51	107,667
Truck Euro-VI emission (kg/year)*	74	1.29	107,667

* Based on real world emission factors from (Task Force on Transportation, 2014) assuming 100.000 km/year.

Sensitivity analysis EU results

An important parameter, especially with regard to the costs effects, is the exchange ratio between electricity and diesel, which has been set at 3.2 kWh_e/litre.

Different sources give either higher or lower values for this ratio. The impact of this ratio on the results was assessed by applying electricity-diesel exchange ratios of 2.8kWhe/litre and 3.6 kWhe/litre. The results are shown in Table 21.

The effect on the emissions is relatively small as compared to the effect on the costs. For all ratios however there are cost savings at an diesel price of € 1.10/litre and an electricity price of € 0.28/kWh_e.

Table 21 **Sensitivity analysis on the EU reduction**

Effect on	Ratio 3.2 kWh/l	Ratio 2.8 kWh/l	Ratio 3.6 kWh/l
CO_2 (kg/h)	5.5 (69%)	5.8 (73%)	5.2 (65%)
NO_x (g/h)	44.8 (93%)	39.2 (93%)	50.4 (93%)
PM_{10} (g/h)	5.4 (96%)	4.7 (96%)	6.0 (96%)
Costs (€/h)	€ 0.80 (22%)	€ 1.10 (29%)	€ 0.50 (14%)

6.3 Specific cases

The potential emission reduction and cost savings for transport operators are dependent on the characteristics of the transport. Ambient temperature, operation mode, and the type of product are important parameters that determine energy consumption of TRUs.

In this paragraph for two main cases the influence of these parameters on costs and environment impacts are illustrated. The main cases are defined for overnight rest period in France and Poland.

For different variant per case the following effect per gross operating hour will be presented:
- the fuel and total cost savings/hour;
- emission reductions/hour (CO_2, NO_x, PM).

For both cases twelve variants were assessed to show the wide variation in possible effects. The variants are made up of all combinations of the cooling temperature (for chilled and frozen products), operation mode (start-stop and continuous) and TRU efficiency (for new TRU systems, and for more and less efficient refrigeration systems (labels New, B and D). The outline and assumptions for the cases are summarised in the tables Table 22 and Table 23.

Table 22 **Scenario 1: France**

Variable	Value
Country of destination: – Ambient temperature – Diesel price – Emission factors France	France: – 12°C average ambient temperature – Diesel price average € 1.02/l, electricity price of € 0.35/kWh – Relative low emission factors for electricity (see 5.2.1)
Cooling temperature for product	Chilled (0°C) and Frozen (-20°C)
Operation mode:	Start-stop, continuous
– COP of refrigeration system (diesel)	New, B and D (litre/$kWh_{cooling}$)
– Ratio diesel/electric	3.0-3.4 kWh/litre (depending on cooling temperature)

Table 23 Scenario 2: Poland

Variable	Value
Country of destination: – Ambient temperature – Diesel price – Emission factors Poland	Poland: – 7.7°C average ambient temperature – Diesel price average € 1.06/l, electricity price € 0.28/kWh – Relative high emission factors for electricity (see 5.2.1)
Cooling temperature for product	Chilled (0°C) and Frozen (-20°C)
Operation mode:	Start-stop, continuous
– COP of refrigeration system (diesel)	New, B and D (litre/kWh$_{cooling}$)
– Ratio diesel/electric	3.0-3.4 kWh/litre (depending on cooling temperature)

In the following section first the cost effects per case will be discussed. In Paragraph 6.3.2 the environmental effect will be discussed for both cases.

6.3.1 Cost effects

Scenario 1: France

The case of France is characterised a relatively low diesel price and relatively high electricity costs. The consequences for the fuel cost effects are shown in Figure 7.

The figure shows separately the results for the different variables, firstly grouped into chilled/frozen, followed by a split into start-stop and continuous and finally split into the energy labels (New, B and D). In start-stop mode, the fuel cost savings per gross operating hour include the on- and off-periods of the TRU.

Figure 7 Fuel cost savings of electrical trailer cooling in France for different variables

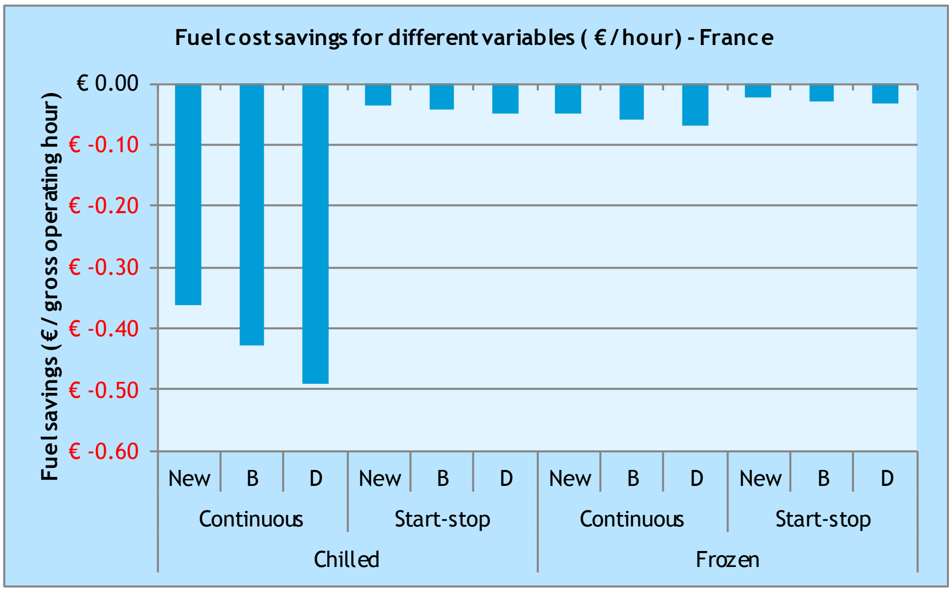
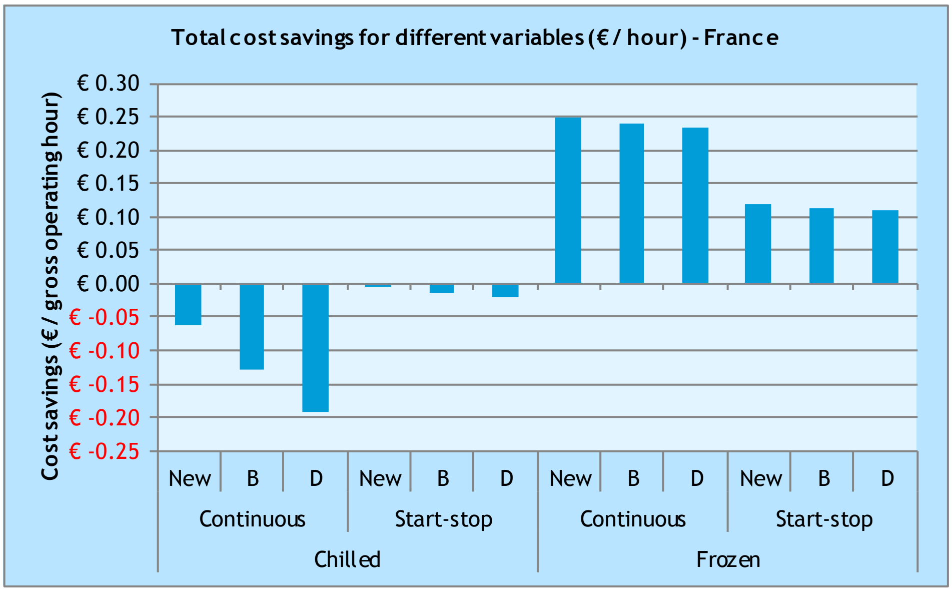


Figure 8 shows for all variants an increase in energy costs, switching from diesel to electricity. The effect is higher in continuous mode than in start-stop mode, which is attributed to the higher fuel consumption in continuous mode. Especially for chilled transport, the costs in continuous mode are much higher.

For chilled transport the diesel mode is relatively more efficient and diesel cost reduction is therefore smaller as compared to frozen transport.
The effect of the energy efficiency label is relatively small as compared to the influence of the other parameters.

The result on the total costs, taking into account the maintenance costs of € 0.30 per net operational hour as well, are shown in Figure 8. For Frozen transport there are net benefits up to € 0.25 per net operation hour, whereas for chilled transport there extra costs up to € 0.20 per net operation hour.

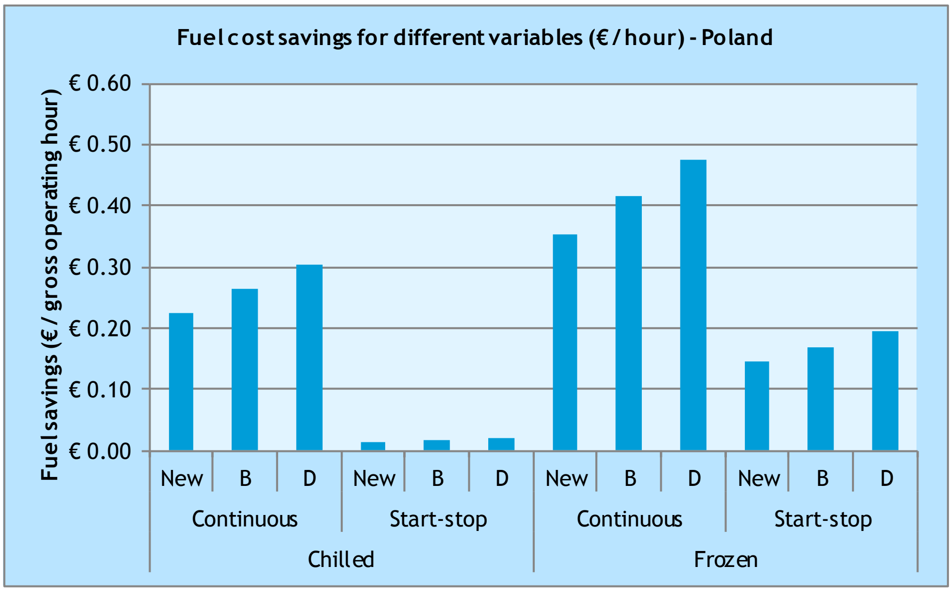
Figure 8 **Total cost savings of electrical trailer cooling in France for different variables**



Scenario 2: Poland

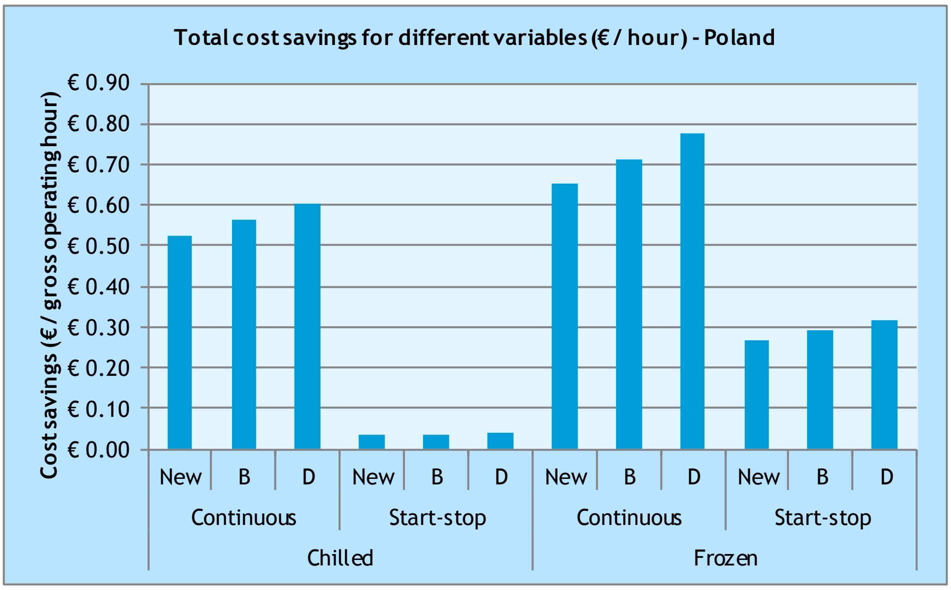
For Poland the average ambient temperature, diesel price and electricity are different as compared to France. The Poland case is characterised by an average diesel price (€ 1.06/litre) and relatively low electricity costs were assumed (€ 0.28/kWh_e).
Figure 9 shows that for all variant there are benefits for switching from diesel tot electricity during resting periods. In start-stop mode the energy consumption for chilled products is relatively low, resulting in lower benefits. In continuous mode for frozen transport the benefits are highest due to the high energy consumption and the relatively high diesel consumption avoided.

Figure 9 **Fuel cost savings of electrical trailer cooling in Poland for different variables**



Taking into account the cost savings for maintenance, the cost savings per net hour are € 0.30 higher (See Figure 10).[5]

Figure 10 **Total cost savings of electrical trailer cooling in Poland for different variables**



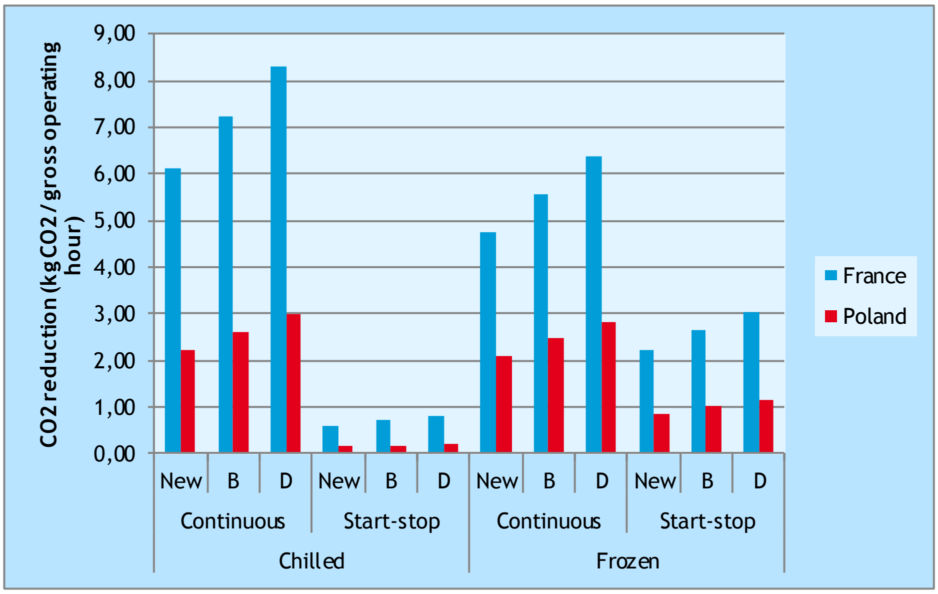
5 For continuous mode the costs saving per gross operating hour also equal €0.30/hour, in start stop mode the savings per gross operating hour are lower as only part of the time the TRU is operating.

6.3.2 Environmental effects

Figure 11-Figure 13 show the environmental impacts of switching to electrical trailer cooling during rest periods for both cases in comparison. The France case is characterised by relatively low electricity emissions, the Poland case by relatively high emissions. The two cases can be seen as a representative range of environmental effects for the EU, as France has the lowest emission factors and Poland the highest (see also Paragraph 5.2.1). In addition the average temperature in France is higher than in Poland.

For both cases in all variants CO_2, NO_x and PM_{10} emission are reduced (see Figure 11-Figure 13).

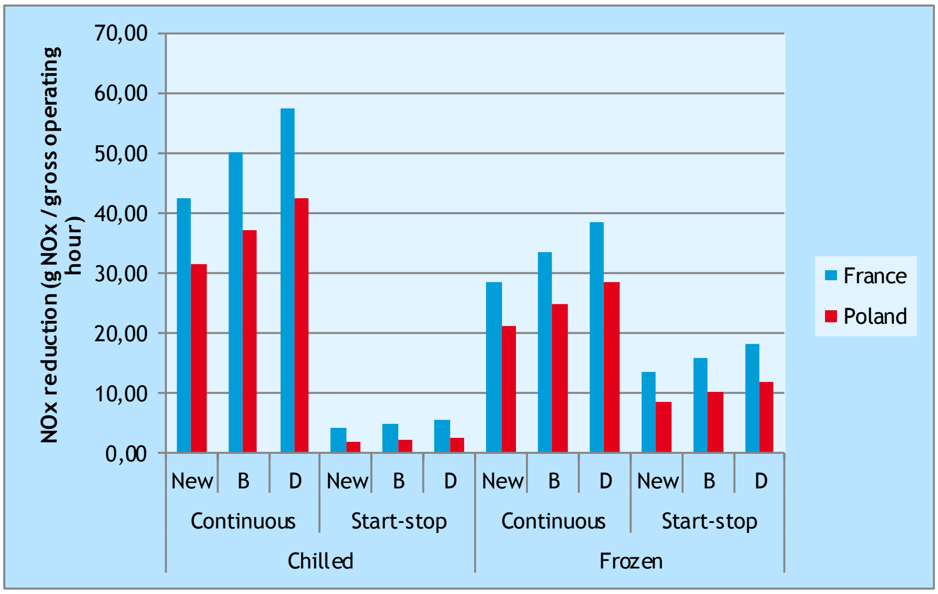
Figure 11 **CO_2 reduction of electrical trailer cooling for different cases (kg/hour)**



The CO_2 reduction in France is higher than in Poland, because of the higher ambient temperature (affecting especially the result in start stop mode) and because of the difference in electricity emission factors. The emissions are up to 4.5 times higher in France, as in case of the start-stop mode for chilled products.

Figure 12 and in Figure 13 show the result on NO_x and PM_{10} for France and Poland. The difference between the two countries is less pronounced as for CO_2. The NO_x and PM_{10} emission of electricity production are, both for Poland and France, relatively small as compared to the diesel aggregate emission, although the electricity emission of the average Polish electricity mix are much higher than for France. The variant show the same relative result as the result on the CO_2 emissions in Figure 11.

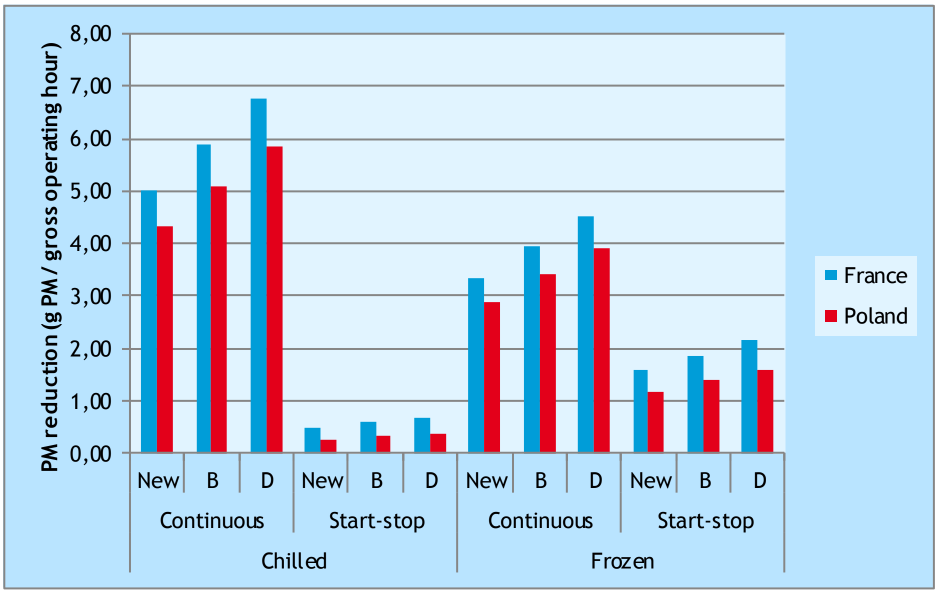
Figure 12 NO_x reduction of electrical trailer cooling for different cases (gram/hour)



The environmental impact on NO_x is very dependent on the fuel consumption per case, just like for CO_2 and also for PM. The range of the effect is somewhat smaller. For France, the NO_x reduction due to electrical trailer cooling is 98% of the NO_x emissions while in diesel mode. And for Poland, this is 73%.

The PM effects for the two cases are similar to the NO_x effects.
The calculations are presented in Figure 13 for all case variants of France and Poland.

Figure 13 PM reduction of electrical trailer cooling for different cases (gram/hour)



The relative emission reductions are the same for the different variant and are summarized in Table 24 for the two cases.

Table 24 Relative emission reduction for the two cases

Effect	France	Poland
CO_2	90-91%	32-40%
NO_x	98%	73%
PM	99%	85%

7 Conclusions and outlook

7.1 Conclusions

NomadPower is developing a power supply network at parking places for temperature controlled transport. This power supply network allows drivers to run the cool units of their trailers on electricity instead of diesel.

The most important market for NomadPower are transport haulage operators on international long distance routes. The transports in this market are often multiple days and require an overnight stop. This means a resting period of nine hours or more in which it would be possible to connect to electricity if this service is present on the location. For these transports the potential of NomadPower is high.

In this report we examined the potential use of NomadPower on parking places in long distance refrigerated transport. For Europe we have concluded that 50–100 million hours of diesel consumption at parking places can be replaced by electricity consumption. This could save on the short term (when 15% of the net operating hours are replaced) 130 million litres of diesel, 290 kton of CO_2, 2.36 kilotonnes of NO_x and 280 tonnes of PM_{10}. The NO_x savings are comparable to the yearly NO_x emissions of 5,000-10,000 Euro-V trucks or 35,000 Euro-VI trucks. The PM_{10} savings are comparable to the yearly PM_{10} emissions of 110,000 Euro-V trucks or 220,000 Euro-VI trucks. Especially the PM_{10} reduction potential is high. The potential PM_{10} reduction per year of the TRU equals the yearly PM_{10} emission of a Euro-VI truck or 50% of the emission of a Euro-V truck. Depending on the electricity prices set by NomadPower, transport operators might save € 180 per year per TRU.

The potential emission reductions are relatively high as currently there are no emission standards applicable for TRU diesel aggregates and emission are therefore relatively high.

The potential emission reduction and cost savings for transport operators are dependent on the characteristics of the transport. Ambient temperature, operation mode, and the type of product are important parameters that determine energy consumption of TRUs. The effect of these parameters on the emission and cost reductions have been illustrated in cases. The cases show a wide variation in environmental and cost effects due to a combination of common variables in the refrigerated transport market. Important observations are:
- The fuel consumption per gross operation hour (and therefore the environmental and cost effects) is dependent on many factors (cooling temperature, operation mode, efficiency of TRU). There is often a pronounced difference between the results in continuous and start stop mode.
- For chilled products the fuel cost savings might also be negative, depending on the electricity price.
- All cases show environmental benefits for switching the TRU from diesel to electricity mode. The environmental reductions are 32-91% for CO_2, 73-98% for NO_x and 85-99% for PM_{10}. The effects mostly depend on the emission factors of electricity.

Finally, the outlook on other markets beside the long distance refrigerated transport market shows a possible broader potential for the technology of NomadPower (see below).

7.2 Outlook

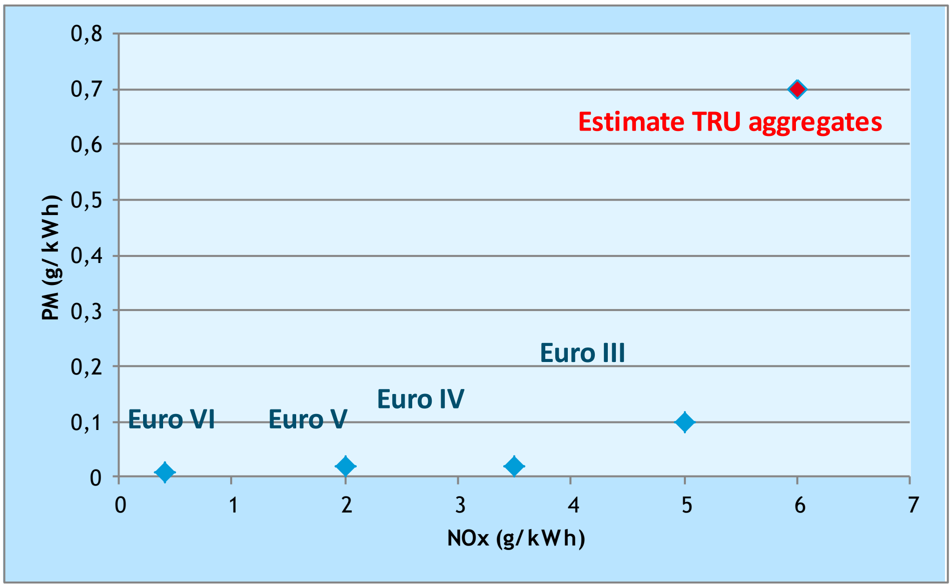
In this report the potential benefits of NomadPower for long distance refrigerated transport have been assessed in terms of environmental benefits and costs. The long distance refrigerated transport market is an important market as during resting periods there is large potential of time to switch the TRU to electricity. We have focussed on the TRU systems with an auxiliary diesel engine, the most common systems in this market.

However, there are other important markets that might benefit from the NomadPower solution as well. TRU systems that make use of the main engine power are an interesting market as well. These types of systems are more common in the refrigerated distribution market. For these systems NomadPower services might be of special interest as these systems requires the truck engine to be turned on during resting periods when it is not possible to electrically connect. The possibility to plug in to NomadPower makes it possible to turn off the truck engine preventing a lot of diesel consumption noise disturbance, even more than for the auxiliary engines. The effects on NO_x and PM_{10} emissions, might however be lower, due to the strict emission limits for truck engines.

Furthermore the refrigerated distribution market in general might be of special interest as the TRUs in this market operate typically in urban areas, where air quality (NO_x and Particulate matter concentration) is of special importance. Many larger cities are facing air quality problems and have, for example, implemented environmental zones for freight transport.
In these environmental zones trucks with older engines (high emission) are forbidden.

For TRU aggregates there are no access restrictions. Taking into account that the truck power (kWh/h) is 5 to 10 times higher in a city environment than the TRU power, it can be concluded from Figure 14 that the TRU NO_x emissions per hour equal the NO_x emission of a Euro-VI truck per hour. On hourly basis, the PM_{10} emission equal the emission of a Euro-III truck and are about 10 times higher than a Euro-VI truck.

Figure 14 Emission factors of truck engines compared to estimated emission factors of TRU aggregates



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Annex A Background information

A.1 Trailer dimensions

The majority of refrigerated road transportation is conducted with semi-trailer insulated rigid boxes. In Europe the external length and width of a semi-trailer rigid box are fixed but the external height and internal dimensions can vary depending on the individual design type. Common standard dimensions depicted in Table 25 (Tassou, et al., 2008).

Table 25 Typical standard trailer dimensions in the EU

Dimensions	External dimensions	Internal dimensions
Length (m)	13.56	13.35
Width (m)	2.6	2.46
Height (m)	2.75	2.5
Surface (m^2)	159.4	144.7
Volume (m^3)	97.0	82.1

The average surface is 151.9 m^2 (calculated from the square root of the product of internal and external surface).

A.2 Lifetime of trailers

Equipment lifetime estimates for land transport refrigeration vary in the literature. RTOC (RTOC, 2011) estimates the average lifetime of refrigerated road vehicles, railcars, and intermodal containers to be between 10 to 15 years but less than 10 years if the equipment is used intensively. IPCC (IPCC, 2006) estimates a range of 6-9 years, and EC (2010) estimates an average of 14 years. Based on these sources and manufacturer information (suggesting a range from 5 to 8 years for the 'first life' with a possible 'second life' of approximately 2 years) ICF (ICF International, 2011) assumes an average lifetime for refrigerated trailers and trucks in the UK of 7 years.

A.3 Thermal conductivity

Usually the body is insulated with insulated equipment. In this case the walls, doors, floor and roof are covered by insulated equipment, by which heat exchanges between the inside and outside of the trailer are limited.
The overall coefficient of heat transfer (K coefficient) specifies the heat transfer between the trailer and the ambient. The ATP (ATP, 2015) classifies insulated vehicles and bodies as either Normally Insulated Equipment (IN, isotherme normal: U coefficient equal or less than 0.7 W/m^2 K or Heavily Insulated Equipment (IR, isotherme renforcé: U coefficient equal or less than 0.4 W/m^2 K.

Trailers that are used for refrigerated transport have a FRC classification and are heavily insulated and have a K (thermal conductivity) of 0.4 W/m^2K.

The performance of insulation materials deteriorates with time due to the inherent foam characteristics. Recent data show a typical loss of insulation value of between 3 and 7% per year which can lead to considerable rise in the thermal conductivity after a few years (6,8). If a 5% yearly ageing is assumed, a vehicle with an initial K coefficient of 0.4 W/m^2 K will have a K-coefficient of 0.62 W/m^2 K after nine years of operation, resulting in a 50% increase in energy consumption and CO_2 emissions (Tassou, et al., 2008).

The K increased from 0.4 to 0.62 in 9 years and transmission load increases by 50% (Tassou, et al., 2008).

A.4 COP values and diesel-electric ratios

ATP test figures

Table 26 gives a range of COP values and resulting ratios diesel - electric of new TRU systems, based on ATP test result from Thermoking and Carrier (from interviews).

Table 26 Coefficient of performance for different operating modes and cooling temperatures at 30 °C ambient temperature

Operating mode	0 °C	-20 °C
Diesel high speed (l/kWh_r)	0.24 (±10%)	0.33 (±25%)
Diesel low speed (l/kWh_r)	0.20 (±5%)	0.28 (±25%)
Electric standby (kWh_e/kWh_r)	0.86 (±10%)	1.0 (±25%)
Ratio diesel low speed - electric (kWh_e/l)*	4.2 (±5%)	3.6 (±5%)

* The ratio cannot directly be calculated from the COP ranges. The COP ranges are based on different TRUs. For the different TRUs de ratio diesel electric has been calculated and the average of ratios is reported.

Measurement TU Delft

Students of TU Delft (TU Delft, 2014) have tested cooling trailers at the charge station of Partner Logistics in Bergen op Zoom.

Their objective was to examine the effects that occur when using electricity instead of a diesel generator as power source for refrigerated transport in terms of fuel consumption, noise and emissions.

The trailers were equipped with a transport refrigeration unit. During the experiment one trailer was used for cooling on electric standby while the other was operated in diesel mode. The energy consumption of the TRUs was measured in start-stop cycles. The diesel generator did not run at full speed load, but switched to a low speed during the experiment. The circumstances under which the two trailers operated were (assumed to be) the same.
The results of the experiment are summarized in Table 27. The table shows the energy consumption figures per gross hour, per net hour and per period.

The energy consumption per gross hour takes into account the off periods and thereby also the difference in cooling capacity between electric and diesel mode. A comparison between electricity consumption and diesel consumption in start-stop mode should therefore be based on a comparison of the energy consumption per gross hour.
However, when the cooling capacity of the diesel and electric mode would be the same, as would more or less be expected (see Table 1), the ratio between electricity and diesel consumption per net hour should be the same as well.

The ratio between electricity and diesel consumption in on- periods should also be the same as the ratio based on the gross fuel consumption regardless of the cooling capacities. Both in electric and diesel mode the system turns of at a certain offset temperature from the set temperature and stops when the temperature is reached. In both electric and diesel mode, therefore the same cooling work is delivered per period.
As can be seen, Table 27 shows different results for the three calculated electricity-diesel ratios, especially at -5°C. The reason for the discrepancy is unknown. In the main report the range of the three results has therefore been used.

Table 27 Electricity-Diesel consumption ratio's calculated in different 3 different ways

	Per gross hour *	Per net hour **	Per on-period **
Temperature -15°C			
Electricity consumption (kWhe/h)	3.13	8.4	1.8
Diesel consumption (L/h)	1.37	2.67	0.57
Ratio (Electricity/Diesel) (kWhe/L)	**2.29**	**3.15**	**3.14**
Temperature -5°C			
Electricity consumption (kWh_e/h)	1.5	10.0	1
Diesel consumption (L/h)	1.04	2.63	0.53
Ratio (Electricity/Diesel) (kWhe/L)	**1.43**	**3.80**	**1.90**

* Per gross hour figures are taken from the TU Delft report.

** Figures per net hour a period are taken from Table 28 and Table 29. Figures per period are calculated taken by dividing the total consumption by the number of cooling periods.

In Table 28 and Table 29 the measurement result for the on-time periods are listed. These results have been used to calculate the fuel consumption per net hour and per period in Table 27.

Table 28 Measurement cycles and energy consumption in electric standby mode

Temperature	Cycle	Duration	Electricity use (kWh)	Energy consumption (kWh/h)
-15	1	0:12:42	1.8	8.4
	2	0:12:32	1.8	8.4
	3	0:11:08	1.6	8.4
	4	0:13:12	1.9	8.4
	5	0:14:32	2.0	8.4
	Total on time	1:04:06	9.0	8.4
-5	1	0:05:56	1.0	10.0
	2	0:05:59	1.0	10.0
	3	0:06:05	1.0	10.0
	Total	0:18:00	3.0	10.0

Measurement -15 in Appendix VI on page 46.
Measurement -5 in Appendix VI op page 47.
Duration from difference between start-stop times per cycle.

Table 29 **Measurement cycles and energy consumption in diesel mode**

Temperature	Cycle	Duration	Diesel consumption (mL)	Diesel consumption (l/h)
-15	1	0:13:07	568	2.60
	2	0:12:46	582	2.73
	3	0:12:44	571	2.69
	Total	0:38:37	1,721	2.67
-5	1	0:13:00	638	2.94
	2	0:13:00	522	2.41
	3	0:10:00	420	2.52
	Total	0:36:00	1,580	2.63

Duration time and mL diesel consumption from pages 48-50 and 57-59

A.5 ATP energy consumption figures

In the ATP test refrigeration units are tested, while running 100% of the time at 30°C ambient temperature. The test results give an indication of the energy consumption of the systems while operating in continuous mode. In Table 30 average test results for different manufacturers are shown.

Table 30 **Energy consumption in ATP tests**

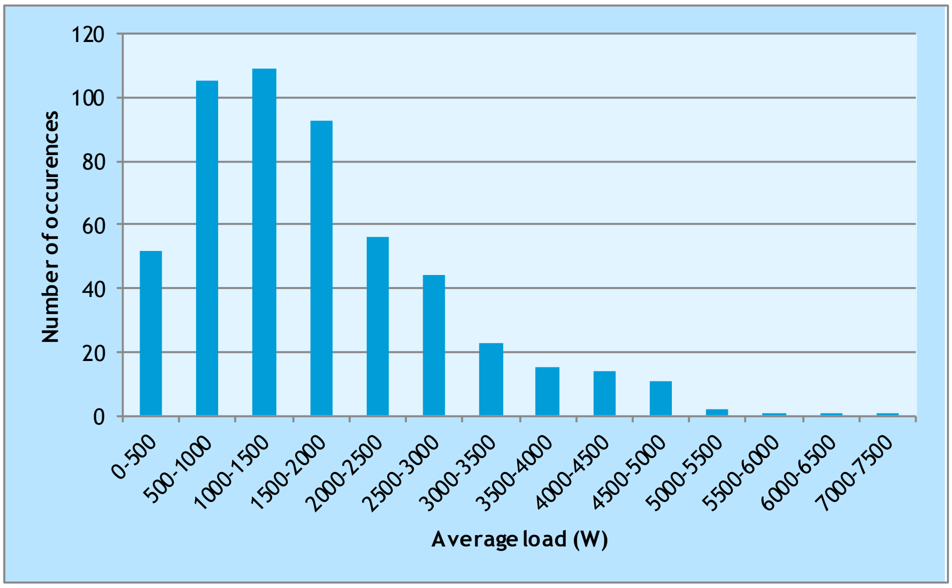
Operating mode	0°C	-20°C
Diesel high speed (l/h)	4.2 l/h (±15%)	3.0 l/h (±25%)
Diesel low speed (l/h)	2.5 l/h (±20%)	1.9 l/h (±15%)
Electric standby (kWh/h)	11.4 kWh/h (±25%)	7.1 kWh/h (±15%)

The result above are valid for relatively new systems. Based on the assumption that average TRU approaches the B label according to UBA (see Figure 4), the energy consumption of the average TRU is assumed to be a Factor 1.3 higher. The resulting energy consumptions are in the main text (Table 6).

A.6 Consumption data from NomadPower

NomadPower was able to provide consumption data from the previous year of the current. From this dataset CE Delft has extracted a typical example of a company profile over the course of one year.

Figure 15 Example of company electricity consumption data for one year



The service of NomadPower was very often used by this company. The loads are mostly similar (80% between 0.6-4.5 kWh/h), but also some that are higher. This corresponds roughly to the transmission loads one would expect, which are between 600 W (0°C at 8°C ambient) and 3,000 W (-20°C at 20°C ambient) (based on a K value of 0.5, surface of 150 m^2).

Higher loads can be explained due to products that are not loaded at the right temperature or a higher k-value, while low loads might be a result of a low ambient temperature. Another explanation is the potential cooling in continuous mode.

Annex B Interviews

Interview reports can be requested via NomadPower.

Table 31 lists the interviewed persons and organisations.

Table 31 Summary of interviews

Interviewee	Company	Type
Ingmar Coppoolse	A. Visbeen en Zonen B.V.	Transporter
Freddy Borghuis	Borghuis Transport	Transporter
Theo Noortman	Amex Logistics	Transporter
Ben Lucassen	L&T Transport v.o.f.	Transporter
André van Asselt	Thermoking	Manufacturer
Eric Oude Bennink	Carrier	Manufacturer
Eeuwe Kooi	TRS	Manufacturer
Andreas Schmid	Frigoblock	Manufacturer
Jos Schreurs	NomadPower	Supplier electricity on parking lots