Update of national Dutch emission factors

Rail emissions

TNO Intern ⟩ TNO 2024 R10284
19 December 2024

Energy & Materials Transition
www.tno.nl
+31 88 866 00 00
info@tno.nl

TNO 2024 R10284 – 19 December 2024

Rail emissions

Update of national Dutch emission factors

Author(s)	Norbert E. Ligterink, Emiel van Eijk
Classification report	TNO Intern
Title	TNO Intern
Report text	TNO Intern
Number of pages	22 (excl. front and back cover)
Number of appendices	0
Sponsor	RIVM
Programme name	Emissieregistratie
Project name	Slijtageemissies van rail
Project number	060.52660/01.14.12

Contents

1 Introduction

Within the Dutch emission inventory, which fulfills the reporting obligation of the Convention on Long-range Air Pollution, the emissions from trains are a minor source. For many years the methodology for train emissions has not been updated (e.g. emission factors used originate from a 1993 memo from RIVM). This has until recent been partly due to a lack of new research and confidence in existing research. Simultaneously however, rail and metro tunnels are blackened by the emissions of trains, also in the case of electric trains and metro lines. The air-quality of underground stations has been a problem for over a century.

Emission factors used so far for calculating rail emissions are based on older studies [1], [2], [3]. As such, more issues can be identified in the methodology used so far: in particular, the rolling resistance of trains are estimated in some older studies at about 120 Newton per ton. This is extremely high, even trucks on the road have lower rolling resistances. Likely, data from hilly surroundings that do not apply to the flat sea-level Netherlands are used while recent measurements from the Netherlands would be more suitable. A minor study based on plume measurements provided emission factor values that make no physical sense and did not match typical totals [4]. The latter research is not incorporated.

There are some complexities in determining train emissions: the source and the magnitude, and the differentiation with train types and activity is varying a lot. Measurements at stations are not representative of the average emissions of trains, because during stopping and acceleration, as they occur at stations, emissions will be substantially higher than at constant speed on a straight track. The bends in rails, however small, also cause additional wear emissions, given the screeching noise of metal-over-metal slip. High pressures and smooth surfaces of the wheel-rail contact causes emitted particles to be small, below 1 micron, and for a substantial part these are emissions to air.

Given new international studies and recent emission measurements on trains in the Netherlands there has been a major update of the methodology and underlying data in 2023. This report provides the background to the new status. Some minor outstanding points are given in the recommendation chapter at the end.

2 Recent research

TNO has carried out measurements on two diesel locomotives, not only determining their emissions, but also the typical usage patterns, which contain a lot of stationary operation [5]. Consequently, emission during stationary operation is an important aspect, especially in shunting operations. Per litre fuel the amount of NOx emissions at low engine load can be up to a factor three higher than during normal operation. Emission factors based on fuel consumption should take account of this variation. Moreover, this study put the rolling resistance of trains at more realistic values between 20 to 70 Newton per ton, strongly dependent on the number of axles and seemingly affected by internal friction, rather than wagon weights. Brake traction, at about 15% of the total power consumed, ensures even lower dependence on the frequency of stops, than in the past.
More recently, the rail construction work came into focus [6]. The specialized machines for rail construction work can have ages up to 40 years, and the diesel engines comply with older and weaker emission standards. They are a small but not negligible part of the total emissions of rail. Since rail emissions are linked to fuel and electricity used, the emission reporting should be consistent with the fuel sold and fuel used reporting. At the moment fuel used or fuel sold for rail construction is not reported. The question remains whether the fuel used for construction is part of the regular reported fuel used for transport.

Recent measurements on passenger trains showed that NOx emissions were high, alternative fuel made limited difference, and the train operation, like the number of stops per kilometre were key aspects in the emissions [7]. Especially rolling out limited the fuel use and emissions. Although these trains had an SCR, few of the particular advantages and problems with SCR were observed.

Internationally, most measurements are remote sensing and tunnel measurements, which put a different perspective on the seminal study at Zurich Hauptbahnhof where very high particle concentrations were measured near the tracks [8] [9]. Switzerland has about the same amount of rail activity as the Netherlands, but the reported particulate matter emission levels are about tenfold, totalling at about 1000 ton PM10 per annum. The Swiss numbers made it to the guidebook, but several countries deviate from these emission factors [10]. A recent CE report also cited this difference without mentioning the questionable context of the Swiss study [11].

A remote sensing study in Austria is one of the studies which shows lower emissions than the Swiss numbers [12]. Tunnel experiments are a common source of information on the overall effect on air-quality, that need to be decomposed to the attributing sources [13] [14]. The clear difference between passenger and goods and this relation with the brake system, is clear from this study. Brake emissions will vary with material composition, velocity, brake pressure, and duration of braking [15]. Multiple studies focus more on the precise mechanism of wear emissions [16], [17]. Further details on wear emissions in wheel-track interaction show the intricate dependencies on the state of the track [18]. Wear emissions of pantographs and catenaries have their own composition and dependencies [19], [20], [21].

There are serious shortcomings in most studies, given the rail-side approach. With the large variations in emissions with circumstances, like accelerating, braking, bends, constant velocity, and technologies, most outcomes are local and specific to the trains and conditions and likely not representative for national levels [7]. The limitations of road side measurements, like remote sensing, are fivefold more for rail emissions. Rail emission during acceleration are six times larger than during constant driving on a straight track, and twenty times larger than during roll out. The coverage of all situations is not guaranteed with remote sensing, and the weighing of the different operations in the total and average emissions are not known. Emissions must therefore be bounded by activity totals, like energy or fuel use.

3 Activity data

Rail transport emissions are expressed in the Netherlands in terms of emission factors per litre (or kg) diesel and per kWh electricity. This activity data is available for the sector via CBS. The methodology of split between passenger and freight is varying over time, mainly dependent on the different expert opinions. An estimate based on the location of fuelling, gives roughly a 47%/53% split in diesel consumption between the freight and passengers respectively for 2020. The fuelling locations for freight trains were considered: Amsterdam, Amersfoort, Geleen, Venlo, Kijfhoek, Maasvlakte, Waalhaven, Zwolle, and Botlek. Other fuelling locations were assumed to be mainly for passengers trains.

Given the link between energy and its dissipation, the expression of emission factors in terms of litres diesel and kWhs of electricity will remain the main methodology. However, with the research sketched above, a wide variation of emission per litre diesel and kWh, depending on the train type and usage is to be expected. Therefor some link to the activity and the g/km and g/hr emissions must be made.

3.1 Types of rail transport

3.1.1 Rail freight transport

Most freight routes are electrified except the routes from Lage Zwaluwe inland to Moerdijk and Oosterwijk. The use of diesel locomotive on electrified routes is mainly for logistic reasons, not common but also not exceptional. The main routes are electrified, running from the sea ports in-land and abroad, notably to Germany. In the source location it is important to make this distinction, as freight transport is expected to have much higher emissions, given the weight, the train material, and the lagging legislation.
The total distance driven by freight trains is about 8.5 million kilometres with an average payload of 800 ton per train, and an average trip distance of 165 kilometres. The latter is basically the distance from Rotterdam to the German border. Given an emission factor of about 2.7 g/km, from the Austrian study, the total non-exhaust particulate matter emissions would be 23 kton.

3.1.1.1 Locomotives

There are about 200 diesel locomotives in the Netherlands. But these may operate also outside the Netherlands, as most rail transport is mainly international. So far, it is unclear how many locomotives per year are assigned to the Dutch usage. The majority of the transport demand is met with electric trains. The main route is called the “Betuwelijn”, running parallel to the A15 motorway from Rotterdam to Germany. Other freight trains operate on the main rail network, with slots assigned in the common planning.

3.1.1.2 Shunting

The most common task for diesel locomotives is shunting operations; combining and disassembling freight trains for transport. The locomotive engine is on for 9 to 11 hours a day, but only a fraction of the time substantial engine power is needed.

3.1.2 Passenger trains

Passenger trains in the Netherlands are mainly electric, except for some regional lines:

1. Groningen and Friesland, beyond Leeuwarden en Groningen city
2. Achterhoek
3. Betuwe
4. Almelo-Hardenberg
5. Nijmegen-Roermond (electrification planned 2024)
6. Zutphen-Hengelo (Oldenzaal)
7.

Diesel passenger trains are almost exclusively light-rail Stadler trains with Stage IIIA and Stage IIIB engines. A railcar is powered by two 300-480 kW engines, with a weight of 80 to 110 ton, two and three railcar. With a maximum velocity of 160 km/h, suggests a maximum driving resistance of less than 200 Newton per ton.

There are about 120 diesel railcars in the Netherlands, Stage IIIA and Stage IIIB. They are used singly, or in combination of two or three railcars combined. Railcars have a length from 40 to 55 metres.

Electric railcars are modernized over the years. Most have brake traction, supplying energy back to the net or charging batteries. This is notable by the sound the trains make entering the stations and the limited screeching noises, associated with metal brakes. Also diesel railcar has electric traction braking, often dissipating the load in a heat bank.

3.1.3 Rail construction and maintenance

Rail construction material is mainly international, operating across Europe, wherever building and maintenance projects occur. Roughly 30 diesel locomotives seem to be assigned to rail construction activities in the Netherlands, as they are owned by Dutch or BENELUX companies. Other specialized equipment is in many cases not self-propelled. These are used for laying new rail tracks or rail track maintenance.

3.2 Energy and fuel use of trains and locomotives

3.2.1 Energy usage per kilometre

Translating overall power use, and emission factors in g/kWh and g/litre to g/km requires knowledge of the energy and fuel use per kilometre. Given the heavy weight of trains, the acceleration contributes significantly to the overall power use, which is then to be spread over the distance between stops.

Table 3.1: The energy use of a 100 ton train to accelerate, and the contribution of energy use per kilometre based on the distance between stops

		Energy use [kWh/km]		
v [km/h]	**energy [kWh]**	**5**	**10**	**15**
60	3.86	0.77	0.39	0.26
80	6.86	1.37	0.69	0.46
100	10.72	2.14	1.07	0.71
120	15.43	3.09	1.54	1.03
140	21.00	4.20	2.10	1.40

The rolling resistance of trains is the second source of energy use. Many different formulae are in use, but the main features are a constant part, i.e., force per ton weight, and a part dependent on the number of axles increasing with the velocity. The former is the rolling resistance, the latter is the internal friction. For freight transport, the latter maybe significant with a low payload.

A 30 newton per ton is an appropriate number for modern trains in a good maintenance state at limited velocity. That translates into a constant 0.833 kWh/km for the 100 ton reference train, which is comparable to the energy usage per kilometre of two heavy trucks.

Electric trains can recuperate energy while braking. This may reduce the energy use by about 15% for freight trains if the energy can be fed back to the electricity net. Most modern diesel railcars use traction to brake, and the energy is dissipated as heat. In some cases brake energy is stored on electric and diesel trains, to be used later.

3.2.2 Fuel and electricity usage

In the Netherlands there is 3041 kilometres rail. Electrified rails, in total 2265 kilometres, typically has two tracks, while non-electrified rail (in total 776 kilometres) is more often single track. Most non-electrified rails are in Gelderland and Groningen. The longest distances are covered, with limited stops and likely lower energy use per kilometre. Hence, the non-electrified rails are less in use, as trains have to pass each other at specific locations. With the cost-benefit of less-frequented rail lines, the electrification is slow. However, in the past decade electrification of both freight lines and passenger lines has kept a steady pace, with further plans being developed for new electrification as a climate action.

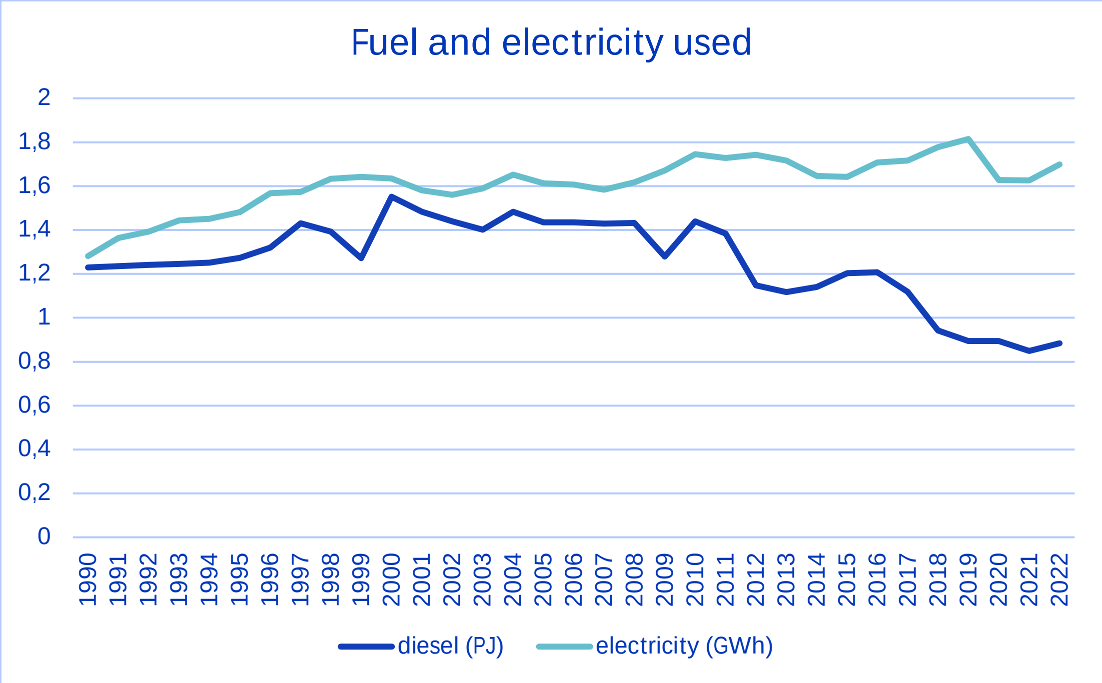

Figure 3.1 The fuel and electricity used over the years by rail traffic

The steady decline of diesel used is a major contribution to the reduction of rail-related tail-pipe emissions of the years.

3.3 Ambient conditions affecting emissions

Ice on the catenary, on frosty nights, tends to draw many sparks from the contact with the pantograph, especially during acceleration when much current is drawn. In Dutch weather conditions, typically only the first train draws these sparks, after which the catenary is heated and the ice is gone.

Rain and leaves on the track have a double role. They reduce the friction and cause slip, thus increasing the risk of wear and emissions, on the other hand they reduce and spread the contact force and limit the particulate matter emissions. Moreover, the particles are partly metal and partly metal-oxides, due to the weather influences. Higher exposure of the rails to ambient conditions increases the wear [22].

4 Emissions of rail transport

4.1 Legislative emission requirements

New diesel engines in trains have to comply with Stage-V standards, which are distinct for locomotives and railcars, and dependent on the power rating. It is therefore expected that diesel freight trains have higher emissions per litre fuel than passenger trains. This has been the case since 2005, and the share of diesel locomotive fuel consumption will affect the total emissions, with likely double the NOx emissions of railcars, due to the age, emission legislation and usage. Currently, non-exhaust emissions are not yet regulated for trains.

4.2 Exhaust emissions of diesel locomotives and railcars

Emission tests of heavy-duty and non-road mobile machinery engines are at high engine loads, typically much higher than the normal use. Consequently, PM emissions are in normal use not much higher than for type-approval, but NOx emissions can be much higher. The CO and HC emissions are linked to the incomplete combustion of the fuel, with associated lower engine efficiency. Therefore, CO and HC emissions are typically lower than the limit, except in cases of defects and deterioration of the fuel injection system.

4.2.1 Legislative classes

Table 4.1: Different emission limits for rail vehicles (combined numbers in brackets)

Limits in g/kWh		Rated power	CO	HC	HC+NOx	NOx	PM	PN [#/kWh]
Stage IIIA	railcar	> 130 kW	3.5		4.0		0.2	
	locomotive	130-560 kW	3.5		4.0		0.2	
	locomotive	> 560 kW	3.5	0.5	*(6.5)*	6.0	0.2	
	locomotive	> 2000 kW and > 5 liter/cyl	3.5	0.4	*(7.8)*	7.4	0.2	
Stage IIIB	railcar	> 130 kW	3.5	0.19	*(2.19)*	2.0	0.025	
	locomotive	> 130 kW	3.5		4.0		0.025	
Stage V	railcar	all	3.5	0.19	*(2.19)*	2.0	*0.015*	**10^{12}**
	locomotive	all	3.5		4.0		0.025	

Stage IIIA became in force in 2006 for railcars and 2009 for locomotives, Stage IIIB in 2012 for both, and Stage V in 2021. Given the typical age of railcars and locomotives it is expected that railcars are replaced within 20-30 years and locomotives within 30-40 years.

Given the total fuel consumption of rail of about 25 million litres, at 4 kWh per litre, the total exhaust PM emission would roughly have been 5 ton around 2005 and decreasing with the introduction of Stage IIIB and Stage V to about 0.5 ton, expected in 2030, with the same activity.

4.2.2 CO2 emissions

CO2 emissions are directly related to the fuel used and with an emission factor of about 2650 grams per litre diesel the main source. Some modern railcar have SCR and the consumption of reagents will add about 0.6% CO2 to the total CO2 emissions.

4.2.3 NOx emissions

NOx emissions are coupled to the combustion process, and thus only applicable for diesel trains. The legislative classes and share of idling will determine the NOx emission per litre fuel [23].

$$NOx\,[g] = 12 * NOx_{limit}[g/kWh] * Fuel[kg]$$

The factor is based of the amount of kWh per kilogram fuel, about a factor 4, and the typical exceedances of the limits in normal use as observed in the measurement program, about a factor 3. Over the years with more stringent regulation, the emission factors decreased.

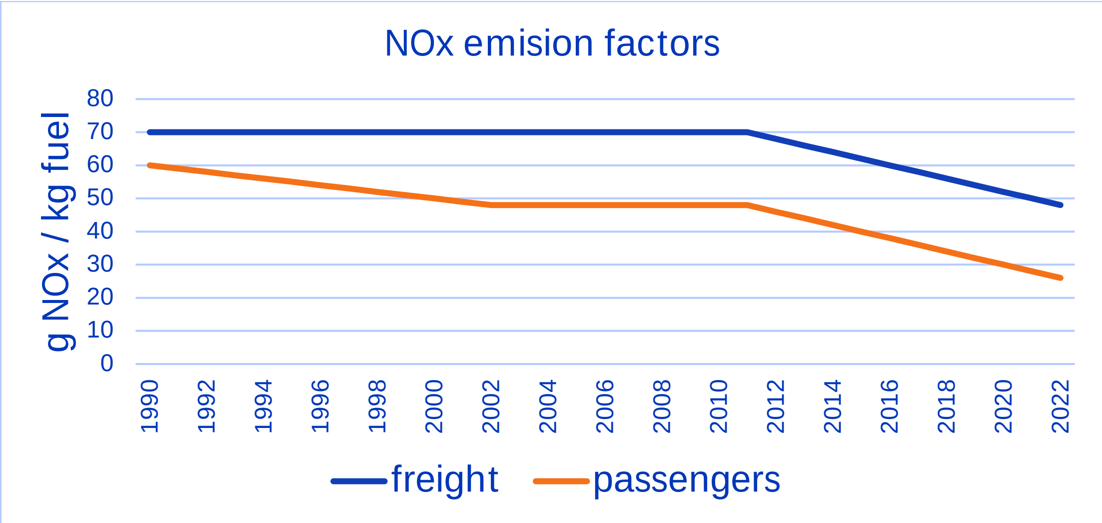

Figure 4.1: NOx emission factors of freight and passenger trains over the years

4.2.4 Particulate matter emissions

PM emissions from the exhaust are also linked to the combustion process, but usually more at higher engine load, which is more common in the test than in normal use, but may deteriorate in normal use and in dynamic operation.

$$PM[g] = 5 * PM_{limit}[g/kWh] * Fuel[kg]$$

The factor 5 is based on a small exceedance of about 25% in normal use about the limit, due to the lack of data, and the amount for fuel per kWh. Given the fact that train engines operate near full load during acceleration, which is normally associated with high particulate matter emissions, there are some concerns this emission factor is low.

More stringent particulate matter legislation was introduced with Stage IIIB, from which date particle emission factors decreased.

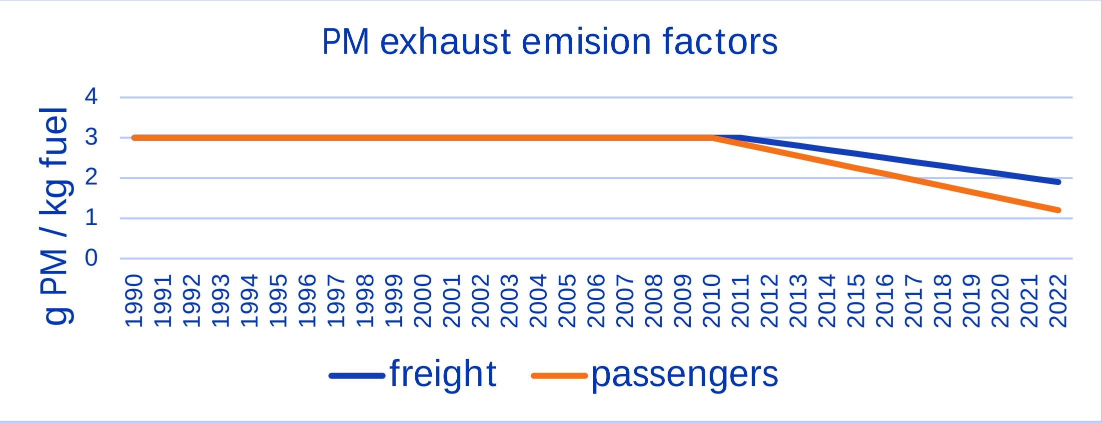

Figure 4.2: PM emission factors over the years

4.2.5 Other pollutants

Also hydrocarbons and carbon monoxide are emitted from the exhaust as products of incomplete combustion. For trains with good working SCR some extra NH3 emissions will occur, but with the limits for trains, the SCR functions only limited and little emissions are expected. Moreover, with the relatively high NOx limit and the stable operation of trains, there is limited risk of high NH3 emissions.

$$CO[g] = 3 * CO_{limit}[g/kWh] * Fuel[kg]$$
$$THC[g] = THC_{limit}[g/kWh] * Fuel[kg]$$
$$NH3[g] = 0.075 * Fuel[kg]$$

Their results are based many of the measurement of Non-Road Mobile Machines, by TNO, which include similar engines in off-road applications [24], [25].

4.3 Non-exhaust emissions

4.3.1 Non-exhaust emissions from pantographs

Only electric trains have pantographs and catenary and such emissions. These emissions are coupled to the electricity usage. In the past the contact strips were from copper, but currently copper impregnated carbon is common. The wear emissions are assumed to be 70% carbon and 30% copper. Most wear is related to the current, and contact wear is a minor part in the total. Consequently, wear emissions are assumed proportional to the energy consumption in kWh, and about a quarter of all the wear emissions are below PM10 and 10% below PM2.5.

$$PM10 [g/kWh] = 2.0 [mg/kWh] * Electricity [kWh]$$
$$PM2.5 [g/kWh] = 0.6 [mg/kWh] * Electricity [kWh]$$
$$Cu[g] = 0.7 [mg/kWh] * Electricity [kWh]$$
$$EC[g] = 1.3 [mg/kWh] * Electricity [kWh]$$

These results are unchanged from the earlier emission estimates, albeit formalized in emission factors related to electricity used.

4.3.2 Non-exhaust emissions of catenaries

Catenaries are made of copper, and the wear emissions are dominated by copper.

PM10 [g/kWh] = 3.4 [mg/kWh] * Electricity [kWh]
PM2.5 [g/kWh] = 1.1 [mg/kWh] * Electricity [kWh]
Cu[g] = 3.4 [mg/kWh] * Electricity [kWh]

These results are unchanged from the earlier emission estimates, albeit formalized in emission factors related to electricity used.

4.3.3 Non-exhaust emissions of brakes, wheels and rails

Brake wear emissions are nowadays mainly a freight transport issue and limited by the recuperative braking, as passenger trains commonly use brake traction. The issue is not necessarily the braking itself but parasitic braking, due to limited maintenance. It is also the cause of fires near rail tracks with heat and sparks from the wheels and brakes.

Wheels and rails have small contact surfaces and high contact pressures, as per axle a typical maximum weight of 25 ton is allowed. Contact slip, i.e., from acceleration, braking, and bends will increase the wear emissions. Based on wear experiments, about half of the total wear is expected to be less than 10 micron and 25% thereof below PM2.5. Therefore, emissions are roughly proportional to power usage and fuel consumption.

The absolute PM10 emissions are based on the Austrian study, i.e., about 0.23 mg/(ton*km) at nearly constant velocity, thus translating, with 0.00833 kWh/(ton*km) into 28 mg/kWh and 110 mg/litre PM10 emissions of brakes, wheels, and rail. Given the energy use of 6.8 PJ total annual energy use the wear emissions are 50 ton PM10 per year, wheel, brake and rail wear.

The PM2.5 emission factors of wheel, rail, and brake wear are:
- 130 mg / kg diesel for diesel trains
- 28 mg / kWh electricity for electric trains

The total wear (TSP) emissions are:
- 182 mg / kg diesel for diesel trains
- 39.2 mg / kWh electricity for electric trains

5 Conclusion: Adaptions in the calculation for 2023

With the findings provided in this report in 2023, the whole series of rail emissions 1990-2022 have been overhauled. This chapter gives an overview of the changes that update the emission calculation of rail traffic in the Netherlands to the latest findings.

5.1 New emission sources

In the Netherlands wear emission of wheels, tracks, and brakes were not included before, but now added to the emission sources of rail. This is a source of about 50 ton of PM2.5 and 70 ton total suspended particles, relatively constant over the years. This contribution is much larger than the PM2.5 emissions of the diesel exhaust gas, that is around 30 ton PM2.5.

5.2 Changes in emission factors

Emission legislation for rail diesel engines is limited and their introduction is slow. However, over the last forty years some gains have been achieved in reducing the environmental impact of trains. Since control of real world emissions is limited, the real world emissions are still substantially higher, by several factors, than the emission limits.

The Sulphur content of diesel has been updated to follow the trend of Non-Road Mobile Machinery. The recent changes in fuel composition were not included before and by making the trend consistent with NRMM, this is corrected.

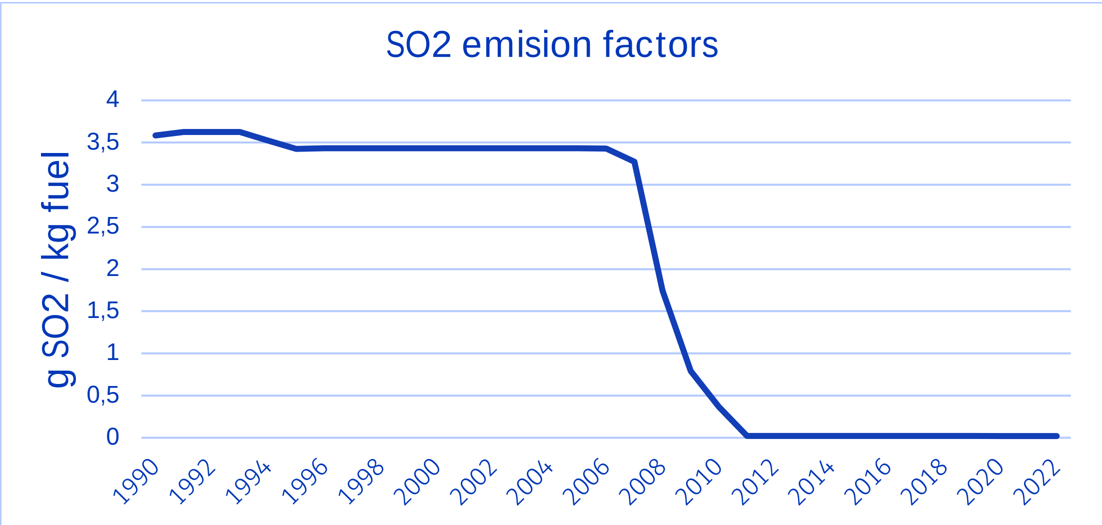

Figure 5.1: SO2 emission factor based on the changing composition of diesel fuel for off-road

The NH_3 emissions and others were not consistent with the emission factors for similar engines, e.g., used in NRMM. These emission factors were made consistent and linked to activity data, i.e., fuel and electricity use.

The CO_2 emission factors are derived from fuel based on the CO_2/kg emissions factors established by CBS on the basis of the diesel fuel composition, e.g., the biofuel admixture. The emission factor changes therefore slightly over the years.

6 Discussion and recommendations

Although the registration of emissions of rail traffic have been improved by this work, the current study also shows that the quality of available data is still lacking. This is especially the case when compared to other modalities like road traffic and mobile machinery. The following chapter gives recommendations for future research and better registration of emissions and activity data.

6.1 Improve emission factors with insights in new emission classes

Table 6.1 shows the emission factors for rail traffic currently advised in the EMEP/EEA air pollution emission inventory guidebook. All emission factors are based on emission limits and research carried out well before the introduction of Stage IIIB emission legislation in 2011, let alone the introduction of the latest stage V emission legislation. In the Netherlands there have been several public studies on rail emissions in the last five years, that could be used to improve the values in the guidebook. The recent studies show that rail NO_x emissions are substantially higher than one would expect from emission standards for these engines. Moreover, some minor improvements with new legislation, Stage IIIB, are now included in the Dutch inventory, although no Stage V engines have been reported to be used so far.

To illustrate the above, the average NO_x emissions of freight trains, prior to Stage IIIA/B legislation, is around 70 g/kg fuel, with emissions in specific circumstances up to 120 g/kg fuel. This is based on the measurements of TNO on several diesel locomotives. This is about 30% higher than both the average and the bandwidth in the EMEP guide book.

Table 6.1: EMEP 2023 guidebook 1.A.3.c

Table 3-1 Tier 1 emission factors for railways

Tier 1 emission factor					
	Code	Name			
NFR Source Category	1.A.3.c	Railways			
Fuel	Gas Oil/Diesel				
Not applicable	HCH, PCB, HCB				
Not estimated	SOx, Pb, Hg, As, PCDD/F, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	52.4	kg/tonne fuel	25	93	Aggregated Tier 2 method
CO	10.7	kg/tonne fuel	6	19	Guidebook (2006)
NMVOC	4.65	kg/tonne fuel	2	8	Guidebook (2006)
NH_3	0.007	kg/tonne fuel	0.004	0.012	Guidebook (2006)
TSP	1.52	kg/tonne fuel	3	23	Aggregated Tier 2 method
PM10	1.44	kg/tonne fuel	2	16	Aggregated Tier 2 method
PM2.5	1.37	kg/tonne fuel	2	14	Aggregated Tier 2 method
Cd	0.01	g/tonne fuel	0.003	0.025	Guidebook (2006)
Cr	0.05	g/tonne fuel	0.02	0.2	Guidebook (2006)
Cu	1.7	g/tonne fuel	0.5	4.9	Guidebook (2006)
Ni	0.07	g/tonne fuel	0.02	0.2	Guidebook (2006)
Se	0.01	g/tonne fuel	0.003	0.025	Guidebook (2006)
Zn	1	g/tonne fuel	0.3	2.5	Guidebook (2006)
Benzo(a)pyrene	0.03	g/tonne fuel	0.01	0.1	Guidebook (2006)
Benzo(b)fluoranthene	0.05	g/tonne fuel	0.02	0.2	Guidebook (2006)
Benz(a)anthracene	0.08	g/tonne fuel	0.03	0.2	Guidebook (2006)
CO_2	3140	kg/tonne fuel	3120	3160	Guidebook (2006)
Dibenzo(a,h)anthracene	0.01	g/tonne fuel	0.004	0.03	Guidebook (2006)

6.2 Start measuring particulate matter emissions

The tailpipe emissions of locomotives and railcars are mainly based on the emission limits, and not real world operations. From the measurement programs at TNO the NO_x emissions are threefold higher than one would expect from translating the emission limits. For PM2.5 there are no such measurements, and given this track record, and the vicinity of trains to city centres with high exposure risks, it would be appropriate to have particulate matter emissions measurements, to ensure the current estimates are proper. The risk of high particulate matter emissions is aggravated by the fact that train engines operate at full engine load during accelerations, when emissions per litre fuel are likely the highest.

6.3 Improve emission factors for non-exhaust emissions

The rail and wheel wear emissions estimates vary greatly across Europe. Brake wear emissions seem to be mainly an issue with freight trains, since passenger trains brake mainly on electric traction. Alternative sources of information, like the Tribology Handbook from 1974 on the actual wear of tracks, provides additional information that put many partial studies into context. However, more systematic and representative studies are needed. Iron and iron oxides in emissions to air, in particular in ultrafine particles, may be of health concern. The composition of wear emissions should be adapted to reflect the impact of rail traffic on this topic. Differences between the studies are likely caused by the location of rail side measurements. No location can capture the true, or average, emissions of trains. However, most tracks are straight, most of the time trains have constant speed, and these results should be a major part of the total result. Therefore, the update of the emission factors relies strongly on this type of data.

The composition of the non-exhaust emissions is still open. For 2023 the composition of track, wheels, and brakes are lumped in with the non-exhaust emissions of catenary and pantographs. This is obviously a limitation, as the latter contain mainly copper and carbon, while the non-exhaust emissions of tracks, wheels and brakes are dominated by iron and iron oxides. Since the Emission Registration project is evaluating the consistency of composition of particle emissions across the field, in particular the emissions to ground and water, the distinct composition profile on track, wheel, and brake emissions is on hold awaiting further guidance for its need and methodology.

6.4 Better registration requires improved availability of activity data

The lack of data on the distribution of fuel to freight, passenger, and construction trains does not allow for a proper distribution of emissions, especially to construction trains, because these are among the oldest and most polluting trains. Currently, the data on fuel consumption is only split between freight and public transport, which makes it impossible to include construction trains in the inventory, while it is expected to be a significant source of pollutant emissions. Further there is little transparency on how the split between freight and passenger transport is implemented. Centralized purchase of fuel and energy by the VIVENS cooperation should allow for clear and transparent distribution of fuel used between train operators and fuelling locations, allowing a clear split between the different usage categories.

Electricity and fuel use are good indicators of emissions, as they link directly to the combustion processes and the energy dissipated, both leading to emissions. Linking emission to activity, like goods and passengers transported, or distances travelled is a complex process, prone to errors. The weight of the train is needed, as well as the velocity signal, in particular for the amount of braking and energy loss. This information is often not available, or tainted by the evaluation process. In order to link emission to operation aspects, even to determine an emission factor per ton*kilometre goods transported, specifics are needed. Generic numbers can vary roughly a factor four with specific operations, as is uncovered in the monitoring programs carried out. A good overview of the fractions of specific operations, like pay load, number of stops, velocity, bends, roll out distance, etc. is a basis for using detailed activity data. However, such data is missing.

References

[1] Netherlands national water board - Water unit, in cooperation with DELTARES and TNO, „Railways, abrasion of pantographs and overhead wires," Netherlands national water board, 2008.

[2] DELTARES, „Slijtage stroomafnemers en bovenleidingen spoorwegen," 2016.

[3] TNO, „Emissies en lokale luchtkwaliteit effecten van spoorlijnen met dieseltractie TNO-034-UT-2010-01727," TNO, Utrecht, 2010.

[4] TNO, „Het effect van dieseltractie op luchtkwaliteit in relatie tot het begrip "Niet In Betekenende Mate" R11030," TNO, Den Haag, 2015.

[5] TNO, „Insight into the energy consumption, CO2 emissions and NOx emissions of rail freight transport R11679," TNO, Den Haag, 2017.

[6] TNO, „Inventarisatie en categorisatie huidige en toekomstige aanbod duurzame mobiele werktuigen, bouwlogistieke voertuigen, spoorwerktuigen en vaartuigen die worden ingezet voor de waterbouw," TNO, Den Haag, 2022.

[7] TNO, „Emissiemetingen Stadler passagierstrein met diesel en HVO R12287," TNO, Den Haag, 2023.

[8] R. e. a. Gehrig, „Contribution of railway traffic to local PM10 concentrations in Switzerland," *Atmospheric Environment,* vol. 41, pp. 923-933, 2007.

[9] B. f. Umwelt, „PM10-emissionen verkehr Teil Schienenverkehr," INFRAS, 2007.

[10] A. q. e. group, *Non-exhaust emissions from road traffic,* 2019.

[11] C. Delft, „Review of Dutch rail diesel emissions calculation methodology, 190415," CE, Delft, 2020.

[12] S. Pistrich, „Analyse von Feinstaubemissionen des Schienenverkehrs," TU Graz, Graz, 2020.

[13] Y. e. a. Lee, „Sources and characteristics of particulate matter in subway tunnels in Seoul, Korea," *In. J. Environ. Res. Public Health,* vol. 15, nr. 11, p. 2534, 2018.

[14] VTI, „Particles in road and railroad tunnel air, 917A," VTI, 2016.

[15] Y. e. a. Tsybrii, „Airborne wear particle emission from train brake friction materials with different contents of steel and copper fibres," *Wear,* vol. 504, nr. 204424, 2022.

[16] Y. e. a. Cha, „Cha, Yingying, et al. "Airborne wear particles generated from conductor rail and collector shoe contact: influence of sliding velocity and particle size.," *Tribology Letters,* vol. 64, pp. 1-20, 2016.

[17] S. e. a. Abbasi, „Particle emissions from rail traffic: A literature review.," *Critical reviews in environmental science and technology,* vol. 43, nr. 23, pp. 2511-2544, 2013.

[18] U. e. a. Olofsson, „Trobologu of the wheel-rail contact-aspects of wear, particle emission and adhesion," *Vehicle System Dynamics,* vol. 51, nr. 7, pp. 1091-1120, 2013.

[19] M. e. a. Kuznar, „A method of predicting wear and damage of pantograph sliding strips based on artificial neural networks," *Materials,* vol. 15, nr. 1, p. 98, 2021.

[20] IASVD, „Pantograph wear assessment in overhead conductor rail systems," IASVD, 2011.

[21] G. Holstrom, „Pantograph-catenary wear modelling using dynamic simulation,” KTH, Stockholm, 2022.

[22] Handbook of Tribology, 1974.

[23] TNO, „AUB (AdBlue verbruik, Uren en Brandstofverbruik): Een robuuste schatting van NOx en NH3 uitstoot van mobiele werktuigen, R12305,” TNO, Den Haag, 2021.

[24] TNO, „Real-world emissions of non-road mobile machinery, R10221,” TNO, Den Haag, 2021.

[25] TNO, „Pilotproject Emissie Monitoring en Periodieke Keuring (EMPK) van bouwmachines, R10553,” TNO, Den Haag, 2023.

Signature

TNO ⟩ Energy & Materials Transition ⟩ Den Haag, 19 December 2024

Valid Signed by Sam van Goethem
on 2024-12-19 11:19:45

Valid Signed by Ruben Goudriaan
on 2024-12-19 13:28:52

Sam van Goethem
Research manager

Ruben Goudriaan
Project manager

Energy & Materials Transition

Anna van Buerenplein 1
2595 DA Den Haag
www.tno.nl

TNO innovation for life