Topsector Logistiek

Insight into the energy consumption, CO_2 emissions and NO_x emissions of rail freight transport

TNO innovation for life

Connekt

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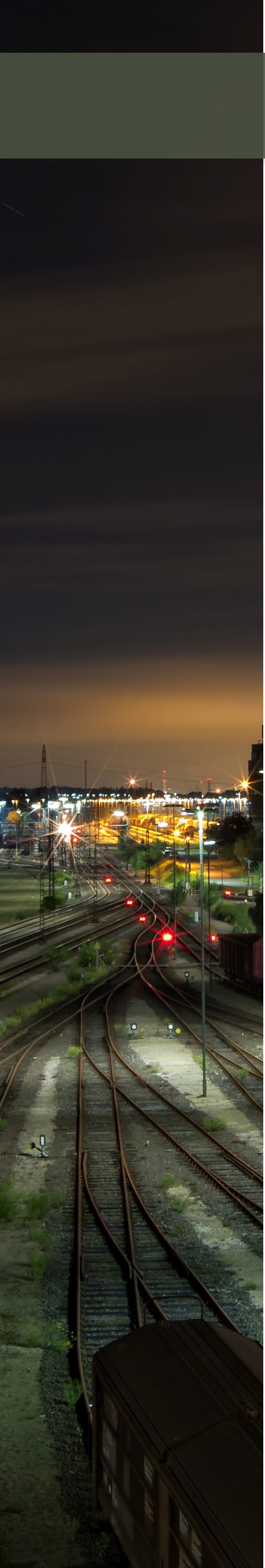

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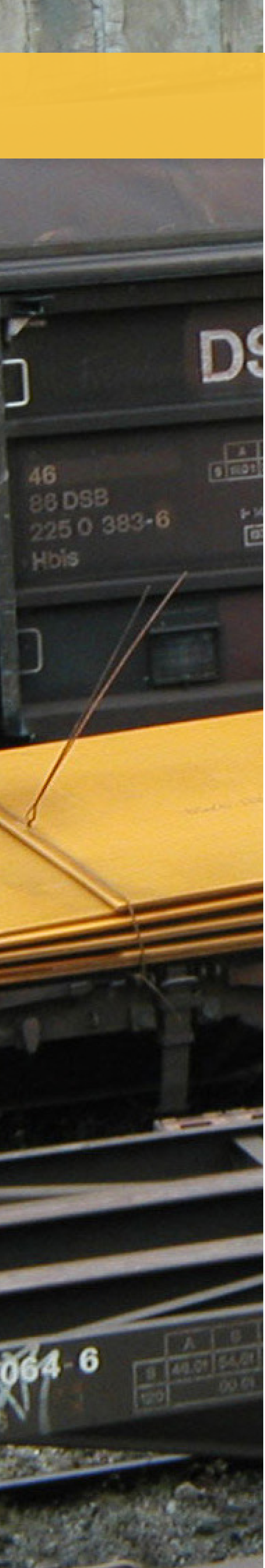


Abstract

Background

The Top Sector Logistics aims to reduce the CO_2 emissions resulting from logistics activities. To realize this ambition, an insight is required into aspects including the CO_2 emissions of the various transport modes. To date only a limited insight has been available into aspects of the CO_2 emissions of rail freight transport.

Freight trains are powered by a combination of electric and diesel locomotives. Diesel locomotives are frequently used for shunting activities in the Rotterdam port area, while electric locomotives are used on (cross-border) long-distance rail routes with destinations in the hinterland.

On behalf of Connekt, TNO analyzed the energy consumption and CO_2 emissions of an electric locomotive and two diesel locomotives. The NO_x emissions were also determined for the diesel locomotives.

Approach

The energy consumption and CO_2 emissions of the electric locomotive were calculated on the basis of the locomotive's logbook, which contains details including the total laden and unladen weight of the train and the train length. The calculations were calibrated using the data from the locomotive's energy meter, which recorded data on the routes in Germany.

The CO_2 and NO_x emissions of two diesel locomotives were measured using the Smart Emission Measurement System (SEMS) developed by TNO.

Conclusions

Conclusions relating to the diesel locomotives measured

- In cases where a shunting profile[1] was expected (and planned), the diesel locomotive was also sometimes used outside the Rotterdam port area during both measurements.
- The diesel locomotive's engine is idling for between 75% and 84% of the time that it is running.
- Around half of CO_2 and NO_x emissions are generated during idling.
- The CO_2 emissions of a single diesel locomotive over the entire measurement period are 60.7 tons. The CO_2 emissions of a single diesel locomotive over the course of a year are comparable with those of four truck and semi-trailer combinations over the same period.

  The NO_x emissions over the course of a year are comparable with those of 200 modern Euro VI truck and semi-trailer combinations over the same period.

Assuming that there are 40 active diesel locomotives operating in the Netherlands, this means that 2,428 tons of CO_2 are emitted annually.

Conclusions relating to the electric locomotive measured

- The typical energy consumption of an electric locomotive is 0.02 kWh per ton-kilometer (tkm). This figure is significantly below that of road transport. For a heavy truck and semi-trailer combination the energy consumption measured on the basis of a given weight transported over a given distance is a factor of two higher.
- In the case of large-volume, low-density loads in particular, this advantage in terms of energy consumption is cancelled out by the heavy weight of rail wagons and the associated running resistance, which is greater than that of trucks.
- The length of the train, more so than its weight, appears to be a decisive factor as regards the energy consumption of the electric locomotive hauling the wagons. Train length has a greater effect than expected. It seems that the longer the train, the more axles there are and the greater the friction generated. This is likely to be the main factor that determines the greater demand for power and greater electricity consumption for the same transported load in ton-kilometers. Reducing the axle friction of wagons therefore appears to be a key factor in reducing the energy consumption of electric locomotives.

The CO_2 emissions resulting from a train journey

It is not easy to link the CO_2 emissions resulting from a train journey to the transport requirement: the transport of a ton of freight over a fixed distance. That is mainly because a large portion of the CO_2 and NO_x emissions of diesel locomotives and of the electricity consumption of electric locomotives is not directly connected to the transport of the load. A significant proportion of the emissions of diesel locomotives are generated during idling and the electricity consumption of electric locomotives seems to depend more on the rolling stock hauled than on the load transported.

[1] *This means that the diesel locomotive is used between yards and terminals in the Rotterdam port area.*

1 Introduction

1.1 Background

The Top Sector Logistics aims to reduce the CO_2 emissions resulting from logistics activities. To realize this ambition, an insight is required into the structure of logistics activities and the CO_2 emissions of the various transport modes.

To date only a limited insight has been available into the performance of rail freight transport in the area of CO_2 emissions, with insufficient consideration having been given to the characteristics of this particular mode. Rail freight transport is supply driven, which means a train will operate with fluctuating tonnages of freight on board. Furthermore, freight trains are powered by (a combination of) electric and diesel locomotives; the latter are frequently used for shunting activities in the Rotterdam port area, while the former are used on cross-border rail routes with destinations in the hinterland. On occasion carriers are forced to use alternative routes due to disruptions on the line. The additional train kilometers that result have an impact on the CO_2 emissions of the train journey in question.

On behalf of Connekt, TNO analyzed the energy consumption of an electric locomotive and the CO_2 and NO_x emissions of a diesel locomotive.

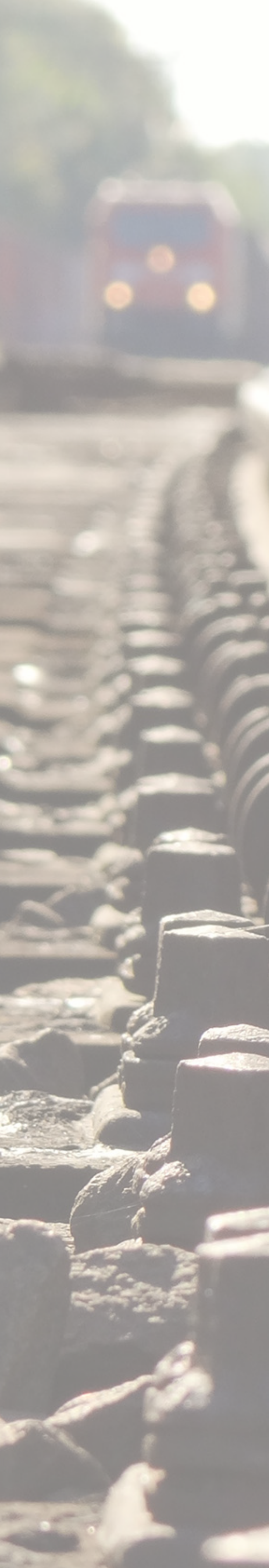
The study consisted of three phases:

1 Market survey of rail freight carriers
2 Measurement of energy consumption and NO_x emissions
3 Analysis of data and reporting

The original research questions were revised following the market survey. This was because, for example, the CO_2 emissions for a specific train journey could not be determined due to a lack of data and an insight was also requested into NO_x emissions, an aspect that had not been included in the original action plan.

The definitive research questions were:

1 What are the CO_2 emissions of a diesel locomotive over a defined measurement period, taking into account the number of train kilometers traveled and the weight hauled by the diesel locomotive?
2 What are the NO_x emissions of a diesel locomotive over a defined measurement period, taking into account the number of train kilometers traveled and the weight hauled by the diesel locomotive?
3 What is the energy consumption (kWh) of an electric locomotive over a defined measurement period, taking into account the number of train kilometers traveled and the weight hauled by the electric locomotive?



1.2 Approach and definition of the study

In this study we focus exclusively on container transport by rail. In contrast to bulk transport, container transport is more dynamic in terms of transport options and the diversity of goods and volumes transported. Because of this diversity, there are more options for characterizing any differences in CO_2 and NO_x emissions.

To answer the research questions, the following approach was taken:

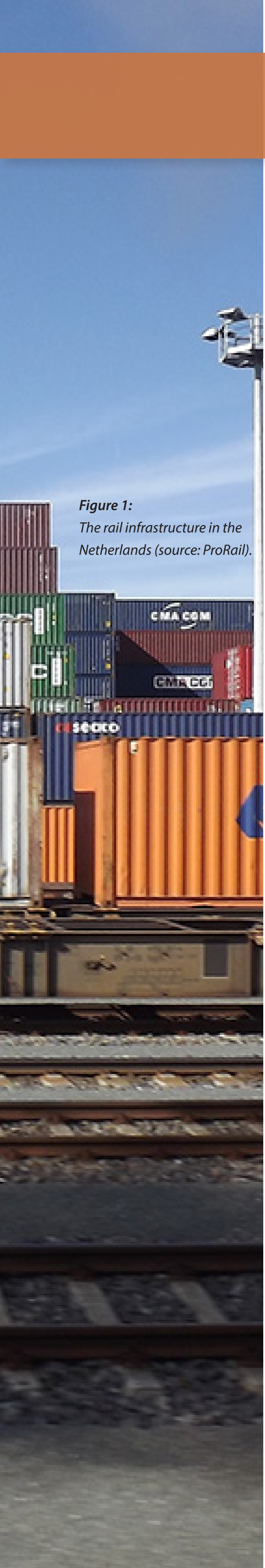
1 Involvement of rail freight carriers in the study. The success of this study depends on the participation of one or more rail freight carriers who are prepared to make resources (locomotive, people, data, etc.) and time available. The purpose of a market survey of rail freight carriers operating on the Dutch rail infrastructure is to assess interest in participating and provide an insight into:
   a the services offered for each route traveled, including frequency and destination(s);
   b the availability of data;
   c the specific needs of the rail freight carrier.

2 Measurement of CO_2 and NO_x emissions. Based on the outcome of the market survey, a measurement plan is drawn up with the participating carrier(s). Agreements are made with each carrier on aspects including:
   a the duration of the measurement;
   b the use and availability of data.

3 Analysis of the data. In the analysis phase of the study the results are analyzed. This analysis allows the CO_2 emissions to be determined. On the basis of the analysis it must also be possible to identify which factors determine any differences in CO_2 emissions.

1.3 Structure

Chapter 2 contains a report on the market survey conducted by TNO. The method used to perform the measurements on the electric and diesel locomotives is then explained in Chapter 3. Chapter 4 details the results of the measurements and the report ends with a presentation of the conclusions in Chapter 5.



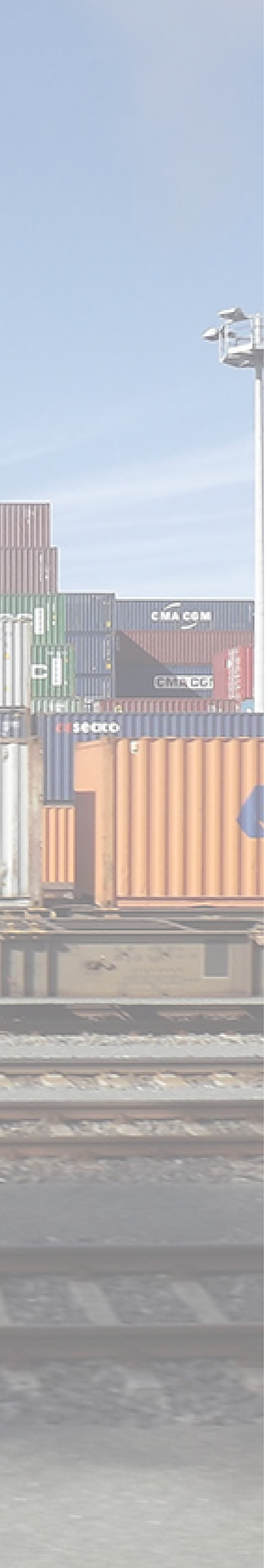
2 Market survey and data collection

2.1 Background

Rail freight carriers (hereinafter: carriers) who transport freight by rail in the Netherlands have to apply to the rail infrastructure manager ProRail for rail capacity (a train path). Different running and deployment characteristics apply depending on the type of good transported and the type of locomotive (electric or diesel) used. These running characteristics determine the speed at which a carrier can travel in relation to the tonnage of the train, but also the capacity, expressed in terms of time, that has to be scheduled for use of the rail infrastructure. The rail infrastructure in the Netherlands is presented in Figure 1.

Figure 1:
The rail infrastructure in the Netherlands (source: ProRail).

To transport their freight, carriers can make use of the Betuwe route (160 km), which is reserved exclusively for rail freight transport, or the combined network (6,570 km). Both passenger and freight trains run on the combined network.
Around 85% of freight trains using the rail infrastructure in the Netherlands have a cross-border destination.
In 2014 some 25,300 freight trains crossed the Dutch/German border via the Betuwe route and around 16,860 did so via the combined network.



2.2 The carriers approached

To actually measure CO_2 emissions, carriers were needed who were willing to participate in the study. Eight carriers were approached.

TNO then held discussions with four carriers to gain an insight into:

1 The services the carriers offer on the route;

2 The frequency of the services operated on a weekly basis, with details of the average number of containers (TEU[2]) transported;

3 The structure of the services, broken down by type of traction (electric or diesel or a combination of the two);

4 The organizations involved in implementing the train journey. A train journey often consists of a number of different sub-processes, which are not necessarily performed by the carrier itself;

5 The type of data that can be made available. Each carrier had the following types of data available:
a Train kilometers traveled;
b Weight hauled expressed in tons per train journey;
c Diesel consumed in liters per month per diesel locomotive;
d Energy consumed in kWh per month per electric locomotive;
e Duration of the train journey (in hours/minutes).

6 The needs of carriers. All carriers indicated that they wanted to focus more on sustainability, alongside costs and the reliability of train journeys. Measuring CO_2 emissions contributes to this and enables carriers to answer shippers' questions in this area. Two carriers indicated that they regarded this study as an opportunity also to measure their emissions of nitrogen oxides (NO_x) in addition to CO_2.

The availability of this kind of data is relevant for the study, as it makes it possible to establish a potential link between weight hauled and train kilometers traveled, on the one hand, and CO_2 and NO_x emissions and energy consumption, on the other.

In the end two carriers undertook to participate in the study, including Rotterdam Rail Feeding.

[2] *Twenty Foot Equivalent Unit, the standard measurement used for containers*

3 Structure of measurement

3.1 Introduction

This study was conducted in collaboration with two carriers. To allow CO_2 and NO_x emissions to be measured, consideration was given, together with these two carriers, to the types of locomotive available, on the one hand, and how these are deployed to perform their services, on the other.

In the case of carrier 1 this resulted in measurements being performed relating to the energy consumption in kWh of an electric locomotive and the CO_2 and NO_x emissions of a diesel locomotive. The $CO_2$and NO_x emissions of a diesel locomotive were also measu-red for carrier 2.

CO_2 is the most important greenhouse gas. The amount of CO_2 released is proportionate to the amount of carbon contained in the diesel. Based on the quantity of fuel consumed it is therefore possible to determine how much CO_2 is emitted. NO_x emissions can vary significantly depending on engine technology and train deployment. The NO_x emissions of diesel engines increase NO_2 concentrations in the air and are therefore a major cause of air pollution[3].

3.2 Measuring CO_2 and NO_x

To allow the emissions behavior and fuel consumption of vehicles to be effectively determined in practice, TNO has developed a measurement tool known as the Smart Emissions Measurement System, or SEMS for short. SEMS can be used to measure the CO_2 and NO_x emissions of vehicles while they are being used in practice on a daily basis. With the help of sensors, the data measured are sent wirelessly from the measurement tool to a database, from where the data are analyzed and processed. The results of the analysis allow statements to be made on the emissions of the vehicle being studied. SEMS has already been used in the inland shipping and road transport sectors.
In this study SEMS was used to measure the CO_2 and NO_x emissions of two diesel locomotives over a defined measurement period.

So that emissions could be recorded as effectively as possible, the SEMS sensors were installed in the exhaust systems of the two diesel locomotives. One sensor measures the concentration of NO_x, while the other measures that of oxygen.

[3] *Emissions of transboundary air pollutants in the Netherlands 1990-2014 RIVM Report 2015-0210 B.A. Jimmink et al.*

The oxygen concentration can then be used to calculate the CO_2 concentration. These concentrations cannot be translated directly into CO_2 and NO_x emissions in grams, but provide an indication of environmental performance relative to other vehicles and vessels. In the case of road transport, diesel cars, vans and trucks dating from around 2015 (Euro 5/V) have emissions in the region of 4 grams of NO_x per kilogram of CO_2. Taken together, all the vehicles currently being used on Dutch roads also have average emissions of 4 g NO_x/kg CO_2. The higher the number of grams of NO_x per kilogram of CO_2, the more NO_x the vehicle emits per quantity of CO_2 emitted and/or quantity of fuel consumed.

A vehicle that emits a relatively high quantity of NO_x per liter of fuel consumed therefore contributes more to air-quality issues than a vehicle that emits relatively little NO_x per unit of fuel consumed. Modern Euro VI trucks have much lower NOx emissions than Euro V trucks. It is partly for this reason that the average NO_x emissions linked to the fuel consumed by all vehicles on Dutch roads taken together are expected to drop below 4 g NO_x/kg CO_2 in the near future.

The fuel consumption figures over the entire measurement period for the first diesel locomotive provide an indication of the total CO_2 and NO_x emissions. However, due to an outdated engine management system, it was not possible to read out the engine data for this locomotive. In this case it was therefore difficult to determine the proportion of emissions generated during idling. During the measurements performed on the second diesel locomotive the engine data could be read out. For this locomotive a clear distinction could therefore be made between the emissions generated in different circumstances.

3.3 Measuring energy consumption (kWh)

The energy consumption of the electric locomotive was calculated on the basis of the locomotive's logbook, which contains details including the total laden and unladen weight of the train and the train length. This method was employed, as the energy meter in the electric locomotive only worked efficiently in Germany. By analyzing the logbook, it was therefore possible also to take the data on kilometers traveled in the Netherlands into account. The data from the energy meter (in Germany) were, however, used to calibrate the calculation based on the logbook.

The energy consumption of the electric locomotive is indicated on an energy meter.
As this meter also displays other values in addition to energy consumption, the energy being consumed is not visible on the display at all times.
To determine energy consumption, use was made of a GoPro camera, which was pointed at the energy meter's display during the train journey.
At the end of the measurement period the images captured were translated into data, on the basis of which analyses were performed to determine the energy consumption in kWh.

4 Results of measurement

This chapter describes the results of the study for each type of locomotive.
The study was conducted over the period from November 2016 to October 2017.

4.1 Results for the diesel locomotive

Both carriers indicated that they mainly use the diesel locomotives measured in this study for shunting activities in the Rotterdam port area. Shunting activities are characterized by the relatively short distances covered, with locomotives traveling between a yard and a terminal, for example. The locomotives in question are also used to put a train together, a process that involves a large number of locomotive movements.

Measurement 1

The first measurement was performed at carrier 1 and the details of this measurement are as follows:

- Measurement period: 29 November 2016 to 16 February 2017
- Operating hours: over the period 656 engine hours were logged by SEMS, with an average of 11.5 hours per working day
- Type of locomotive: diesel hydraulic locomotive, type G1206 manufactured by MaK

Train deployment

One point that stands out immediately when analyzing the results is that the diesel locomotive is not only used in the Rotterdam port area, but also travels towards destinations elsewhere in the Netherlands and across the border with Germany. For some of this time the train travels at higher speeds. The thin red line in Figure 2 shows this clearly.

Discussions with carrier 1 revealed that the locomotive is somtimes used as a replacement for electric trains that have been delayed or have broken down. How the locomotive can be used most efficiently, in the light of current circumstances, is considered on an ongoing basis.

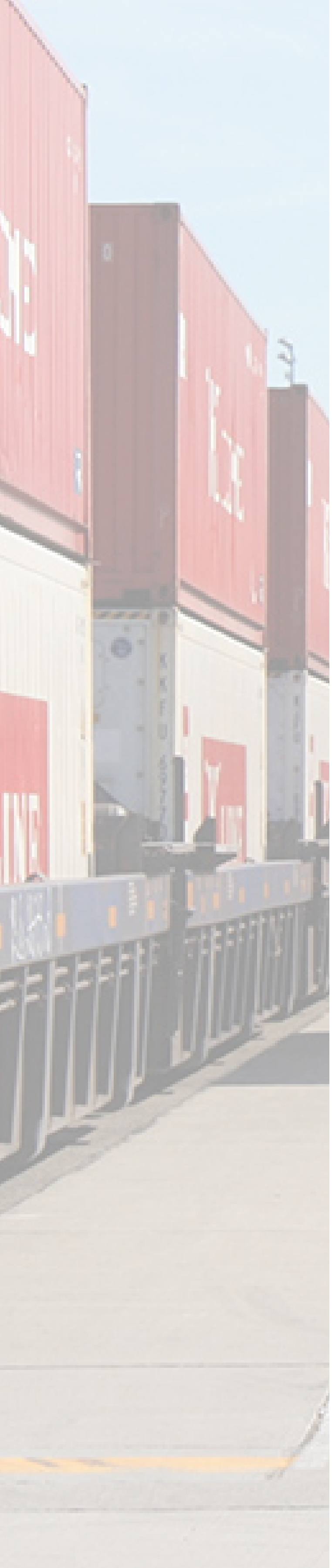


Figure 2:
Deployment of the diesel locomotive at carrier 1 - the thin red lines on the map indicate where the ocomotive traveled during the measurement period.

CO_2 and NO_x emissions

In spite of the fact that the locomotive is used outside the Rotterdam port area, it nevertheless has a shunting profile, characterized by a variable and limited engine load.

If we divide up the speed of travel as follows:

- Stationary (0 km/h);
- Shunting (10-40 km/h);
- Long-distance travel (>40 km/h);

we can note that the locomotive is stationary with its engine running for 50% of the time and is operating with limited power ('shunting') for 34% of the time. It is also apparent that the locomotive does not often travel at a constant speed and performs a great deal of braking and accelerating, which is in keeping with the profile of a shunting locomotive.

If we translate this deployment of the locomotive into CO_2 and NO_x emissions, the following picture emerges (Figure 3):

1. During the measurement period the locomotive was idling for 75% of the time. This means that the engine was running, but the locomotive was not accelerating, braking or traveling; in other words, it was stationary. Over the measurement period this means that the locomotive emitted an average of 35 grams of NO_x per kilogram of CO_2. This is comparable with a truck fitted with a Euro 0 engine (1990) and is 10 times higher than Euro V diesel trucks from 2010-2015.
2. During the measurement period the locomotive was in operation for 25% of the time, emitting an average of 12 grams of NO_x per kilogram of CO_2.

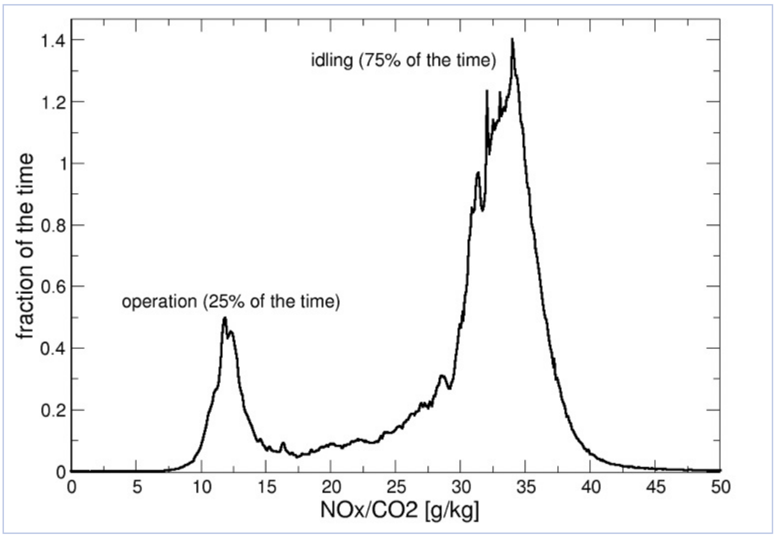


Figure 3:
The amount of NO_x per kilogram of CO_2 over time shows that this diesel locomotive has two different operating modes. For much of the time (the height and width of the peak) its emissions are 35 g NO_x/ kg CO_2. This situation is associated with idling and a low load. A smaller peak at 12 g NO_x/kg CO_2 represents the proportion of time when the engine is delivering high power. At this time NO_x emissions are lower in relative terms, but are likely to be higher in absolute terms.

Measurement 2

The second measurement was performed at Rotterdam Rail Feeding and the details of this measurement are as follows:

- Measurement period: 26 June 2017 to 16 September 2017 (82 days)
- Operating hours: over the period 820 engine hours were logged by SEMS, with an average of 9.5 hours per working day
- Type of locomotive: type BR203 manufactured by Alstom

Train deployment

Unlike the locomotive of carrier 1, the locomotive of carrier 2 does not travel beyond the Rotterdam port area or beyond Zevenaar on the Betuwe route.

Although this diesel locomotive also operates on the Betuwe route, it is mostly used for shunting activities in the Rotterdam port area. A train arriving from the hinterland is generally electrically powered. In a yard the locomotive is then switched, from electric to diesel. Once the diesel locomotive has been coupled to the train, the wagons are checked. At this point the diesel locomotive is idling to deliver air to the pneumatic installations, such as the wagon brakes. Following the check, the train continues its journey, generally towards a terminal, to deliver or collect the wagons' load (or a combination of the two). At this point the engine is running at a low speed, as little power is needed. If the train calls at another terminal to unload freight from or load freight onto the wagons, the large diesel locomotive idles again. Once the wagons have been loaded at the terminal, the driver checks the brakes and the locomotive idles to deliver air to the pneumatic installations. Once loading and unloading have been completed at the terminal, the train departs on full power towards the hinterland.

To reduce idling, Rotterdam Rail Feeding has fitted some diesel locomotives with a modernized auxiliary diesel engine on its own initiative. Together with a small electric compressor, this supplies the pneumatic installation without any need for the main engine to be running. Fitting such a system is extremely difficult due to the stringent approval requirements and the limited space available on the diesel locomotives. If a change is made to a diesel locomotive, according to RRF a range of studies must be conducted to ensure it does not affect the locomotive's safety and running characteristics.

CO_2 and NO_x emissions

If we translate this deployment of the locomotive into CO_2 and NO_x emissions, the following picture emerges:

1. During the measurement period the locomotive was idling for 84% of the time. Over the measurement period this means that the locomotive emitted an average of 24 grams of NO_x per kilogram of CO_2. This can be seen in Figure 4.
2. During the measurement period the locomotive was in operation for 16% of the time, emitting an average of 12 grams of NO_x per kilogram of CO_2. This is the left-hand peak in Figure 4.

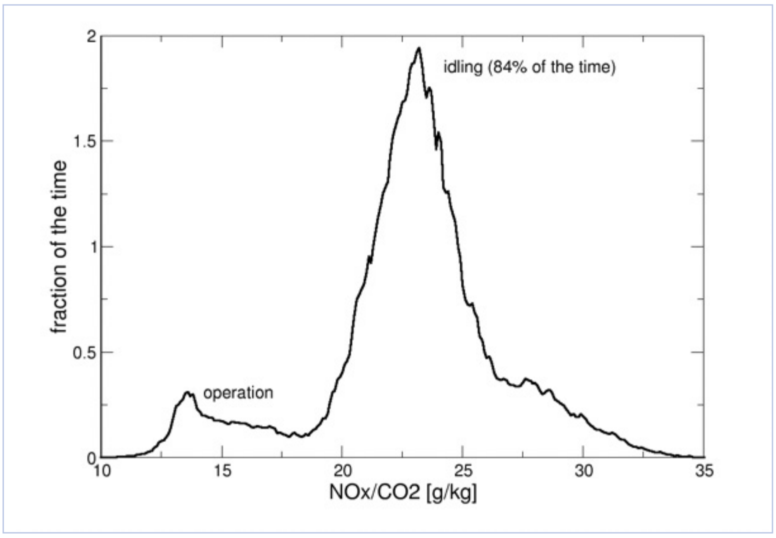


Figure 4: *This figure shows that the picture that emerges for the second diesel locomotive is comparable with that of the first. The majority of emissions are generated during idling. Figure 5 shows how these are distributed over different engine speeds.*

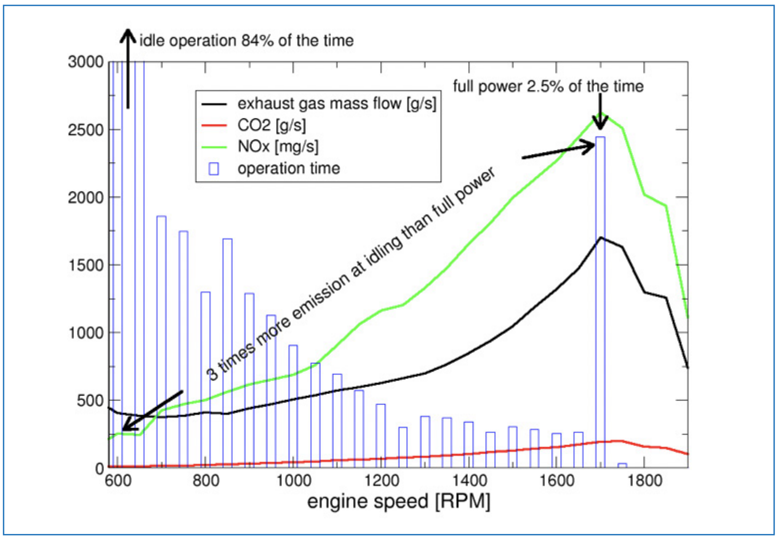


Figure 5: *The variation in NO_x and CO_2 emissions per second over the range of engine speeds, with the distribution of time shown in blue.*

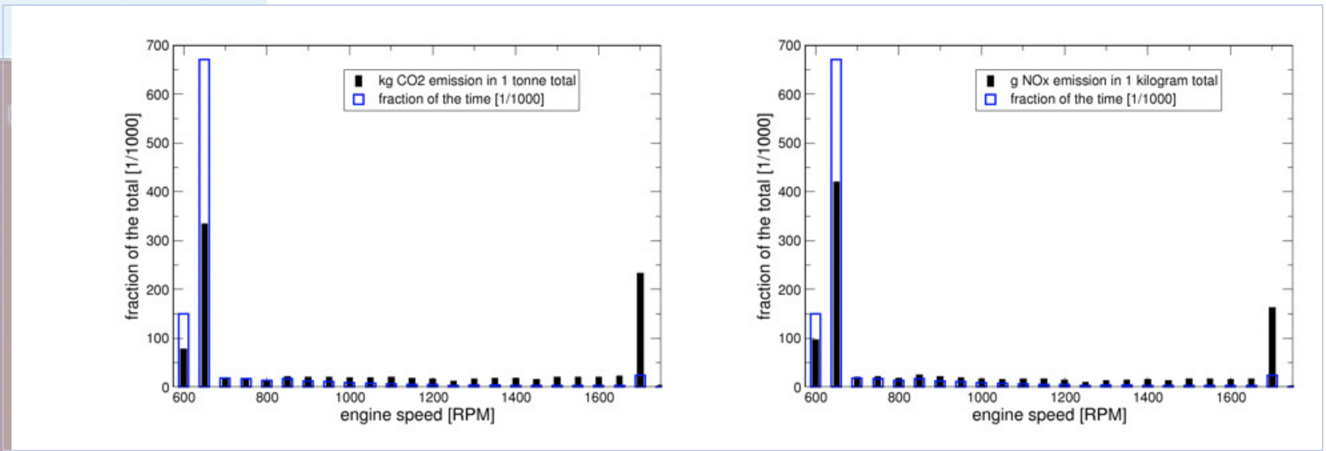
RESULTS OF MEASUREMENT

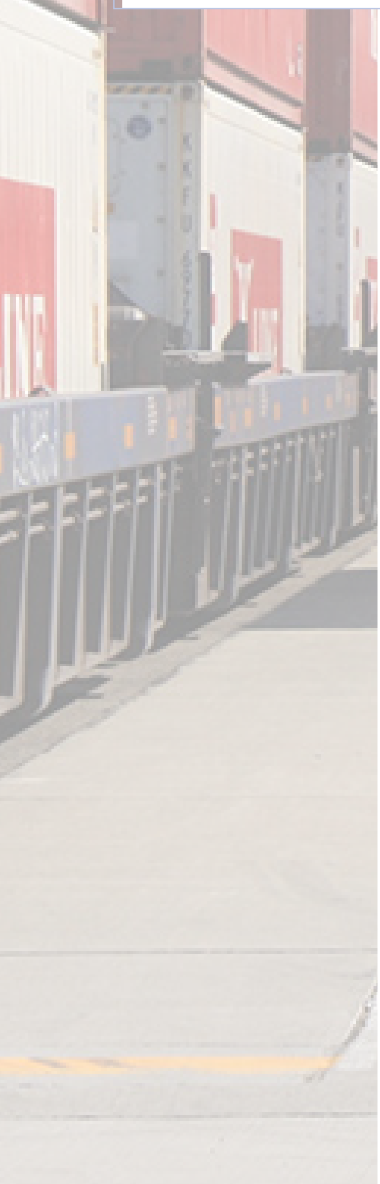
Figure 6:

The left-hand figure shows kilograms of CO_2 distributed over the various engine speeds per ton of CO_2. The corresponding situation for NO_x is presented in the right-hand figure. In the case of CO_2 a little under half of emissions are generated during idling and in the case of NO_x a little over half.

The operations performed by the second locomotive are comparable with those of the first: a great deal of time is spent idling and a limited time operating with a high load. During idling fuel consumption is lower, raising the question as to what extent idling contributes to total CO_2 and NO_x emissions. As sufficient data are available for the second diesel locomotive, this can actually be determined.

Figure 6 shows the total emissions of CO_2 (left) and NO_x (right) distributed on the basis of engine speed. A high column therefore means either that the engine was operated at this speed for a long period or that the emissions per second are high for this speed, or both. For clarity, the fraction of the time is indicated in the 'hollow' columns.





For most of the time the diesel locomotives are idling.
Fuel consumption is low, and consequently so are CO_2 emissions, but due to the large proportion of time it accounts for, idling is responsible for almost half of total fuel consumption and more than half of total NO_x emissions. Despite the fact that it accounts for just a small proportion of time, operation at the highest speed contributes around 30% to CO_2 emissions and around 20% to NO_x emissions.

The total CO_2 emissions of the second locomotive (over the entire period) are 60.7 tons. This corresponds to 22,300 liters of diesel, or 272 liters per day. The average CO_2 emissions per second are 20.6 grams, which is comparable with the CO_2 emissions of a truck and semi-trailer combination on a motorway. In terms of CO_2 emissions per day this diesel locomotive is therefore comparable with four truck and semi-trailer combinations under normal usage conditions. A different picture emerges in the area of NO_x emissions. In the road transport sector NO_x emissions are declining rapidly with the introduction of new legislation. A modern Euro VI truck and semi-trailer combination (constructed from 2015 onwards) has NO_x emissions of 0.5 g/kg CO_2. For the diesel locomotives in question, when deployed as described over the course of a year, the figure is a factor of 50 higher. In the area of NO_x emissions the emissions per year of one diesel locomotive are comparable with those of 200 truck and semi-trailer combinations. There are around 70,000 truck and semi-trailer combinations in the Netherlands.

Diesel sales for rail transport stand at around 1 PJ[4] per year. That corresponds to 23 million kg of diesel and 84 ktons of CO_2. If the diesel locomotives measured are indicative of the average NO_x emissions per kilogram of CO_2 (around 25 g NO_x/kg CO_2), the total per year is 2.1 kton NO_x. That tallies closely with the CBS's estimate of 1.8 kton NO_x for rail transport.

4.2 Results for the electric locomotive

Measurement 3

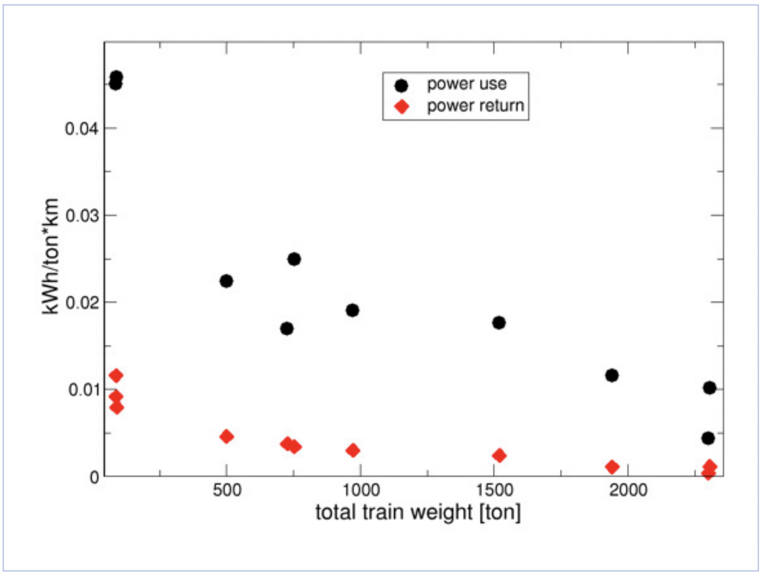
The third measurement was performed at carrier 1 and the details of this measurement are as follows:

- Measurement period: 29 November 2016 to 16 February 2017
- Type of locomotive: type BR189 manufactured by Siemens

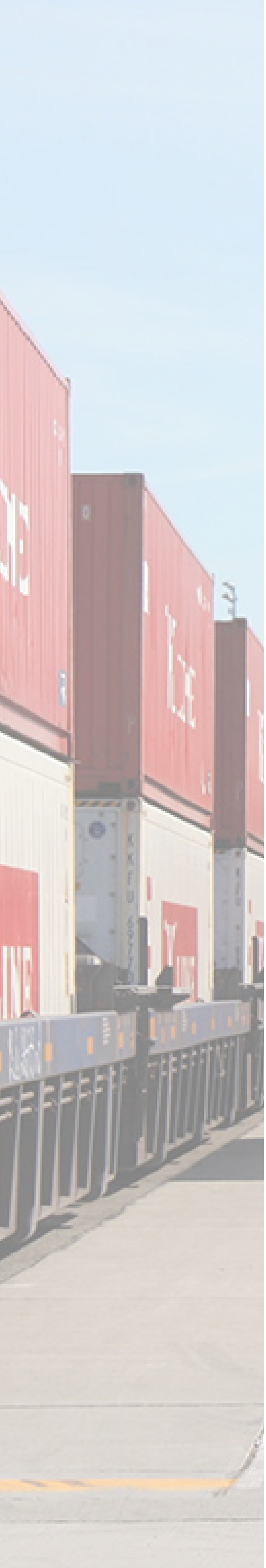
Train deployment

Carrier 1 uses the electric locomotive to transport freight between the Netherlands and Germany. The results are based on the train kilometers traveled in Germany.

It is generally assumed that electricity consumption (kWh) measured on the basis of a given weight transported over a given distance (ton-kilometers) is constant. That does not appear to be the case, however.
The length of the train has a major influence on the total electricity consumed. This is mainly due to the fact that longer trains pull more wagons, which means there is greater friction. resulting in a need for greater power (kW) and work (kWh).
The share of acceleration and braking in the total electricity consumed is not particularly large (5%-10%). This takes into account the fact that energy is fed back into the grid during braking.



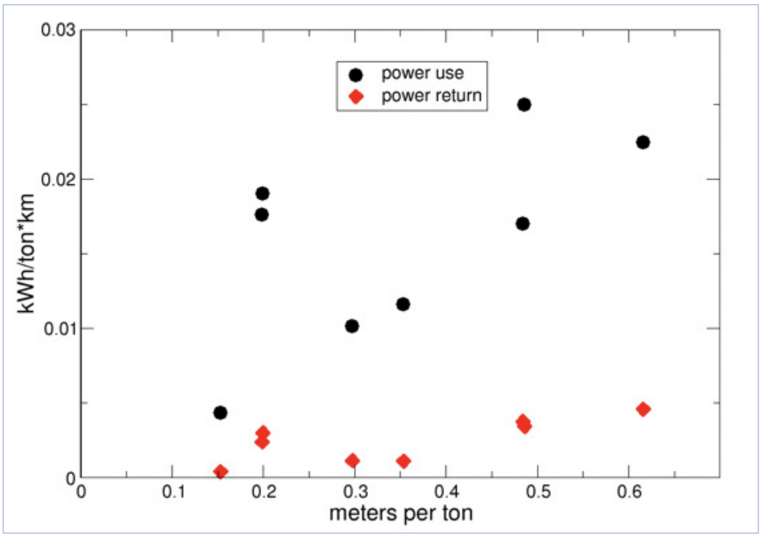
[4] *CBS, transport and mobility 2015.*



The optimum consumption of an electric train is 0.01 kWh/tkm, but there are also much higher consumption factors. The assumption that electric locomotives have a fixed energy consumption per ton-kilometer over long distances cannot be confirmed in this study. The variation in consumption is more than 100%, which is greater than for road transport.

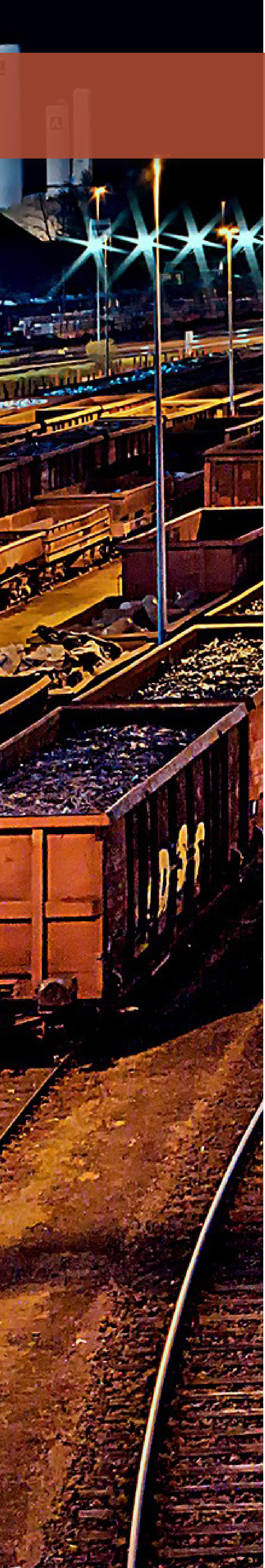
The assumption of a fixed kWh figure per ton-kilometer would mean that the points in the figures would be horizontal. In reality the difference between the highest and lowest values is a factor of 3.

The typical energy consumption of 0.02 kWh per tkm is, however, significantly lower than that of road transport. For a truck and semi-trailer combination the energy consumption is a factor of two higher. In the case of smaller vehicles the ratio is even less favorable.



The weight of the rolling stock relative to the load transported determines whether this figure applies in all concrete situations. For a truck the weight of the load is typically 60% or less of the total weight. Due to the heavy weight of rail wagons and the associated running resistance, rail transport is not associated with lower energy consumption in the case of lighter, large-volume, low-density loads.

CO_2 emissions vary according to the energy consumed, whether this is in the form of electricity or liquid fuel. In the future we expect a more immediate reduction in CO_2 emissions to come from the measures taken to make electricity production more sustainable.



5 Conclusion

General conclusion

It is not easy to link the CO_2 emissions resulting from a train journey to the transport requirement: the transport of a ton of freight over a fixed distance. That is mainly because a large portion of the CO_2 and NO_x emissions of diesel locomotives and of the electricity consumption of electric locomotives is not directly connected to the transport of the load. A significant proportion of the emissions of diesel locomotives are generated during idling and the electricity consumption of electric locomotives seems to depend more on the rolling stock hauled than on the load transported.

Main questions dealt with in the study

In the first instance this study aimed to focus on the further characterization of the CO_2 emissions of rail freight transport by taking the various sub-processes of a specific train journey into account. To date there had been an insufficient insight in this area.

In the end the decision was made to reformulate the research questions for three reasons:

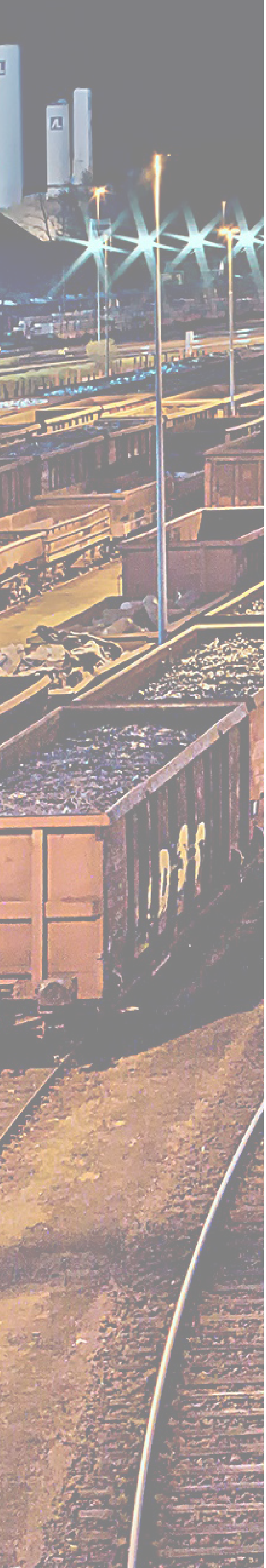
1. The results of the market survey revealed that the available data were not sufficient to allow the sub-processes to be analyzed
2. The locomotives measured are not always used or cannot always be used as planned, making it impossible to perform the continuous measurement of a specific train journey
3. Partly at the request of the participating carriers, and in consultation with Connekt, it was decided also to determine the NO_x emissions of diesel locomotives

The following questions were therefore answered in this study:

1. What are the CO_2 emissions of a diesel locomotive over a defined measurement period, taking into account the number of train kilometers traveled and the weight hauled by the diesel locomotive?
2. What are the NO_x emissions of a diesel locomotive over a defined measurement period, taking into account the number of train kilometers traveled and the weight hauled by the diesel locomotive?
3. What is the energy consumption (kWh) of an electric locomotive over a defined measurement period, taking into account the number of train kilometers traveled and the weight hauled by the electric locomotive?

Results of measurements 1 and 2 on the diesel locomotive

For both measurements we used the measurement tool SEMS, which allowed us to identify where the diesel locomotive was, how it was used and therefore what the load was on the engine, as well as what concentrations of CO_2 and NO_x were emitted as a direct consequence of this. For measurement 1 we were only able to measure concentrations of CO_2 and NO_x, as it was not possible to read out certain data from the engine software. In measurement 2 the correct engine software was present, which meant that, in addition to concentrations of CO_2 and NO_x, emissions of CO_2 and NO_x could also be determined.



CONCLUSION

The conclusions are as follows:

- In cases where a shunting profile[5] was expected (and planned), the diesel locomotive was also sometimes used outside the Rotterdam port area during both measurements.
- The diesel locomotive's engine is idling for between 75% and 84% of the time that it is running.
- Around half of CO_2 and NO_x emissions are generated during idling.
- The CO_2 emissions of a single diesel locomotive over the entire measurement period are 60.7 tons. The CO_2 emissions of a single diesel locomotive over the course of a year are comparable with those of four truck and semi-trailer combinations over the same period.
- The NO_x emissions over the course of a year are comparable with those of 200 modern Euro VI truck and semi-trailer combinations over the same period.

Assuming that there are 40 active diesel locomotives operating in the Netherlands, this means that 2,428 tons of CO_2 are emitted annually.

Emissions legislation for Non-Road Mobile Machinery (NRMM)

Non-Road Mobile Machinery (NRMM), which includes trains and inland vessels, but also excavators and generators, is subject to different emissions requirements than trucks. The emissions limits are less strict, but the test procedure is also more limited. Low and dynamic engine loads are hardly covered by the NRMM test procedures. The fact that emissions during idling are relatively high, and consequently make a significant contribution to the total NOx emissions of diesel locomotives, is probably linked to these restrictions in current NRMM legislation. Future NRMM legislation, referred to as'Stage V', should resolve these problems, although it is possible that engine idling will continue to be covered insufficiently in the legal requirements.

Results of measurement on electric train

- The typical energy consumption of an electric locomotive is 0.02 kWh per ton-kilometer (tkm). This figure is significantly below that of road transport. For a truck and semi-trailer combination the energy consumption is a factor of two higher.
- In the case of large-volume, low-density loads in particular, this advantage in terms of energy consumption is cancelled out by the heavy weight of rail wagons and the associated running resistance, which is greater than that of trucks.
- The length of the train, more so than its weight, appears to be a decisive factor as regards the energy consumption of the electric locomotive hauling the wagons. Train length has a greater effect than expected. It seems that the longer the train, the more axles there are and the greater the friction generated. This determines to a large extent the greater demand for power and greater electricity consumption for the same transported load in ton-kilometers. Reducing the axle friction of wagons therefore appears to be a key factor in reducing the energy consumption of electric locomotives.

[5] *This means that the diesel locomotive is used between yards and terminals in the Rotterdam port area*

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