Review of Dutch rail diesel emissions calculation methodology

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Content

Summary

Introduction and objective

The Task Force on Transportation is responsible for calculating the emissions of environmental pollutants from mobile sources in the Netherlands. One of the mobile sources is railways. The methodology for calculating the emissions for railways was for a large part updated last in 1993. Therefore, RIVM asked CE Delft to analyse the current methodology and make recommendations for future work.

The objective of this study is to:
- analyse energy consumption of railways, especially diesel consumption and the division between passenger trains and freight trains;
- assess the emission factors used and make recommendations for improvement.

Findings

From analysis, the following conclusions can be drawn:
- The share of passenger transport in diesel consumption in the current methodology (35%) seems to be too low, because of changes over the last decade in freight rail diesel energy consumption. While the use of diesel in freight transport decreased as a result of the use of the Betuweroute, the diesel use in passenger transport on regional lines increased. A better estimate would be around 55-60% share for passenger transport.
- The fleet of railcars has been completely renewed since the Dutch methodology has been determined, which is likely to have resulted in a reduction of emissions over time. This is not reflected in the current methodology.
- There is limited knowledge of diesel rail emission factors. Since the publication of the 2004/26 Directive, the number of studies published focussing on diesel rail emissions is limited. This implies that there is limited knowledge of the current real world situation.
- The Netherlands use an average rail diesel emission factor for NO_x of 77.5 g/kg fuel in the calculations reported to UNECE, while another value is reported in the background data. The new value, which stems from a TNO measurement, may well reflect the situation for freight transport. It is questionable, however if the new value is representative for railcars.
- While the emission factors used for freight transport might reflect the real world situation rather good, as recent measurements have been done and the fleet is old, the situation for passenger rail transport is quite different. The fleet is rather young and about half of the fleet meets the Tier IIIB standard, which requires diesel particulate filters and/or NO_x reducing after treatment technologies. Using a specific fuel consumption figure of 250 g/kWh (reflecting high share of idling), the PM emission factor would be 0.1 g/kg. Real world emissions may be higher, two or three times the emission factor that could be calculated on the basis of the standard. Still the gap with the emission factor currently used (3.0 g/kg) is large. Therefore, we advise to study the particulate emissions of the diesel passenger fleet in depth, or use the Tier 2 default values as proposed by the EEA guidebook. The same is true for NO_x emission factor. Based on the fleet composition, share of engine idling and the EU standards, there may be a gap between the emission factor used and the emissions of the young fleet of railcars.

- The Netherlands only take wear and tear emissions of abrasion of overhead lines, pantographs and carbon brushers into account, while literature suggest that wear and tear of brakes and track are the largest contributors to particle emissions.

Recommendations

Following the conclusions, these recommendations are made:
- Adapt the distribution of rail diesel fuel consumption over passenger and freight transport. The 35% share that is allocated to passenger should be raised to a value off 55-60% as a first indication. It should be noted, however, that regional lines are being electrified (Maaslijn, Zwolle-Kampen, Landgraaf-Herzogenrath and others) leading to new shares.
- Consider performing emission measurements on diesel railcars — like for freight locomotives, to update the applied emission factors. If performing measurements is deemed too costly, a second best step is application of the recommended values by the EEA guidebook (PM and NO_x).
- Consider the development of a Tier 3 approach, by outweighing the costs and benefits of gathering more detailed information on the structure of the fleet and lifetime dependent emission factors. As part of this consideration, a consultation amongst active neighbouring countries (Germany, Switzerland) on their approach, might be a first step.

1 Introduction

1.1 Background

The Netherlands Pollutant Release and Transfer Register (PRTR) is the national database for the sectoral monitoring of emissions to air, water and soil of pollutants and greenhouse gases. The database was set up to support national environmental policy, as well as to meet the requirements of the National Emission Ceilings (EU), the CLRTAP, the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (National System). These policies cover the constant updating of the PRTR, the process of data collection, processing and registration, and the reporting of emission data for some 350 compounds.

An important goal of PRTR is to ensure the quality of the emission estimates in the database. It is good practice to implement quality assurance, quality control and verification procedures in the development of national emission inventories to accomplish this goal, to guarantee transparency, consistency, comparability, completeness and accuracy of national emission inventories.

The Task Force on Transportation of the PRTR is responsible for calculating the emissions of environmental pollutants from mobile sources in the Netherlands. One of the mobile sources is railways. The methodology for calculating the emissions for railways was for a large part updated last in 1993. Therefore, RIVM has asked CE Delft to perform an in-depth review of the methodology for calculating rail transport emissions in the Netherlands (PRTR, 2019).

1.2 Objectives

The objective of this study is to:
- assess the energy consumption of railways, especially diesel consumption and the division between passenger trains and freight trains;
- assess the emission factors used.

In this review we:
- check the total diesel and electricity consumption with the original data sources and verify if there are methodological improvements necessary;
- analyse the assumptions for the division of diesel consumption between passenger and freight trains;
- cross check the implied emission factors of NO_x and PM with that of France, Belgium, Germany and United Kingdom;
- review available literature;
- draw conclusions and recommendations about the current methodology and options for optimization.

1.3 Current methodology

The current methodology uses diesel fuel consumption reported by VIVENS (tonnes) and an expert judgement for the distribution of division of diesel fuel consumption over freight and passenger transport (see Figure 2). The diesel fuel consumption is subsequently multiplied with emission factors (kg/ton) specified for passenger and goods transport. The emission factors currently used are included in Table 1 in Chapter 3.

1.4 Reading guide

Chapter 2 focuses on the total diesel consumption, Chapter 3 discusses the emission factors used and in Chapter 4 conclusions and recommendations are made.

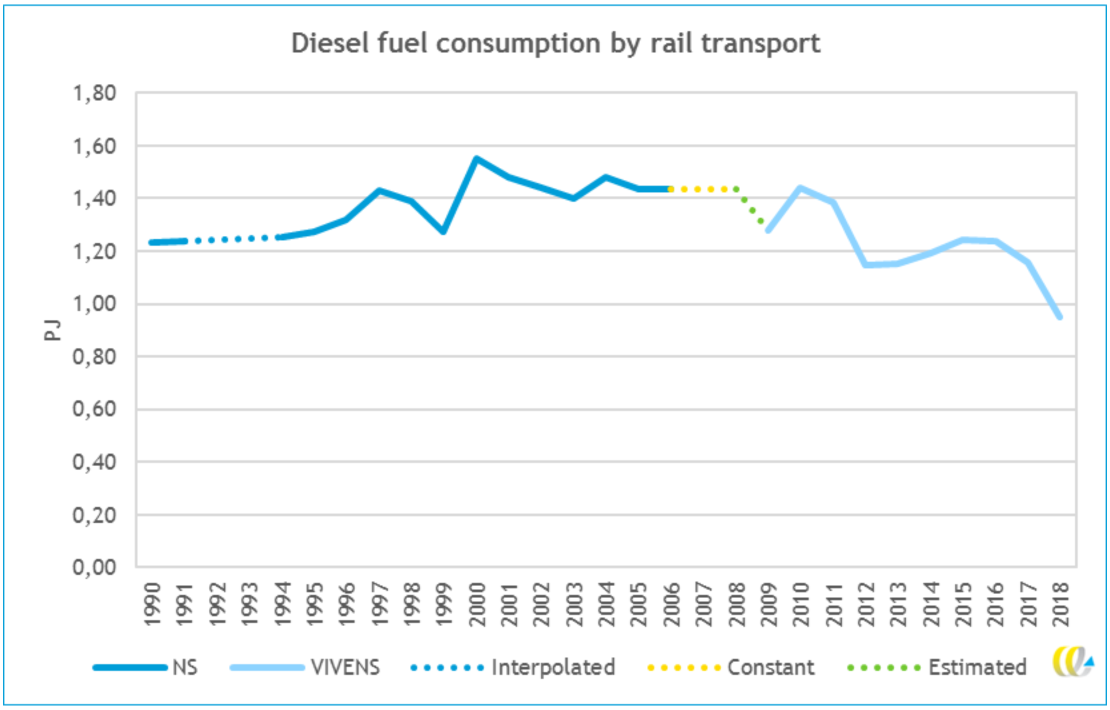
2 Energy consumption of rail transport in the Netherlands

Energy consumption of railways consists of diesel and electricity consumption. The data in the PRTR is derived from the national Energy Balance. In this chapter we review the original sources of the data and compare them with other sources that we found.

2.1 Diesel consumption of rail transport

Fuel deliveries to railways are derived from the Energy Balance (Rijksoverheid, 2019). Since 2010, the CBS derives these data from VIVENS, a cooperation of rail transport companies that purchases diesel fuel for the entire railway sector in the Netherlands. Before 2010, diesel fuel deliveries to the railway sector were obtained from Dutch Railways, which was responsible for the purchase of diesel fuel for the entire railway sector in the Netherlands until 2009. The diesel consumption for rail transport from 1990 until 2018 is displayed in Figure 1. Until 2009, data was not available for all years and therefore CBS made estimates and interpolations to determine the diesel consumptions for those years. For 2006-2008 the diesel consumption was assumed to be constant. In 2009 an estimate of 15% reduction for cargo was used for rail diesel consumption, passenger rail was assumed to remain constant.

Figure 1 - Diesel consumption for rail transport (including underlying data sources or assumptions)

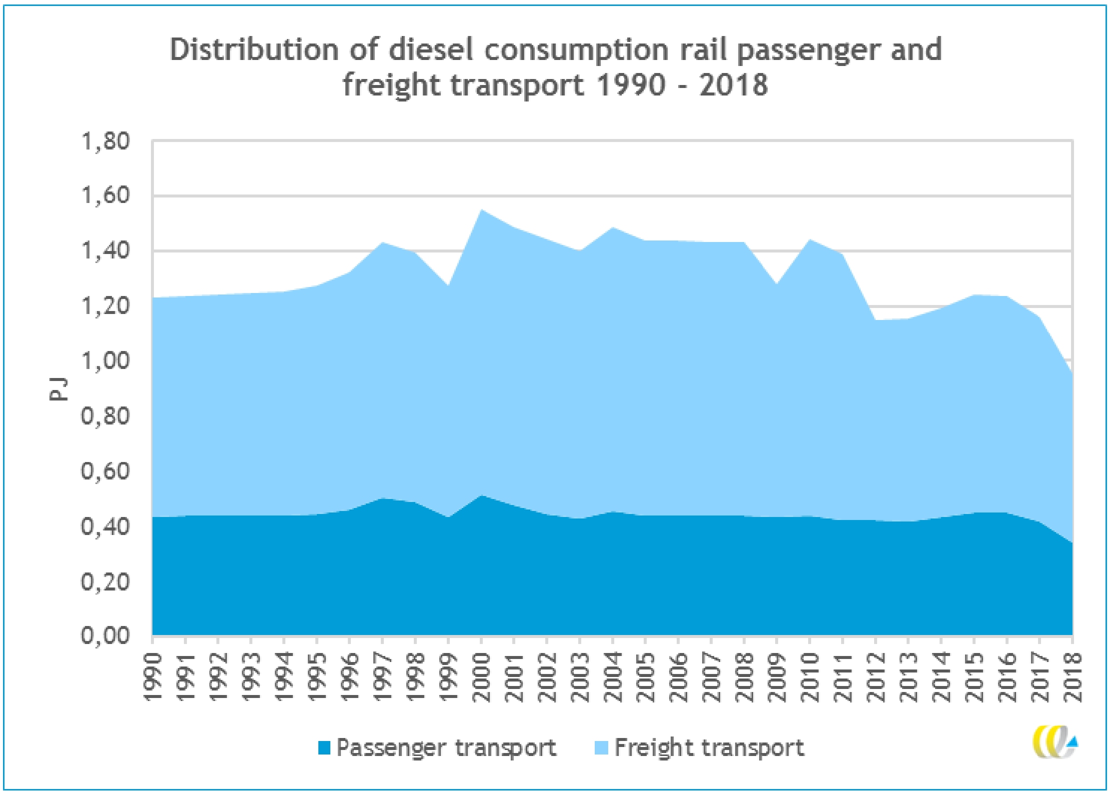


Source: (CBS, 2020).

2.2 Share of diesel fuel consumption for rail and passenger trains

The percentage of diesel consumption by passenger trains has been around 30-35% of total diesel consumption of rail transport in the period 1990-2003. The share of freight trains was 65-70%. The data was derived from NS, who provided both their own diesel consumption and those of third parties to CBS. After 2003 (with a share of 30% for passenger trains), no new data was collected for the specific distribution between passenger and freight trains. The share for passenger trains in total diesel fuel consumption for rail transport was assumed constant at 30%.
For 2009 the fuel consumption of freight transport was estimated to have dropped 15%. With the assumption that fuel consumption of passenger transport remained constant, the share of passenger transport in the diesel consumption increased to 35%. This has been assumed constant for 2013-2018.

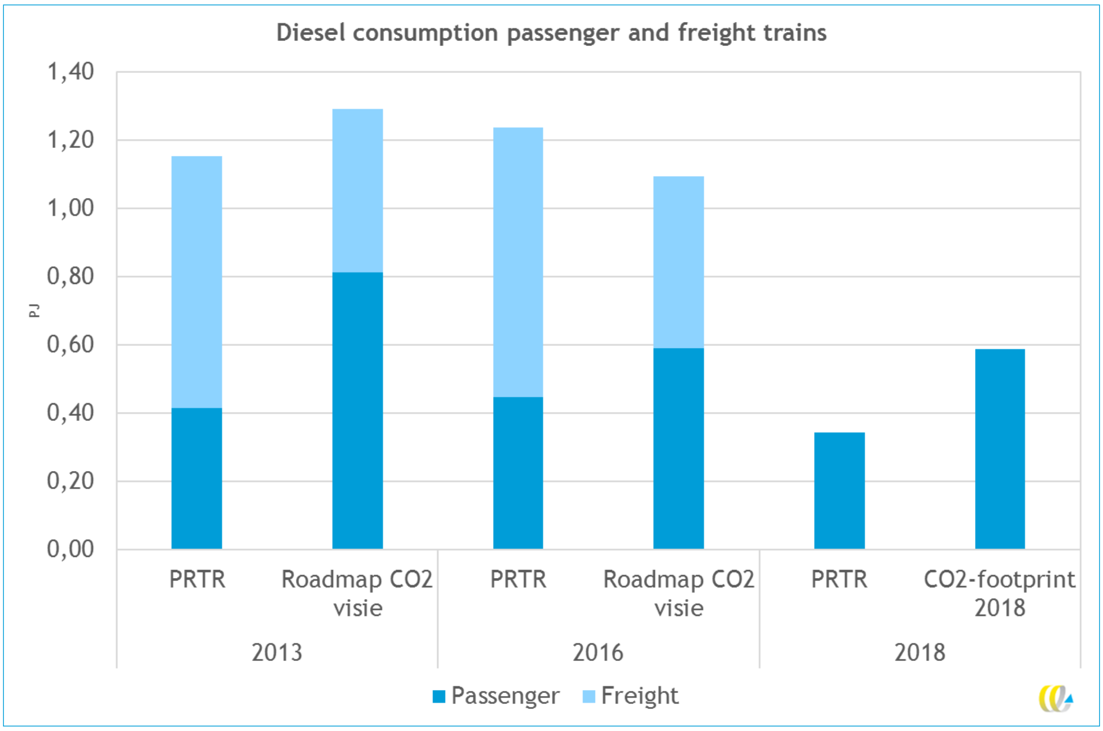
Figure 2 – Distribution of diesel consumption over rail passenger and freight transport



Source (Klein, et al., 2019).

However, some recent carbon footprinting studies show that the share of diesel consumption in rail freight transport might have decreased further in the last decade. CE Delft combined fuel purchases from Arriva rail with passenger volumes of Arriva and other regional rail transport companies to estimate diesel consumption of passenger trains in 2013 and 2016. In Ricardo (2019) data from up-to-date scheduled timetables and the energy consumption (usually declaration by transporters) was used to yield the energy consumption for passenger transport in 2018. Although not as precise as fuel sales, this gives an indication for the share of passenger train fuel consumption relative to cargo. From these sources, a share of 55-60% is deemed more plausible.

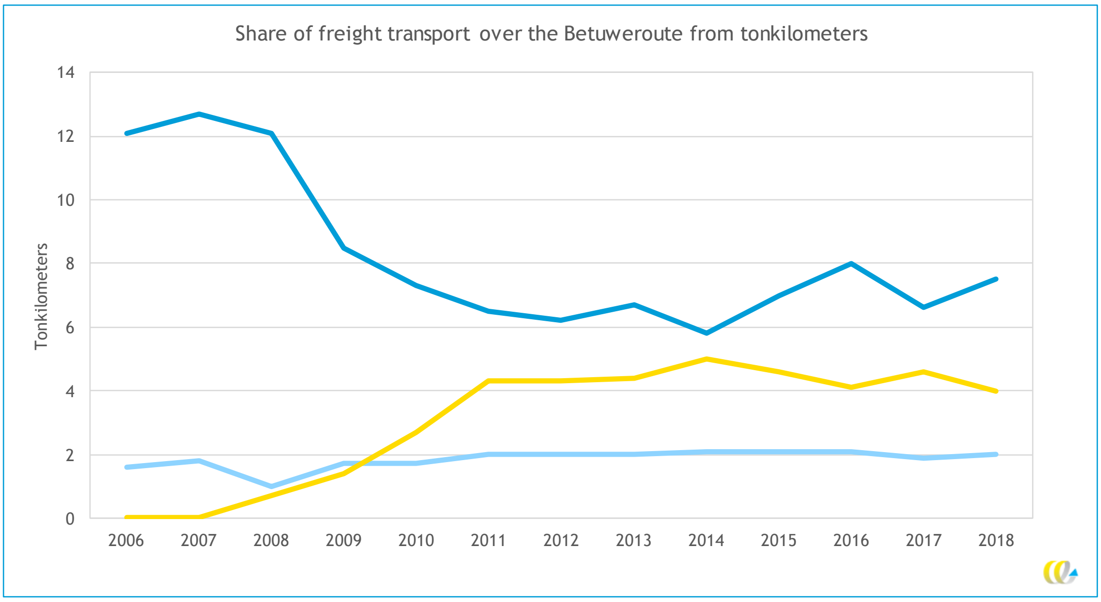
Figure 3 - Diesel consumption of diesel and passenger trains



Source: CE Delft (2018) ; Ricardo (2019).

According to (KiM, 2017) around 80% of freight transport along the Betuweroute is electric. At the same time, the share of total rail freight transported over the Betuweroute has increased over time, as is displayed in Figure 4. Therefore, it would make sense to assume that in the period 2008-2018 the share of electric trains in total rail freight transport has increased significantly. That would cause diesel consumption of rail freight to decrease.

Figure 4 - Total rail freight transport that is transported over the Betuweroute



Source: (ProRail, 2019).

Recent numbers from (ProRail, 2020) confirm that the share of electrical trains on the Betuweroute has indeed increased over the years. The share of electrical trains on the Betuweroute is 95%, which is even higher than the 80% mentioned by (KiM, 2017).
From Table 1 it also becomes clear that the share of electrical tonkilometres is higher than the share of diesel tonkilometres in the Netherlands. It is worth mentioning the Havenspoorlijn includes shunting, which is always executed by diesel locomotives.

Table 1 - Share of diesel and electric in freight transport in the Netherlands in 2018

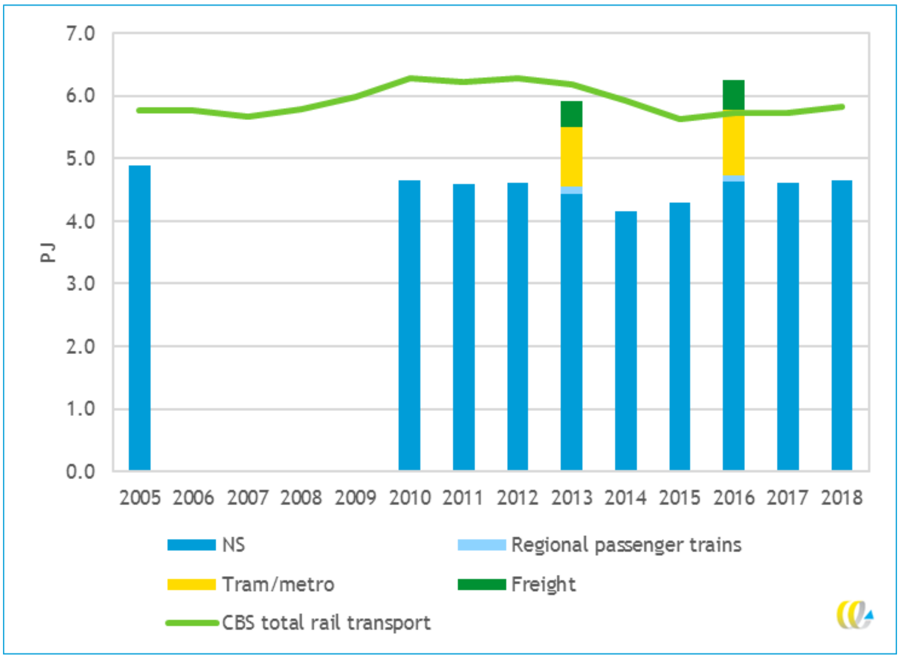
	Tonkilometres (billions) (ProRail, 2019)	Share electrical (ProRail, 2020)	Share diesel (ProRail, 2020)	Tonkilometres electrical (calculated)	Tonkilometres diesel (calculated)
Betuweroute	4,0	95%	5%	3,8	0,2
Havenspoorlijn	2,0	67%	33%	1,3	0,7
Gemengd net	7,5	50-75%	50-25%	3,8-5,6	3,8-1,9
Total	**13,5**	**66-80%**	**34-20%**	**8,9-10,8**	**4,6-2,7**

Sources: (ProRail, 2019; 2020).

2.3 Electricity consumption

NS reports their total electricity consumption in their annual report. This is displayed in Figure 5, and the total electricity consumption by rail transport seems to follow this trend. For 2013 and 2016, CE Delft (2018) gives the total electricity consumption for rail separately for NS, other regional passenger trains, tram/metro and freight transport.
The figure for freight is a rough estimation, based on information of two individual freight operators. The figures for tram/metro are based on annual reports of HTM (the Hague), RET (Rotterdam) and GVB (Amsterdam). For 2013, the total figure according to CBS is higher than reported by CE Delft (2018).

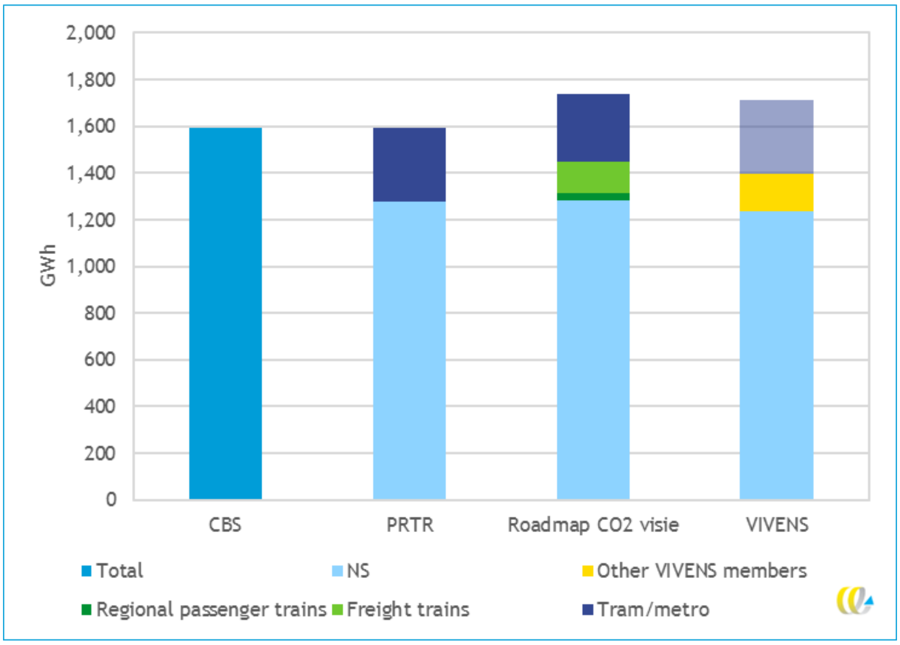
Figure 5 - Rail energy consumption



Source: NS; CE Delft (2018).

For 2016, the electricity consumption figure for rail is lower than the consumption by NS + other VIVENS members (which is a mix of regional passenger transport operators and freight operators).

Figure 6 – Electricity consumption by railway (2016)



Note: The transparent part of the VIVENS bar reflects tram/metro data reported under Roadmap CO_2-visie. (CE Delft, 2018).

The 2016 figure from CE Delft (2018) consists of estimates for the separate consumptions of NS (1,284 GWh), freight operators (134 GWh, based on extrapolation of electricity consumption of two operators), regional passenger train operators (32 GWh based on the energy savings report of one operator) and tram/metro (GVB 45 GWh tram + 77 GWh metro, HTM 64 GWh, RET 24 GWh tram + 73 GWh metro, together: 287 GWh).

2.4 Conclusions

The following conclusions can be drawn:

- Comparison with other sources, indicates that the overall electricity consumption according to CBS/PRTR is slightly underestimated in 2016.
- Vivens is currently used as a source for diesel consumption, The Vivens data include the diesel conmsumption of most operators. It should be checked if diesel consumption from regional operators, like Arriva, Synthus and Breng is included.
- The share of passenger transport in diesel consumption seems to be too low, because of changes over the last decade in freight rail diesel energy consumption. While the performance of freight transport decreased as a result of the use of the Betuweroute, the performance of passenger transport on regional lines increased[1]. A better estimate would be around 55-60% share for passenger transport according to other sources (CE Delft (2018) ; Ricardo (2019), see Figure 3).

[1] See FMN-note 'De ontwikkeling van regionaal spoor in Nederland'.

3 Emission factors for rail transport

3.1 Introduction

In this chapter, the emission factors used for calculating the pollutant emissions of rail diesel transport are reviewed. Dutch emission factors are compared with the international practise (Section 3.3 and 3.4) and available literature (Section 3.5). In addition and overview of the European legislation is included. The chapter ends with conclusions.

Table 2 shows the emissions factors used. The source for emission factors used in (Klein, et al., 2019) for rail is now 27 years old.

Table 2 - Emission factors for rail traffic (grams/kg of fuel)

	Passenger (Klein, et al., 2019)	**Freight** (Klein, et al., 2019)	**Tier 1** (EEA, 2019)
CO	15.0	6.0	10,7
VOC (combustion)	5.0	1.4	4,7
NO_x	35 (77,5)	68 (77,5)	52,4
PM_{10} (combustion)	3.0	1.0	1,4
NH_3	0.010	0.010	0,007

TNO (2017) has studied the NO_x emissions of diesel rail locomotives. On the basis of two representative locomotives, it was concluded that the NO_x emission factor for freight transport should be higher. The new figure is 77.5 g/kg for rail transport as a whole, this is the number between brackets in Table 2. This figure is not yet reported by PRTR, but has been used in the calculations, as implied emission factor calculation illustrates (Section 3.4).

3.2 EU legislation

In the European Commission White Paper of 28 March 2011 'Roadmap to a Single European Transport Area — Towards a competitive and resource efficient transport system', railways are mentioned to play a significant role in achieving climate goals.

Emissions of European railway engines' are regulated by the non-road mobile machinery (NRMM) directives. Emission limits for diesel engines are described in Stage I to V regulations. However, railways were excluded from Stage I, II and IV and Stage V will not apply to railways until 2021. In Table 3 an overview is presented of the five stages and its applicability to railways (EU, 2004).

Table 3 - Introduction Stage I to V regulations for diesel engines

	Effective from	Engine range (kW)	Includes railcars?	Includes locomotives?	Directive
Stage I	1999	37-560	No	No	97/68/EC
	2004	18-560	No	No	2002/88/EC
Stage II	2001	37-560	No	No	97/68/EC
	2004	18-560	No	No	2002/88/EC
Stage IIIA	2006	19-560	Yes	Yes	2004/26/EC
Stage IIIB	2011	37-560	Yes	Yes	2004/26/EC
Stage IV	2014	56-560	No	No	2004/26/EC
Stage V	2021	0 >	Yes	Yes	2018/1628

Long-term railway projects require heavy investments. Therefore, engines in projects which were launched before the application of 2018/1628 should be exempted from this regulation if the project is at an advanced stage of development.

Table 4 displays emissions in different stages per category:
- stage IIIA and IIIB standards apply to engines above 130 kW for propulsion of railroad locomotives (R, RL and RH) and railcars (RC);
- stage V standards apply to engines of any power for the propulsion of rail locomotives (RLL) and railcars (RLR).

Table 4 - Emissions in Stage IIIA, IIIB and V for railways

Category	Net Power	Date	CO	HC	HC + NO_x	NO_x	PM	PN
	(kW)		(g/kWh)					(1/kWh)
Stage IIIA								
RC A	P > 130	2006	3.5	-	4.0	-	0.2	
RL A	130 ≤ P ≤ 560	2007	3.5	-	4.0	-	0.2	
RH A	P > 560	2009	3.5	0.5*	-	6.0*	0.2	
Stage IIIB								
RC B	P > 130	2012	3.5	0.19	-	2.0	0.025	
R B	P > 130	2012	3.5	-	4.0	-	0.025	
Stage V								
RLL-v/c-1 (Locomotives)	P > 0	2021	3.5	-	4.0	-	0.025	
RLR-v/c-1 (Railcars)	P > 0	2021	3.5	0.19	-	2.0	0.015	1×10^{12}

* HC = 0.4 g/kWh and NO_x = 7.4 g/kWh for engines of P > 2,000 kW and D > 5 litres/cylinder.
Source: (Dieselnet, n.d.; TransportPolicy.net, [2018]).

3.3 EEA Emission Inventory Guidebook

The objective of the European Environment Agency (EEA) Emission Inventory Guidebook is to help countries in making and reporting proper emission calculations in the context of UNECE Convention on Long-Range Transboundary Air Pollution, which amongst other require countries to report emissions in the European Monitoring and Evaluation Programme (EMEP) (EEA, 2019).

Emissions of railways are described in Chapter 1.A.3.c of the 2019 version of the EMEP/EEA Air Pollutant Emission Inventory Guidebook. Within this chapter, three types of locomotives are distinguished (EEA, 2019):
1. Diesel locomotives.
2. Electric locomotives.
3. Steam locomotives.
Diesel and electric locomotives are used for freight and passenger transport. In this review only diesel locomotives will be discussed.

The principal emissions produced by railways are: SO_x, NO_x, PM (including black carbon), and to a lesser extent CO, NMVOCs and some metals. In this review only the NEC emissions will be considered.

Diesel trains

Diesel trains either use a diesel hydraulic engine for propulsion or a diesel-electric engine for traction. In the latter case, the train or locomotive is equipped with an electric motor and an on-board generator for electricity production. Since 2011, only diesel with a maximum of 10 ppm sulphur (road diesel) is allowed in the Netherlands.

In Table 5 the properties of the three categories of diesel trains are listed.

Table 5 - Types of diesel propulsion units

Category	Usage	Power output range of engine (kW)	EEA guidebook fuel consumption factor (kg/h) (Tier 2)
Shunting locomotive	Shunting freight wagons	200-2,000	90.9
Railcar	Short distance traction (passenger, urban/suburban traffic)	150-1,000	53.6
Line-haul locomotive	Long distance traction freight and passengers	400-4,000	219

The guidebook contains various emission calculation methods, ranging from generic (Tier 1) to situation specific (Tier 3). The differences between Tier 1, 2 and 3 are displayed in Table 6.

Table 6 - Description of Tier 1, Tier 2 and Tier 3

	Measure of activity	Method/Assumptions	Required information
Tier 1	Fuel sales	– No distinction between different types of locomotives – An average value from the guidebook may be used to determine emissions	Distinction gas oil and diesel: – Only required for calculation of SO_2 emissions – All other emission factors are equal for both fuels
Tier 2	Fuel sales	– Method differentiates between line haul, shunting locomotives and rail cars – For each category values are described in the guidebook	– Numbers of locomotives and average fuelling – Fuel consumption factors may be applied if information is unavailable

	Measure of activity	Method/Assumptions	Required information
Tier 3	Number of locomotives times average number of hours used	– Assuming average locomotive emissions characteristics for individual groups locomotives (e.g. lifetime) – In-depth calculations are needed on groups of locomotives to determine emissions – No emission factors provided in the guidebook	Required information: – Fuel consumption – Source population (age; power range) – Activity data for operations at group level

Source (EEA, 2019).

Emission factors defined by Tier 1 and 2 method

Different tables for emissions are presented in the guidebook within the various methods:

- Tier 1: average for emission factors per pollutant are presented for all locomotives in Table 3.1 of the guidebook.
- Tier 2: average emission factors per pollutant are displayed in Table 3.2 to 3.4 in the guidebook for:
  - line-haul locomotives;
  - shunting locomotives;
  - railcars.

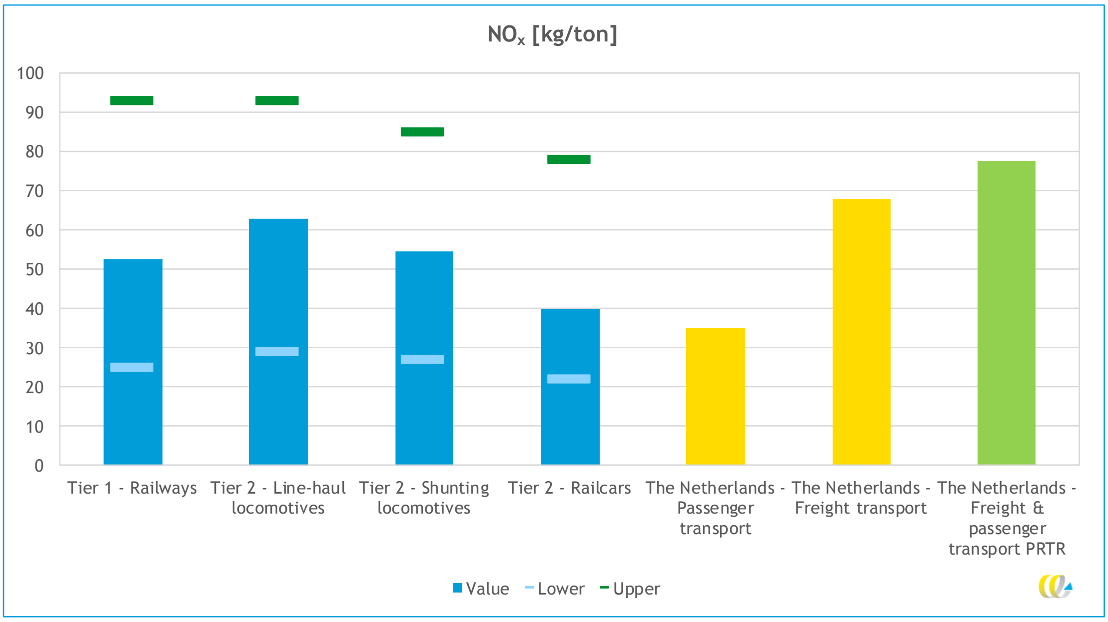
  Additionally, Tier 2 requires information on fuel consumption statistics per locomotive type in order to apply the different emissions. When this information is not available, the fuel consumption factor from Table 5 of this review may be adopted.
- Tier 3: emissions must be calculated from detailed information on locomotives and activity. The guidebook does not contain the any information for use.

The guidebook suggests that If detailed information is available, then use this data as much as possible. The updated guidebook uses data from various sources:

- Tier 1 uses the aggregated Tier 2 method and uses values from the 2006 version of the guidebook.
- Tier 2 uses (Halder & Löchter, 2005, p. 54) as a basis for the emission factors. The emission factor for NH_3 is adopted form the Exhaust Emissions from Road Transport from the guidebook (EEA, 2019, p. Chapter 1.A.3.b.iii).
- Tier 3 uses (Halder & Löchter, 2005, p. 54) and (Boulter & McCrae, 2007).

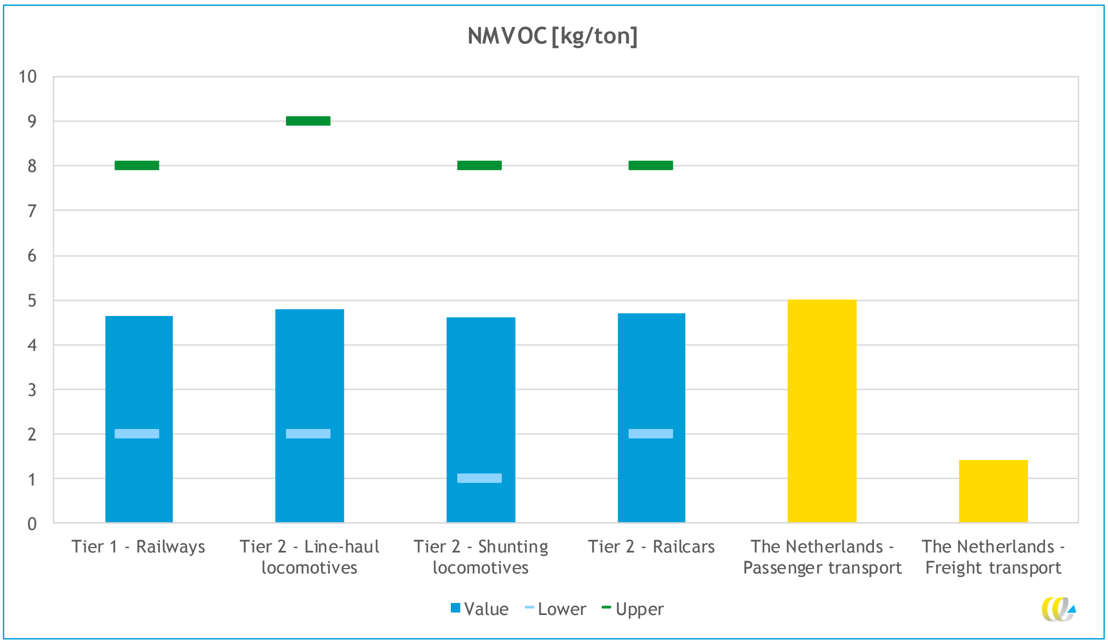
As illustrated before, the Netherlands apply the Tier 2 method. Hereafter, we show the emission factors for the various Tier methods from the guidebook in comparison to the values used for emission calculation in the Netherlands, which are presented in Table 2. In addition, the lower and upper boundary values from the Tier 1 and Tier 2 methods are displayed. These lower and upper boundary values are the 95% confidence interval for these emissions. The emissions are displayed in Figure 7 to Figure 12 and in Table 7.

Figure 7 - NO_x emission factors for Tier 1, Tier 2 and the Netherlands



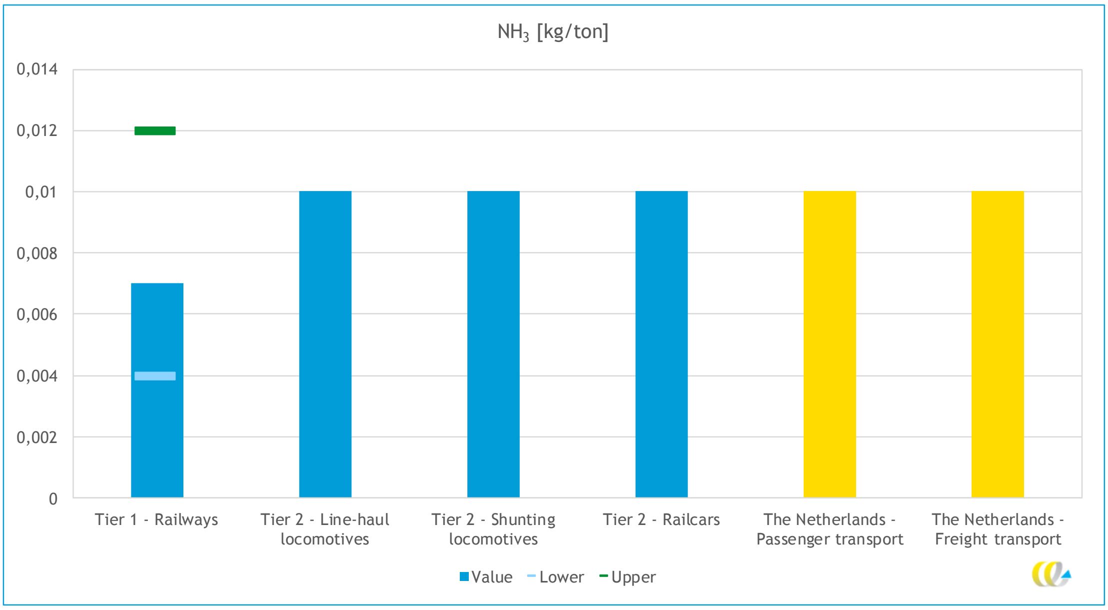
The NO_x emission factors for diesel rail passenger transport in the Netherlands are below the Tier 1 and Tier 2 values. However, the emission factors for rail freight transport are relatively high and the new value from PRTR (green bar in Figure 7) is close to the Tier 1 and 2 upper values.

Figure 8 - NMVOC emission factors for Tier 1, Tier 2 and the Netherlands



The NMVOC rail diesel emission factors for passenger transport in the Netherlands are comparable to the Tier 1 and 2 values in Figure 8. The NMVOC emission factor for freight transport is signifantly lower than the other values and is comparable to the lower value in Tier 2 – Shunting locomotives.

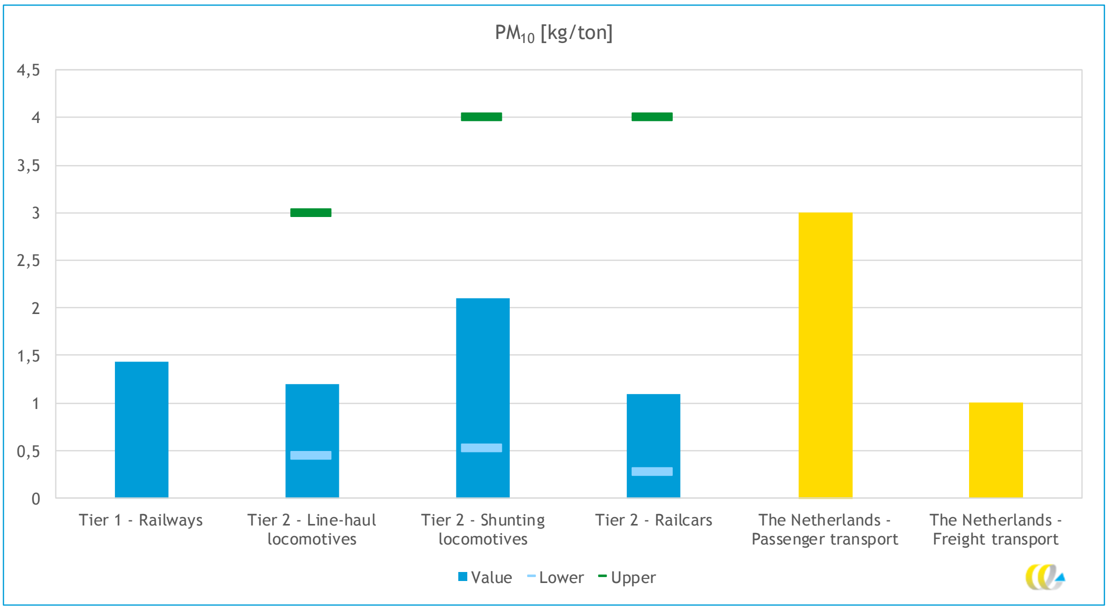
Figure 9 – NH_3 emission factors for Tier 1, Tier 2 and the Netherlands



Note: Upper and lower values are not shown consistently, as they do not represent a 95% confidence interval.

Figure 9 shows the emission factors for NH_3. The Dutch values do not significanlty deviate from the Tier 1 and 2 emission factors.

Figure 10 – PM_{10} emission factors for Tier 1, Tier 2 and the Netherlands (exhaust)

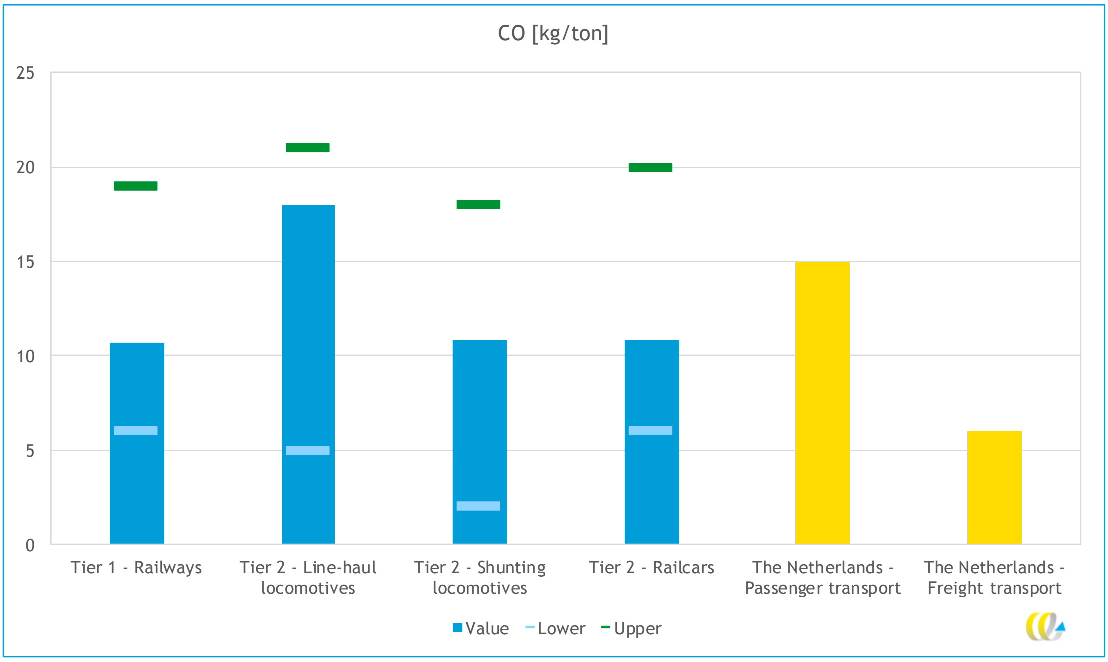


Note: Upper and lower values are not shown consistently, as they do not represent a 95% confidence interval.

The values for PM_{10} emission factor used by the Netherlands are relatively high for passenger transport, and low for freight transport, if compared to the Tier 1 and Tier 2 emission factors.

The $PM_{2.5}$ emisisons are strongly comparable to Figure 10, only the values are different. $PM_{2,5}$ is derived from PM_{10} by multiplying PM_{10} with 95%. This method is both used in the guidebook as in the Netherlands.

Figure 11 - CO emissions Tier 1, Tier 2 and the Netherlands



For CO emissions the same conclusion can be drawn as for PM: passenger transport emissions — that should be compared to railcars — are relatively high, while freight trains emissions are relatively low.

For the Tier 1 method the guidebook presents a formula to determine the SO_2 emissions for all locomotives. This same method may be applied in Tier 2. The SO_2 emissions are the same in the Netherlands. However, SO_2 emissions are anually adjusted on the sulphur content in diesel fuel.

Table 7 - SO_2 emissions in EEA guidebook and in the Netherlands

	Guidebook Tier 1		The Netherlands	
	Sulphur content in the fuel (% by the mass)	SO_2 (kg/ton)	Sulphur content in the fuel (% by the mass)	SO_2 (kg/ton)
Gas oil	0.1	0.2	0.1	0.2
Diesel	0.005	0.01	0.005	0.01

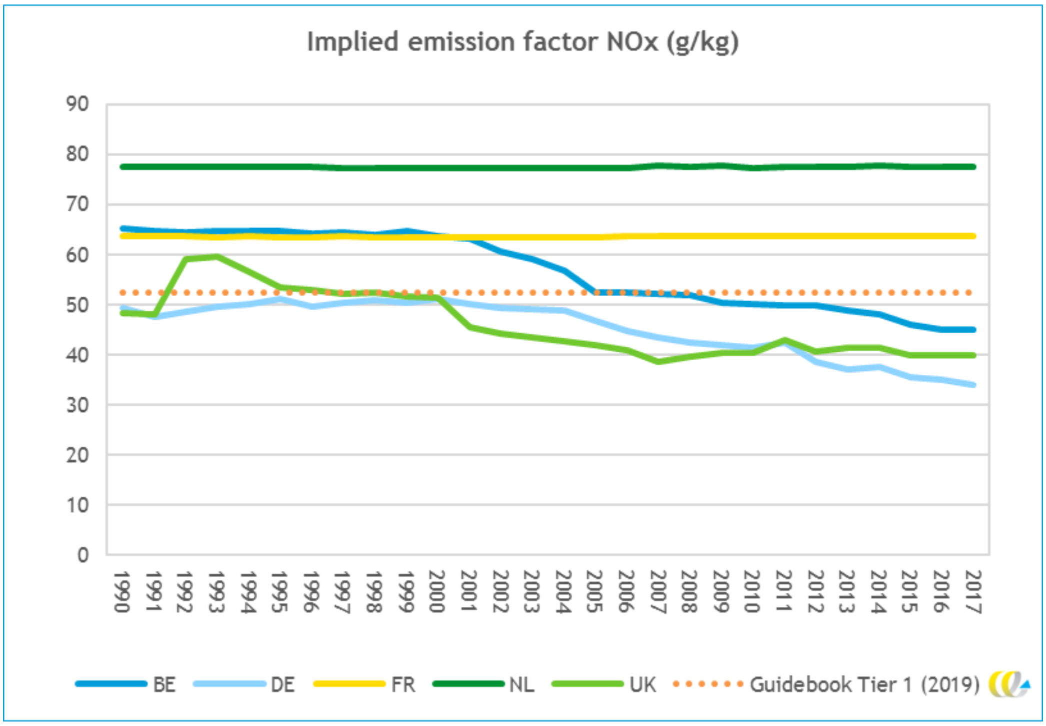
3.4 International comparison of implied emission factors

In order to better understand state-of-the art emission factors used, we compared the implied emission factors[2] (IEF) as reported under the UNECE Convention on Long-Range Transboundary Air Pollution. Hereafter, we show the trends in IEFs for various countries, Tier 1 of the guidebook and reflect on the Dutch IEFs compared to other countries for the main pollutants.

France and the Netherlands tend to use constant factors throughout the time period for emission calculation of the main pollutants (NO_x, NH_3, NMVOS). For $PM_{2.5}$ the Netherlands is the only country with a more or less constant emission factor.

In accordance with Figure 13, for NO_x, the IEF of the Netherlands is relatively high, around 20 to 120% higher than other countries. The NO_x emission factor in Belgium, Germany and the UK shows a declining trend. The declining trend could be caused by new engines in the fleet meeting stricter engine regulation or a shift from freight to passenger trains or vice versa with different emission factors.

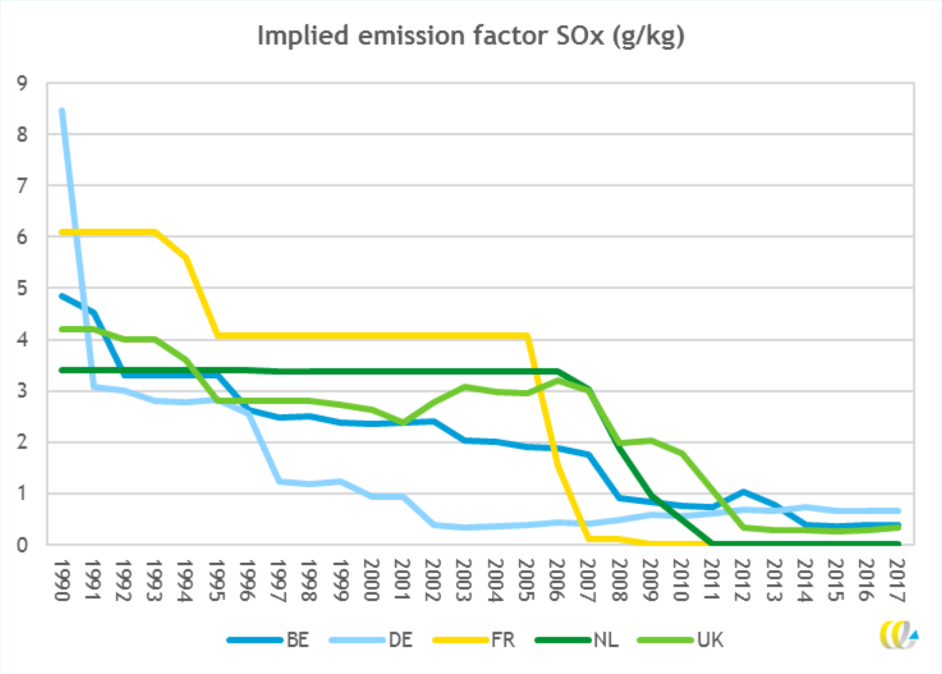
Figure 13 - Implied emission factors for NO_x



SO_x emission factors are declining throughout the time period, due to desulphurisation of diesel fuels in all countries, see Figure 14. The value for SO_x is in the guidebook presented as a formula and therefore not presented in Figure 14.

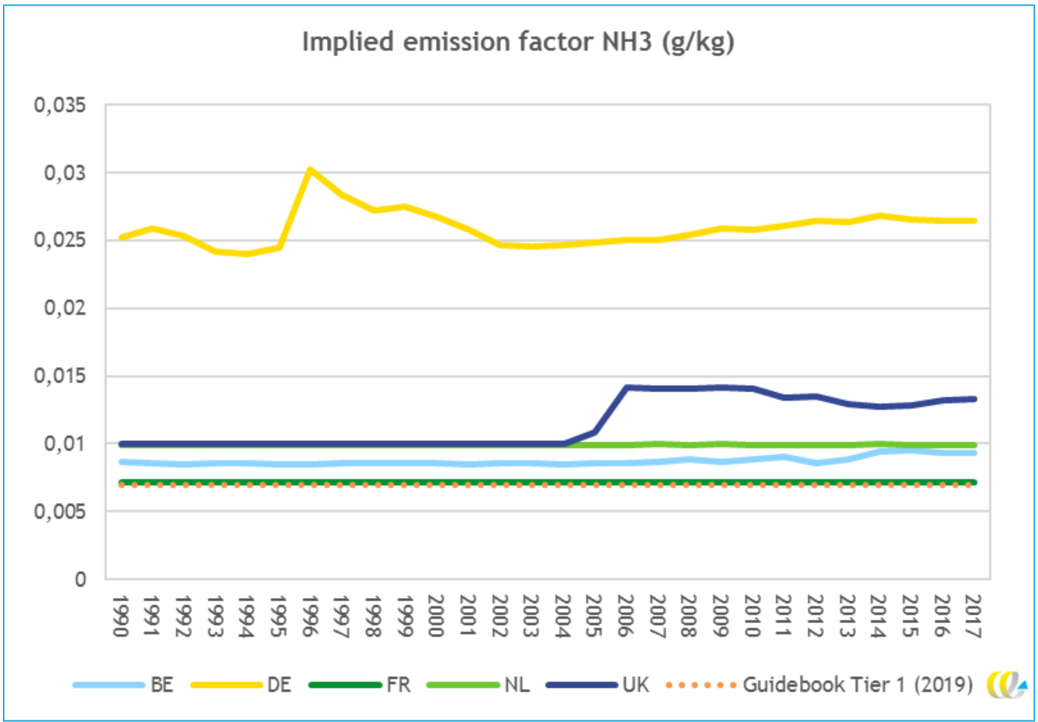
[2] An implied emission factor has been calculated from the reported results, emissions and fuel consumption. The implied emission factor is calculated from total rail diesel emissions and total fuel consumption.

Figure 14 - Implied emission factors for SO_X



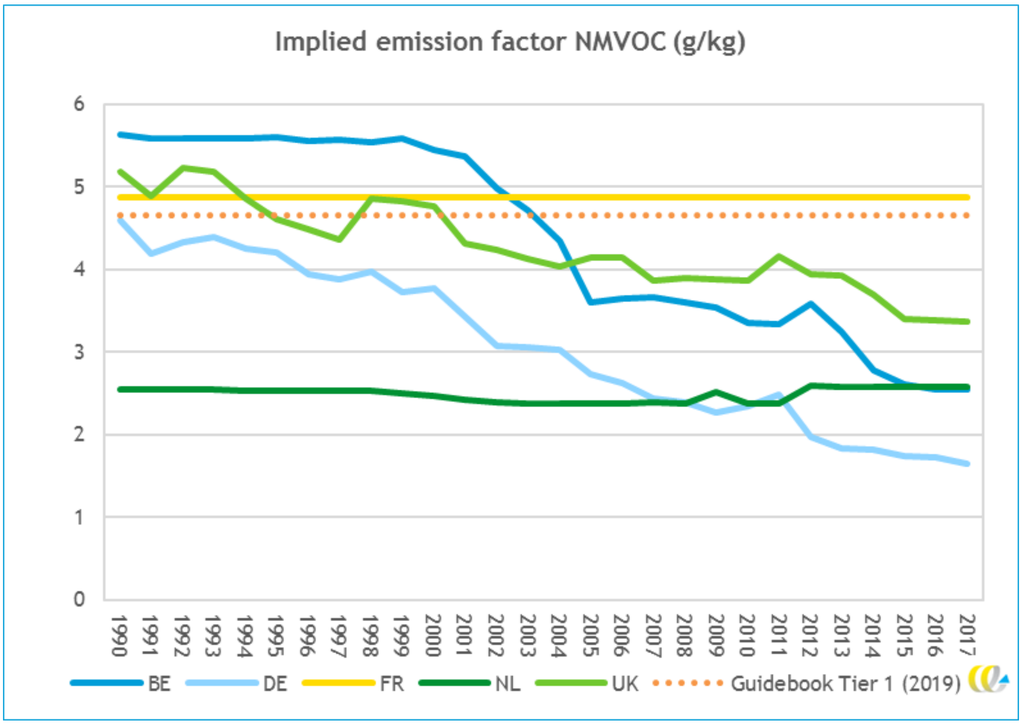
As is displayed in Figure 15, the Dutch emission factors of ammonia are in the same range as other countries, except for Germany that uses a much higher estimate. France applies the same value as the guidebook.

Figure 15 - Implied emission factors for NH_3



The implied emission factors for NMVOC are declining for Belgium, Germany and the UK throughout the time period, see Figure 16. The IEF of the Netherlands is comparable to that of other countries in 2017 but below the value in the guidebook 2019.

Figure 16 – Implied emission factors for NMVOC



A comparable figure for PM cannot be made, as countries report wear and tear emissions of the whole railway sector. Wear and tear emissions are higher than exhaust emissions. Setting the total PM emissions against the diesel fuel consumption, does not make sense.

3.5 Review of relevant literature

Table 8 presents an overview of emission factors from different literature sources.
The following remarks apply to this table:

- EcoPassenger (2016) and EcoTransIT (2019) are tools to determine emissions for each transportation mode for passengers and freight accordingly:
  - in EcoTransIT emission factors of the UIC 2 standard are used for the Netherlands. The UIC emissions standard is based on the ISO 8178 test method, where cycle F is applicable to locomotives (Dieselnet, 2001),
  - in EcoPassenger categories are made from local trains to intercity trains and main locomotives and railcars.
- In STREAM 2016 the same factors are used as displayed in Table 2.
  In TRANSFORM (2010) a comparison is made between different sources, such as EU legislation and EcoTransIT. Other sources used in the TRANSPHORM paper were also mentioned as sources in the EEA Emission Inventory Guidebook. The paper presents recommendations on emission factors as a conclusion to the comparison of the different sources. It is worth mentioning that older versions of the EU legislation and EcoTransIT are used for the Transphorm research.

Table 8 - Emission factors in various sources (g/kg fuel)

Source	CO	NO_x	PM_{10}	NH_3	HC/VOC
EcoPassenger	-	41,8	0,77	-	2,6
Transphorm (2010)	10,8	48,3	1,37	-	-
EcoTransIT	-	45,2	1,19	-	3,8

Wear and tear emissions

The PRTR takes wear and tear emissions of the overhead contact lines into account and assumes an emission factor of 15 mg/kwh for wear of the overhead line and 10 mg/kWh for wear of electric motor's carbon brushes, based on a source from 1993 (CTO, 1993).
For diesel trains, no wear and tear emissions are taken into account.

Belgium, for example, also takes wear of brakes and rails into account. The wear of brakes and rail emission are the largest contributors to total suspended particle emissions (TSP).

Table 9 – Belgian emission factors for non-exhaust emissions from rail transport for PM and Cu

	TSP (g/km)	% PM_{10} of TSP	% of $PM_{2.5}$ of TSP	Cu (mg/GJ)
Brakes	7.4	29%	29%	0
Wheels	1.53	50%	0%	0
Overhead wires	0.187	100%	100%	961
Rails	6.732	50%	25%	0

Source: Flemish Environment Agency, 2019.

CE Delft's STREAM (2014) study analysed the wear and tear emissions on a number of more recent sources (Heldstab & Kljun, 2007; TNO, 2008) and takes the same categories into account as the Belgium emission registration.

The STREAM figures illustrate a significant role of wear and tear in the total emissions. The figures for diesel railcars reveal a 30% share of wear and tear emissions in the total PM_{10} emissions (with 29 and 66 mg/pax-km for wear and combustion PM emissions, respectively). The wear figure for an electric regional train is comparable.

3.6 Diesel fleet characterisation

3.6.1 Passenger trains

Table 10 – Number of passenger trains per carrier in the Netherlands

	Operators						
Type of propulsion	**Arriva**	**Breng**	**Connexxion**	**Keolis**	**NS**	**Qbuzz**	**Total number**
Diesel	101	9		4			114
Built between 1997-2003	10			4			14
Built between 2006-2012	91	9					100
Electrical	46		1	16	854	10	927
Built between 2003-2006					90		90
Built between 2006-2012	22				268	10	300
Built after 2012	24		1	16	496		537
Total amount	**147**	**9**	**1**	**20**	**854**	**10**	**1,035**

Based on (Arriva, n.d.; Keolis Nederland, n.d.; NS, n.d.).

Emissions characteristics

The fleet of diesel passenger trains can be divided into categories sorted by the year of construction, see Table 11. In some cases, the trains of a certain type were built in overlapping categories. In those cases, it was not clear how many were built per category and therefore were all placed in the category with the oldest year of construction. The values displayed in Table 11 could therefore be conservative. The categories were adopted from the EU emission legislation and previous UIC non-binding regulations (CE Delft, 2003).

Table 11 - Diesel railcars sorted per year of construction.

	NO_x (g/kWh)	PM (g/kWh)	Railcars (%)	Railcars (Number)	Railcars 2020 (Number)
Built before 1996	16	1.6	0,0	0	0
Built between 1997-2003	12	0.8	13,8	14	7
Built between 2003-2006	6-9	0.25	0,0	0	0
Built between 2006-2012	4	0.2	86,2	100	84
Built after 2012	2	0.025	0,0	0	0
Total			**100**	**114**	**91**

3.6.2 Freight trains

About 20 train operators are active for freight transport in the Netherlands. In 2017, three operators had a market share of almost 75% of freight transport based on train kilometres (Markt, 2019). These operators are:

1. DB Cargo (market share of 40-45%).
2. Captrain (market share of 15-20%).
3. Rotterdam Rail Feeding (market share of 5-10%).

For the purpose of this study, the three main operators were asked to share information on their current fleet. Table 12 is based on the responses of DB Cargo Netherlands N.V. and Rotterdam Rail Feeding. Captrain did not send a response back and thus the numbers of Captrain are unknown.

Table 12 - Number of locomotives for freight transport per operator in the Netherlands

	Operators		
Type of propulsion	**Rotterdam Rail Feeding**	**DB Cargo NL**	**Total amount**
Diesel	16	39	55
Built between 1997-2003	1		1
Built between 2003-2006	5		5
Built between 2006-2012	10		10
Built before 1996		39	39
Electrical	4	3	7
Built between 1997-2003		3	3
Built before 1996	2		2
Unknown	2		2
Total amount	**20**	**42**	**62**

Based on the market share, the numbers in Table 12 would suggest this resembles 45-55% of the total fleet in the Netherlands. However, the market shares of DB Cargo Netherlands N.V. and Rotterdam Rail Feeding include kilometres from other locomotives as well:

- DB Cargo Netherlands N.V. is part of DB Cargo AG. DB Cargo AG is responsible for all management and is the owner of locomotives that are used for international freight transport. DB Cargo AG has a total of 118 locomotives that are permitted on Dutch railways. These locomotives are exclusively used for line-haul activities.
- Rotterdam Rail Feeding has a license in the Netherlands for locomotives from clients that are used. These locomotives are not displayed in Table 12.

Therefore, the numbers in Table 11 resemble a smaller percentage of the total market share. Additional information is needed to form a clear picture of the usage of locomotives in the Netherlands.

DB Cargo Netherlands N.V. and Rotterdam Rail Feeding provided us with additional information about their fleet:

- Analysis of the fleet of DB Cargo Netherlands N.V. shows that the complete fleet of diesel locomotives (39 pieces of DE 6400 type) was built between 1994 and 1999. The diesel locomotives are only used as line-haul locomotives because some parts of the rail network are not electrified. All other line haul activities from DB Cargo are executed by electric locomotives. From 2020 onwards the 39 diesel locomotives will be modernized and equipped with either new diesel engines or hybrid engines to reduce emissions.
- From the 16 diesel locomotives of Rotterdam Rail Feeding, 10 are shunting locomotives and 6 are line haul locomotives. Rotterdam Rail Feeding expects to start replacement of the 10 shunting locomotives in 2030. These shunting locomotives are built between 2003 and 2012.

Table 13 displays the share of shunting and line haul activities of the diesel locomotives from Table 12.

Table 13 - Share shunting and line haul activities of diesel locomotives per operator (measured in hours)

	Shunting	Line-haul
Rotterdam Railfeeding	60%	40%
DB Cargo Netherlands N.V.	71%	29%

Other information on the share of diesel and electric in the Netherlands

In Table 14 information is displayed on the share of electric and diesel per part of the railway network. The information is provided by ProRail and Railcargo. The Betuweroute is used for about 50% of all freight transport to Germany.

Table 14 - Share electric and diesel for freight transport per part of the railway network. Kilometres and tkm are adopted from Railcargo for the year 2018

	Share electric	Share diesel	Kilometres (millions)	tkm (millions)
Betuweroute (A15 tracé)	95%	5%	2,4	4,0
Havenspoorlijn (Kijfhoek – Maasvlakte incl. emplacements)	66.7%	33.3%	1.4	2.0
Rest of the network	50-75%	50-25%	5,5	7,5
Total			**9,3**	**13,5**

With regards to the rest of the network the following applies:

- Most freight transport to Belgium is electric.
- Freight transport to Germany via Venlo is powered by an electric locomotive in the Netherlands. In Venlo the locomotive is replaced by a diesel locomotive for the transport through Germany.

3.7 Conclusions

From this chapter, we found the following conclusions:

- The fleet of railcars has been completely renewed since the Dutch methodology has been determined. If real-world emissions have been lowered according to the emission standards, the fleet renewal will have resulted in a reduction of emissions over time.
- There is limited knowledge of diesel rail emission factors. Since the publication of the 2004/26 Directive, the number of studies published focussing on diesel rail emissions is limited. This implies that there is limited knowledge of the current real world situation.
- The Netherlands use an average rail diesel emission factor for NO_x of 77.5 g/kg fuel in the calculations reported to UNECE, while another value is reported in the background data. The new value, which stems from a TNO measurement (TNO, 2017), may well reflect the situation for freight transport. However, the current fleet of locomotives in freight transport will be modernized within the coming years which could consequently lead to lower emission factors. Thus, it is unclear how long for the PRTR value for NO_x is applicable to the Dutch situation.
- The Netherlands only take wear and tear emissions of abrasion of overhead lines, pantographs and carbon brushers into account, while literature suggests that wear and tear of brakes and rail tracks are the largest contributors to particle emissions.

4 Conclusions and recommendations

In the previous chapters we presented the results from the literature review and data analysis. At the end of each chapter, we listed conclusions concerning the chapter. In this chapter, we will present the main conclusions and recommendations from both chapters.

4.1 Conclusions

From the previous chapters, the following conclusions can be drawn:

- In Chapter 2 we concluded that a 55-60% share for passenger transport in diesel consumption is more likely than the 35% assumed by PRTR. However, in Chapter 3 we concluded that both the freight and passenger fleet in the Netherlands will be electrified and/or modernized. Therefore, the exact share of passenger transport in diesel consumption is likely to change over the years.
- The fleet of railcars has been completely renewed since the Dutch methodology has been determined. Assuming that real-life emission will (to some extend) follow the decrease in emission according to new emission standards, this will have resulted in a reduction of emissions over time. The PRTR emission factors, however, have not shown such a development.
- The new NO_x value from PRTR for the Netherlands is based on measurements by TNO and is higher than NO_x values in other countries and from the EEA guidebook.
- The fleet average emission factors are determined by the fleet composition in terms of engine age. By modernizing the fleet, the emission factors will change. Hence, over time the emission factors will become lower.

4.2 Recommendations

Following the conclusions from Chapter 2, 3 and 4, we suggest the following recommendations:

- Consider to adapt the distribution of rail diesel fuel consumption over passenger and freight transport. The 35% share that is allocated to passenger rail should be changed upwards, with a value of 55-60% as a first indication. It should be noted, however, that regional lines are being electrified (Maaslijn, Zwolle-Kampen, Landgraaf-Herzogenrath) and other regional lines which could also change the allocation factor.
- To better understand the differences, the sources for the total electricity consumption should be double checked (is Betuweroute (CIEBR) included and all tram/metro sources?). We recommend PRTR to check if electricity consumption of other parties than NS (regional passenger and freight operators) is included in the rail electricity statistics.
- Consider performing emission measurements on diesel railcars — like for freight locomotives, as the current emission factors used are from an old source and have not been validated since then. The single emission factor does not take into account the composition of engines in the fleet in terms of engine age and emission standard. There are good reasons to determine new emission factor as the fleet has been renewed completely since the emission factors were determined. The fleet is also expected to renew in the coming years.

- Update the emission factors for railcars. If performing measurements is deemed too costly, a second best step is application of the recommended values by the EEA guidebook (PM and NO_x).
- Consider the development of a Tier 3 approach, by outweighing the costs and benefits of gathering more detailed information on the structure of the fleet and lifetime dependent emission factors. As part of this consideration, a consultation amongst active neighbouring countries (Germany, Switzerland) on their approach, might be a first step.
- While the emission factors used for freight transport might reflect the real world situation rather good, as recent measurements have been done and the fleet is old, the situation for passenger rail transport is quite different. The fleet is rather young and about half of the fleet meets the Tier IIIB standard, which requires diesel particulate filters and/or NO_x reducing after treatment technologies. Using a specific fuel consumption figure of 250 g/kWh (reflecting high share of idling), the PM emission factor would be 0.1 g/kg. Real world emissions may be higher, two or three times the emission factor that could be calculated on the basis of the standard. Still the gap with the emission factor currently used (3.0 g/kg) is large. Therefore, we advise to study the particulate emissions of the diesel passenger fleet in depth, or use the Tier 2 default values as proposed by the EEA guidebook. The same is true for NO_x emission factor. Based on the fleet composition and standard, there may be a gap between the emission factor used and the emissions of the relatively young fleet of railcars. The Dutch emission factor for railcars is, however, closer to the proposed Tier 2 value by the guidebook.
- We recommend a review of the currently used wear and tear emissions in the Netherlands and to include wear and tear emissions from rail tracks.

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