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Clean on track

Reducing emissions from diesel locomotives

Report

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Contents

Summary

Reason: Environmental performance diesel locomotives lags behind
Up till now there has been little attention in the European transport and environmental policy for the air pollution that is caused by freight transport over rail. The share of diesel locomotives, relative to the NO_X and PM_{10}-emissions of European road transport, has after all always been rather small, about 3 and 1% respectively. Still there are four arguments to be given to take on these emissions.

The first argument is the expected strong increase of the above-mentioned share in the coming years. The causes for this are:

- the EU intention to absorb the expected growth in transport by means of rail transport;
- the expansion of the EU with the accession countries, that generally have a larger share of non-electrified rail tracks;
- the liberalisation of the rail transport sector, with many new small transport companies that largely operate diesel locomotives;
- the rapid increase in the environmental performance of road transport.

The second argument is the fact that at the moment the diesel locomotive, besides the sea vessel, is the only transport mode that is not subject to emission standards. Engines of lorries, inland navigation vessels and aircraft are all subject to such standards. Especially in road transport the emission standards are strict; truck engines that are produced from 2009 onwards will emit 80 to 90% less than engines from 1990.

The third argument is a consequence of the second: rail transport will have to deal with the emissions of diesel locomotives in order to maintain its image as a relatively clean mode of transport. The current NO_X and PM_{10}-emissions of transport by means of diesel powered trains are equal to or higher than that of transport by lorry and will fall behind in the coming years.

The fourth argument is cost-effectiveness. Now that other transport modes need to take ever more expensive measures to reduce their emissions, it seems only logical to investigate whether those reductions are far more cost-effective in diesel locomotives.
At the moment EU directive 97/68/EC on the emissions of non-road mobile machinery is under revision. This directive covers the engines of diesel powered railcars that are used for the transport of passengers. Recently the Environment Council has proposed to include diesel locomotives with an engine power rating of over 560 kW in this directive. The Dutch ministry of environment supports this development and has asked CE to undertake an orientative study into the developments in the market for diesel locomotives and their current and future environmental performance.

Objectives

This study has three objectives:

1. To increase understanding of the current and future use of diesel locomotives.
2. To analyse the technical possibilities to reduce the emissions from diesel locomotives.
3. To show policy options that stimulate the reduction of emissions from diesel locomotives.

The market for diesel locomotives

The use of diesel locomotives in Europe varies and depends on the degree in which railway lines are electrified. The total number of diesel locomotives in the EU-15, Switzerland and Norway is about 13,000 units. The average engine power rating is about 1,000 kW, where the average engine power of an electric locomotive is much larger: about 4,000 kW.

On the basis of an average lifetime of 30 years it can be estimated that yearly several hundreds of diesel locomotives are sold. Besides the selling of new locomotives and engines also retrofitting of new engines in existing locomotives takes place. The degree in which this happens is unknown, but it is an important sideline of the manufacturers.

Beside application in locomotives the engines are also used as engine for inland navigation ships or in road vehicles. The market for these engines is therefore larger than mentioned above, which makes investments in environmental improvements more profitable. In addition, manufacturers can benefit from the developments in truck engines.

In the EU-15 there are about 500 railway companies. Six large (national) companies take care of two-thirds of the transported volume over rail. Generally, rail transport companies prefer electric locomotives because these are cheaper to operate. However, many times there are technical barriers that prevent the use of electric locomotives. In these cases the diesel locomotives proves to be a flexible alternative that is also cheaper to buy. Especially the lower purchase price carries great weight for the small rail transport companies that have emerged on the market after it opened up.

Use, emissions and current emission standards

The user characteristics of diesel locomotives, according to experts, correspond with the ISO 8178/F test cycle which consists of 60% idle, 15% partial load and 25% full power. There are however large deviations possible in practice, especially between shunting and main line conditions.

The NO_X-emissions that are measured over this test cycle range between 10-15 g/kWh. For PM_{10} the measurements vary between 0.10 and 0.50 g/kWh. A reasonable average for the emission factors of the current fleet in the EU-15 seems to be 12 g/kWh for NO_X and 0.40 g/kWh for PM_{10}.

The Union Internationale des Chemins de Fer (UIC), of which almost all large railway companies are associated, sets emission standards for the rolling stock of its members. There is however no active check on the compliance and sanctions on non-compliance do not exist. The UIC-standards for 2003 are stricter than the current average emission factor: 9.5 and 0.25 g/kWh for NO_X and PM_{10} respectively. In 2008 these standards are further tightened to 6 and 0.20 g/kWh. In the recent proposal for the inclusion of diesel locomotives in the directive on non-road mobile machinery, the Working Party Environment of the Council adopts the UIC-standards and proposes a further tightening from 2012 onwards.

In the United States the EPA has set emission standards for diesel locomotives that roughly corresponds with the UIC-standards, but are based on other test cycles that are specially designed for locomotives. These cycles distinguish between shunting conditions and mainline operational conditions.

Technical options for emission reduction
Possible technical options to reduce emissions consist of a further optimisation of the engine and application of after-treatment of exhaust gases. In addition the fuel quality can be improved, particularly by a reduction of the sulphur content.

Optimisation of the engine can achieve an emission reduction of 50% at most. The costs amount about 10-15% of the purchase price of an engine. In addition the fuel consumption can increase slightly. In the current state-of-the-art diesel locomotives, which comply with the UIC-2003 standards injection retarding, electronic motor-management and turbochargers are applied. In order to comply to the 2008-standards an optimisation of the existing systems will do and catalyst converters or particle filters are not necessary.

The after-treatment of exhaust gases comes into focus with a further reduction of the standards. The extra investment costs of these options are hard to estimate at the moment, but are believed to range between 20 and 50 € per kW of engine power for a particle filter or SCR system.

The sulphur content of diesel, that currently is allowed to be 2,000 ppm at most, will have to decrease for the application of exhaust gas re-circulation and after-treatment techniques. The EPA estimates the extra production costs involved to produce 15 ppm diesel to be 1.3 €ct per liter.

Finally we have investigated what the cost-effectiveness, in terms of € per reduced kg of NO_X and PM_{10}, is, when compared to the options that are considered for truck engines. The uncertainty in these estimates is large, as both costs and environmental effects are for the moment fairly uncertain. The result is shown in Table 1.

Table 1 An indication of cost-effectiveness of various measures to reduce NO_x and PM_{10}-emissions of diesel locomotive and lorries

	Annual costs (€/ locomotive)	Reduction %		Cost effectiveness (€/kg)	
		NO_X	PM_{10}	NO_X	PM_{10}
diesel locomotives					
Improved Combustion	~ 5,700	~20	~ 20	~ 1	~ 15
Selective Catalytic Reduction (SCR)	~ 16,000	~70		~ 1.5	--
Diesel Particle Filter	~ 11,200		~ 70	--	~ 25
lorries					
EURO IV → EURO V lorries	~ € 700 per lorry	~40		~ 5 - 10	--

Form the table we can conclude that it is very likely that technical measures in diesel locomotives are much cheaper than the technical measures that are foreseen for truck engines. From the point of cost-effectiveness measures for diesel locomotives are therefore justifiable.

Policy options to reduce emission from diesel locomotives
We have studied three policy options to reduce the emissions of diesel locomotives.

The first option is the introduction of emission standards for new diesel locomotives. As we have seen this is a cost-effective option for the reduction of emissions. A drawback of this option is that it slowly affects the emissions of the entire fleet of diesel locomotives.

The second option is a differentiation of the user charge for rail infrastructure on the basis of these emissions standards. This proves the most cost-effective option for the reduction of emissions. This is due to the facts that rail transport companies have the freedom to take measures in the entire range of company activities (including logistical and load optimisation) in response to the charge differentiation.
The third option is the introduction of a minimum level for the excise duty on diesel for diesel locomotives. This option has the advantage that it improves the functioning of the internal market (at the moment the excise duty varies between 0 and 0.47 € per litre) and that it gives an incentive to reduce fuel consumption and CO_2-emissions. However, for the reduction of NO_X and PM_{10}-emissions this option is less effective and efficient.

We have subsequently estimated the possible effects of an EU-wide introduction of these options on the emissions of NO_X and PM_{10} of diesel locomotives in 2020. When the proposed emissions standards are indeed adopted, this will lead to a reduction of the emissions in 2020 of about 30%. A differentiation of the user charge with a range of about 0.8 € per train-km could lead to a reduction of about 50%. Finally, an excise duty at the minimum level for road transport (30 €ct per litre) results in a reduction of about 5%, next to a reduction of CO_2-emissions.

Recommendations

On the basis of the findings of this study, the arguments given in the introduction and the future developments in European rail transport, we recommend:

- to introduce phased standards at the EU-level for the emissions of NO_X and PM_{10} of new diesel locomotives;
- to stimulate the actual *use* of cleaner locomotives as much as possible by differentiation of the existing user charges for rail infrastructure on the basis of these emission standards.

In addition, the functioning of the market of international rail transport can be improved, and the CO_2-emissions reduced when an EU-minimum level for the excise duty on diesel for locomotives is introduced.

Samenvatting

Aanleiding: milieuprestatie diesellocomotieven blijft achter
In het Europese verkeer- en milieubeleid is er tot dusverre nauwelijks aandacht geweest voor de luchtverontreiniging die wordt veroorzaakt door vrachtverkeer over het spoor. Het aandeel van diesellocomotieven ten opzichte van de NO_X- en PM_{10}-uitstoot van het Europese goederenwegvervoer is immers altijd niet zo groot geweest, ruwweg respectievelijk 3 en 1%. Toch is er een viertal reden op te noemen om deze uitstoot aan te gaan pakken.

De eerste reden is dat het bovengenoemde aandeel de komende jaren flink zal toenemen. De oorzaken hierachter zijn:

- het voornemen om een groot deel van de verwachte vervoersgroei op te vangen met het spoorvervoer;
- de uitbreiding van de EU met de toetredingslanden, die in het algemeen meer ongeëlektrificeerd spoor hebben;
- de liberalisering van de railsector, met veel nieuwe kleine vervoerders die vaker diesellocomotieven gebruiken;
- de snelle milieuverbeteringen in vooral het wegverkeer.

De tweede reden is dat de diesellocomotief op dit moment - naast het zeeschip - het enige vervoermiddel in Europa is waaraan nog geen eisen voor de uitstoot zijn gesteld. Voor motoren van vrachtauto's schepen en vliegtuigen bestaan er al wel eisen. Met name in het wegtransport zijn de eisen fors; vrachtautomotoren die vanaf 2009 worden geproduceerd zullen 80 tot 90% minder NO_X en PM_{10}-uitstoten dan motoren uit 1990.

De derde reden is een gevolg van de tweede: het spoorvervoer zal de emissies van diesellocomotieven moeten aanpakken om haar imago van relatief schone vervoerwijze te kunnen bestendigen. De huidige uitstoot van NO_X en PM_{10} van vervoer per dieseltrein is gelijk aan of slechter dan vergelijkbaar vervoer per vrachtauto, en zal de komende jaren verder achterraken.

Een vierde reden is kosteneffectiviteit. Nu andere vervoerwijzen steeds duurdere maatregelen moeten treffen om hun uitstoot te verminderen ligt het voor de hand om te kijken of verminderingen bij diesellocomotieven niet veel kosteneffectiever zijn.
Momenteel wordt EU-richtlijn 97/68/EC voor emissies van mobiele werktuigen gewijzigd. Onder deze richtlijn vallen ook de motoren van spoorrijtuigen met dieselaandrijving die bestemd zijn voor het vervoer van passagiers (de zogenaamde railcars). Recent is een voorstel gedaan voor de opname van diesellocomotieven met vermogens boven de 560 kW in deze richtlijn en het stellen van emissie-eisen. Het Ministerie van VROM steunt deze ontwikkeling en wil zich hiervoor sterk maken. Ze heeft daarom aan CE gevraagd een verkennend onderzoek uit te voeren naar de ontwikkelingen in de markt voor diesellocs en de huidige en toekomstige milieuprestatie van deze voertuigen.

Doel
Deze studie heeft een drieledig doel:

- het vergroten van het inzicht in het huidige en toekomstige gebruik van diesellocomotieven;
- het analyseren van technische maatregelen om de uitstoot van diesellocomotieven te verminderen;
- het in beeld brengen van enkele beleidsopties om de uitstoot van diesellocomotieven te verminderen.

De markt voor diesellocomotieven
Het gebruik van diesellocs varieert in Europa en hangt af van de mate waarin spoorlijnen geëlektrificeerd zijn. Het totale aantal diesellocomotieven in de EU15 plus Noorwegen en Zwitserland is momenteel ca. 13.000 stuks. Het gemiddelde motorvermogen is ongeveer 1.000 kW, terwijl het vermogen van een elektrische loc veel groter is: gemiddeld rond de 4.000 kW.
Op basis van een gemiddelde levensduur van 30 jaar kan worden geschat dat er jaarlijks enkele honderden nieuwe locs op de markt worden gebracht. Naast de verkoop van nieuwe locomotieven en motoren vindt er ook zogenoemde 'retrofitting' van motoren plaats in bestaande locs. De mate waarin dit plaatsvindt is onbekend, maar het is een belangrijke nevenactiviteit van de fabrikanten.
Naast toepassing van motoren in locomotieven zijn er ook toepassingen als scheepsmotor of bij wegvoertuigen. Hierdoor is de markt voor motoren groter dan hierboven aangeduid en dat maakt investeringen in schone technologie rendabeler. Bovendien kunnen fabrikanten profiteren van de ontwikkelingen bij de vrachtautomotoren.

In de EU-15 bestaan ca. 500 spoorwegbedrijven. Zes grote (nationale) bedrijven verzorgen tweederde van het vervoerde volume. In het algemeen verkiezen railvervoerders elektrische locomotieven omdat die goedkoper zijn in het gebruik. Vaak zijn er echter technische belemmeringen die het gebruik van elektrische locs onmogelijk maken. De dieselloc is dan een flexibel alternatief, dat bovendien in aanschaf voordeliger is. Met name dat laatste telt zwaar voor de kleine spoorvervoerders die sinds het openstellen van de markt zijn toegetreden.

Gebruik, emissies en bestaande emissie-eisen
De gebruikerskarakteristiek van diesellocomotieven komt volgens deskundigen goeddeels overeen met de ISO 8178/F cyclus, welke bestaat uit 60% stationair, 15% deellast en 25% vollast. Er zijn echter flinke afwijkingen mogelijk, met name tussen rangeren en rijden op de lange afstand.
De NO_X-emissies die zijn gemeten over deze cyclus variëren van 10 tot 15 g/kWh. Voor PM_{10} variëren de metingen van 0,10 tot 0,50 g/kWh. Een redelijk gemiddelde voor de emissiefactoren voor het huidige park in de EU-15 lijkt 12 g/kWh voor NO_X en 0,40 g/kWh voor PM_{10}.

De Union Internationale des Chemins de Fer (UIC), waarbij vrijwel alle grote spoorwegmaatschappijen zijn aangesloten, stelt emissie-eisen aan het nieuwe materieel van haar leden. Ze controleert deze eisen echter niet actief en verbindt geen sancties aan overtreding. De UIC-eisen voor 2003 zijn strenger dan de gemiddelde emissiefactor, namelijk 9,5 en 0,25 g/kWh voor NO_X en PM_{10} respectievelijk. In 2008 worden deze normen aangescherpt naar 6 en 0,20 g/kWh. In het recente voorstel voor opneming van diesellocs in de richtlijn voor mobiele bronnen neemt de Europese Commissie de eisen voor 2008 over en stelt een verder aanscherping voor vanaf 2012.
In de Verenigde Staten bestaat er wel EPA-wetgeving op het gebied van diesellocomotieven, welke grofweg overeenkomt met de UIC-eisen maar die

over andere, speciaal voor locomotieven ontwikkelde, testcycli wordt gemeten. Deze cycli maken onderscheid tussen rangeeromstandigheden en vervoersomstandigheden.

Technische opties voor emissiereductie

Mogelijke technische maatregelen om emissies te reduceren bestaan uit een verdere optimalisatie van de motor en toepassing van nabehandeling van uitlaatgassen. Daarnaast kan de brandstofkwaliteit worden verbeterd door met name een verlaging van het zwavelgehalte.

Optimalisatie van de motor kan een emissiereductie van maximaal 50% bewerkstelligen. De kosten bedragen ca. 10-15% van de aanschafprijs van een motor. Daarnaast kan het brandstofverbruik licht stijgen. In de huidige state of the art diesellocs, welke voldoen aan de UIC normen van 2003, worden injectievertraging, elektronische motor management systemen en turboladers toegepast. Om aan de 2008-normen te voldoen, kan worden volstaan met de optimalisatie van bestaande systemen, zonder de toepassing van katalysatoren en deeltjesfilters.

Deze nabehandeling van uitlaatgassen komt in zicht bij een verdere verscherping van de normen. De extra investeringskosten van deze opties zijn op dit moment lastig in te schatten maar variëren tussen 20 en 50 € per kW motorvermogen voor een deeltjesfilter of SCR systeem.

Het zwavelgehalte van de brandstof, dat nu maximaal 2.000 ppm mag zijn, zal voor het toepassen van uitlaatgasrecirculatie en uitlaatgas-nabehandelingstechnieken omlaag moeten. Een schatting van de EPA gaat ervan uit dat de extra productiekosten voor 15 ppm diesel ca. 1,3 €ct per liter bedragen.

Ten slotte hebben we bekeken hoe kosteneffectief deze verbeteropties zijn in € per verminderde kilogram NO_X en PM_{10} vergeleken met de verbeteropties die nu bij vrachtautomotoren worden overwogen. De onzekerheid in deze schattingen is hoog omdat zowel kosten als milieueffecten vooralsnog tamelijk onzeker zijn. Het resultaat staat in Tabel 2.

Tabel 2 Een indicatie van de kosteneffectiviteit van verschillende maatregelen om de uitstoot van NO_x en PM_{10} te verminderen bij diesellocomotieven en vrachtauto's

	jaarlijkse kosten (€/ locomotief)	reductie %		kosteneffectiviteit (€/kg)	
		NO_X	PM_{10}	NO_X	PM_{10}
Ddiesellocomotieven					
Verbeterde verbranding	~ 5,700	~20	~ 20	~ 1	~ 15
Selectieve Katalytische Reductie (SCR)	~ 16,000	~70		~ 1.5	--
Diesel-deeltjesfilter	~ 11,200		~ 70	--	~ 25
Vrachtauto's					
EURO IV → EURO V	~ € 700 per vrachtauto	~40		~ 5 - 10	--

We kunnen uit de tabel opmaken dat het heel waarschijnlijk is dat maatregelen aan diesellocomotieven veel goedkoper zijn dan maatregelen die bij vrachtautomotoren op de rol staan. Vanuit het oogpunt van kosteneffectiviteit zijn maatregelen aan diesellocomotieven daarom goed verdedigbaar.

Beleidsmaatregelen voor minder uitstoot van diesellocomotieven

We hebben een drietal maatregelen voor vermindering van de uitstoot van diesellocomotieven onder de loep genomen.

De eerste is invoering van emissienormen aan nieuwe diesellocomotieven. Zoals we hebben gezien is dit een kosteneffectieve optie voor vermindering van de emissies. Een nadeel is dat deze optie slechts heel langzaam doorwerkt in de uitstoot van de totale vloot van diesellocomotieven.
De tweede is differentiatie van spoorinfrastructuurheffing op basis van deze emissienormen. Dit is de meest effectieve en kosteneffectieve optie voor de reductie van emissies. Dit komt doordat spoorvervoerders de vrijheid hebben maatregelen te nemen in het hele spectrum (inclusief logistieke en beladingoptimalisatie) van bedrijfsactiviteiten als antwoord op de heffingsdifferentiatie.
De derde optie is de invoering van een minimumniveau voor de accijns op diesel voor diesellocomotieven. Deze optie heeft als voordelen dat ze de werking van de interne markt verbetert (momenteel variëren de niveaus van 0 tot 0,47 €/liter) en dat ze een prikkel geeft voor vermindering van brandstofverbruik en CO_2-emissie. Voor reductie van NO_X- en PM_{10}-uitstoot is dit echter een minder effectieve en kosteneffectieve optie.

Vervolgens hebben we een inschatting gemaakt van de mogelijke effecten van een EU-brede invoering van deze opties op de uitstoot van NO_X en PM_{10} van diesellocomotieven in 2020. Wanneer de voorgestelde emissienormen inderdaad worden aangenomen leidt dit tot een ca. 30% lagere uitstoot in 2020. Een differentiatie van de gebruikersheffing met een range van ca 0,8 €/treinkm kan leiden tot een vermindering van maximaal ca. 50%. Ten slotte kan een accijnsniveau ter hoogte van het minimumtarief voor het wegvervoer (30 €ct per liter) leiden tot een reductie van ca. 5%, en daarnaast ook tot minder CO_2-uitstoot.

Aanbevelingen
Op basis van de bevindingen van deze studie, de in de inleiding gegeven argumenten en de geschetste toekomstige ontwikkelingen in het Europese spoorvervoer, bevelen we aan:
- gefaseerde normen in te voeren op EU -niveau voor de uitstoot van NO_X en PM_{10} van nieuwe motoren voor diesellocomotieven;
- het daadwerkelijke *gebruik* van schonere locomotieven zoveel mogelijk te stimuleren door de bestaande heffingen voor het gebruik van spoorinfrastructuur de differentiëren op basis van deze normen.

Daarnaast kan de marktwerking in het internationale spoorvervoer worden verbeterd en de CO_2-uitstoot worden verminderd door een EU-minimumniveau in te voeren voor de accijns op diesel voor locomotieven.

1 Introduction

1.1 Background and prospects

At the moment there is no EU policy on emissions and noise from diesel locomotives that are used for rail transport. For the other modes of transport - road transport and inland shipping - emission standards are already in effect and generate results.
Especially in road transport progress in emission reductions has been impressive over the past decade, and emissions of NO_X and PM_{10} are decreasing in spite of the large growth in vehicle kilometres. Environmental improvements in the rail transport sector progress however very slowly.
From the point of fairness it can be argued that not only the road transport sector can be forced to reduce emissions, especially not when the environmental performance of road transport is better.
In addition the measures that the road transport sector needs to take in order to comply to future, more stringent emission standards will be relatively expensive. At the same time relatively cost-effective options for the rail transport sector are still open.
Finally one can argue that the introduction of pricing principles in rail traffic is in line with the European policy principles of the White Paper that strives for the internalisation of the external costs of all transport modes.

One possibility to improve the environmental performance of rail transport is to set emission standards. At the moment there is an opportunity for this through the amendment of the EU-directive 97/68/EC on emissions from non-road mobile machinery that is currently under discussion. However, in its latest proposal the Commission argues that inclusion of diesel locomotives in the directive is not feasible because this requires the definition of a separate test cycle to reflect the operating conditions of locomotives. Furthermore, the Commission argues that from an inventory it appears that the size of the emissions is too small to justify emission standards. In order to investigate future options for emission standards the Commission recommends further study. While writing this report, the Working Party Environment of the Council has laid down a proposal for the inclusion of diesel locomotives in the Directive. This proposal is supported by a majority of the Member States and will therefore likely be adopted. Further details on the emission standards that are contained in this proposal are given in section 6.3.

With a lack of EU emission standards for diesel locomotives and the progress in the other modes the diesel locomotives are expected to fall behind in environmental performance. As a consequence, the current share in transport emissions in the EU (ca. 5-10%) is expected to increase over the coming years. This is undesirable and would possibly have consequences, since the EU countries committed themselves to national emission ceilings (NEC) in EU Directive 2001/81/EC.
In addition to a lack of emission standards we foresee 3 important developments that will influence rail transport in the EU over the coming years and that will possibly lead to a larger use of diesel traction:

1. The intention to enlarge the modal share of rail transport (and inland shipping) in relation to road transport, as stated in the EC White paper.
2. The liberalisation of the EU rail transport market.
3. The enlargement of the EU with the accession countries.

Below we address these developments in more detail.

1.1.1 Influence of the White Paper

In its White Paper “European Transport Policy for 2010: time to decide” the European Commission states that it wishes to stimulate rail transport. This it will do by investments in infrastructure, improvements in safety and opening up of the market. The investments in infrastructure should allow for a Trans European Network (TEN) of railways that connect important trading and transit locations by means of a high capacity, rapid and efficient network.
Unless the growth of rail transport is facilitated by the use of electric traction this policy is expected not to be beneficial to the environment per se. In this respect the White Paper only proposes to start a dialogue with the rail industries on voluntary emission standards.

1.1.2 Liberalisation of the rail transport market

To improve the effectiveness and competitive power of the transport by rail, the European Council decided to liberalise the rail sector. This started in 1991 by separation of the ownership and exploitation of the track and third party access (91/440/EEG).

At the moment, Europe is working on the improvement of ‘interoperability’. This implies that technical and organisational differences between Member States have to be neutralised. The goal is to obtain smooth rail traffic throughout all Member States. By 1 January 2006, the European rail network will be opened to international rail freight competition. From 1 January 2008, the internal market will be opened to national rail freight competition (cabotage) as well.

As a results of possibilities for third party access a number of new companies emerged on the rail transport market, mainly to transport freight. In the Netherlands for example these relatively small companies operate a small fleet of locomotives. Since some parts of the Dutch railways are not electrified, for example parts in the Rotterdam seaport area, these companies use mainly diesel locomotives. Only large railway companies, such as Deutsche Bahn or Raillion Benelux, possess a large enough fleet and have the financial strength to allow the purchase and use of both diesel and electric locomotives.

1.1.3 Expansion of the EU market with accession countries

Over the next years the European Union will expand with the accession of several East-European countries, such as Poland and the Czech Republic. This expansion will enlarge the European internal market and will add thousand of kilometres of railways to the European network.
A large part of these railways is not electrified yet and electrification will probably take many years, if executed at all. As a consequence, the locomotive fleet of the accession countries largely consists of diesel locomotives. Added up with the relatively large modal share of rail transport in these countries (ca. 40%), we can expect the importance of diesel traction for rail transport in Europe to increase in the next years. This expectation is further fed by the fact that railway companies in the current EU will probably choose diesel traction for transport of freight to and from the accession countries once the liberalisation comes into full effect.

1.2 Objectives of this study

The final objective of this study is to contribute to improvement of the environmental performance of diesel locomotives in European rail transport, by putting this issue on the political agenda. To this end this report tries to provide background information, arguments and options for emission reductions.

1.3 Study demarcations

Focus on freight transport
The prime focus of this study is on European railway companies that transport freight. The reason for this is that we expect international rail transport of freight to benefit the most from the liberalisation, enlargement of the EU-market with the accession countries and EU modal shift policy.

Scope complementary to Commission proposal
The initial Commission proposal on the amendment of EU-Directive 97/68/EC, did not include diesel locomotives but only covered railcars with an engine power below 560 kW (the majority of all railcars). This study has therefore a scope that can be seen as complementary to the initial Commission proposal. However, recently the proposal of the Working Party Environment of the Council on this directive also includes locomotive engines.

Focus on NO_X and particle emissions
This study concentrates on emissions of nitrous oxides (NO_X) and particles (PM_{10}), since these emissions are typical for the diesel engine and are largely responsible for the environmental effects of rail transport.

1.4 Report outline

This report starts with an inventory of the European market for diesel locomotives and engines in chapter 2. With the inventory we try to gain insight into the size and structure of the market as well as the future trends that both the railway companies and the manufacturers expect.
In chapter 3 we aim to give an overview of the emissions of diesel locomotives by describing their characteristics of use as well as the most commonly used emission factors. In this chapter we also give an overview of the current legislation in this field and we address noise.
We compare the emissions of diesel locomotives with other modes of transport in chapter 4. This chapter forms a key chapter in the argumentation for the need to improve the environmental performance of diesel locomotives.
Chapter 5 addresses technical options for the improvement of the environmental performance of diesel locomotives.
The economic incentives that would lead to improvement of the environmental performance of diesel locomotives are described in chapter 6.
Finally, chapter 7 summarises the conclusions and recommendations of this study.

2 The European market for diesel locomotives

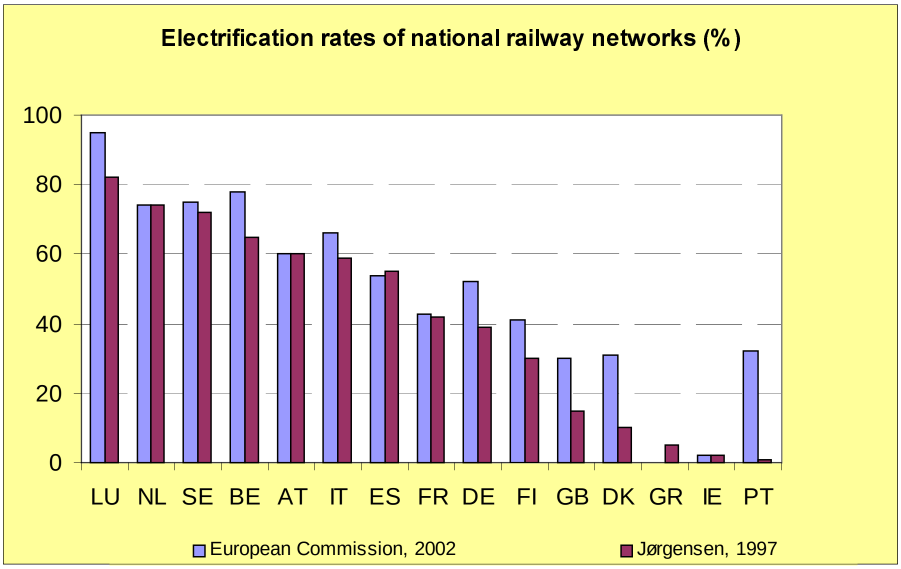
2.1 Introduction

In this chapter, we make an inventory of the European market for diesel locomotives. With the inventory we try to gain insight into the size and structure of the market as well as the future market trends that both the railway companies and the manufacturers expect.

2.2 Size and structure of the European locomotive fleet

The degree of electrification of the railway network varies greatly throughout Europe. This has a major influence on the type of traction that is used. Luxembourg, the Netherlands, Sweden and Austria have the highest rate of electrification. In Portugal, Ireland, Greece, Denmark and the United Kingdom most railroads are not electrified. Figure 1 presents the electrification rates throughout Europe.

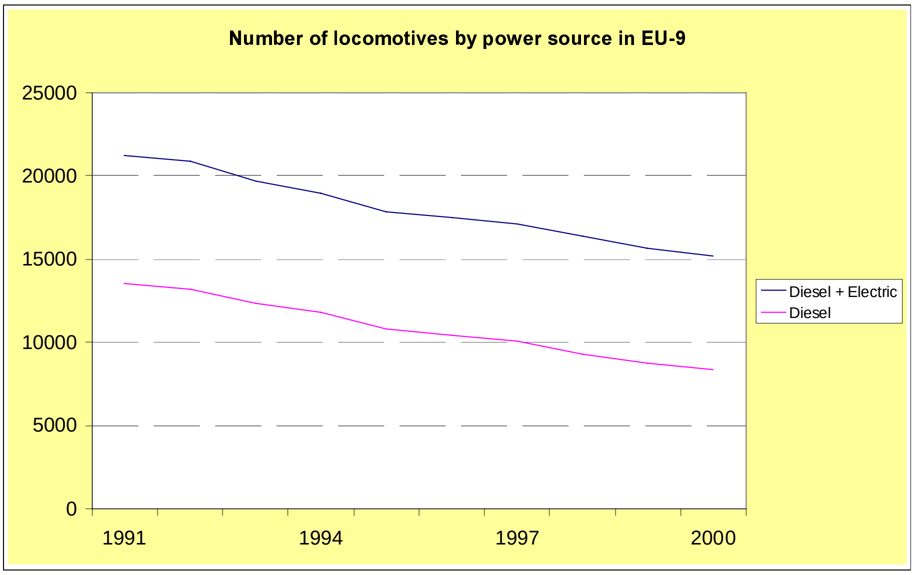
Figure 1 Electrification rates of national railway networks



Source: European Commission (2002); Jørgensen (1997)

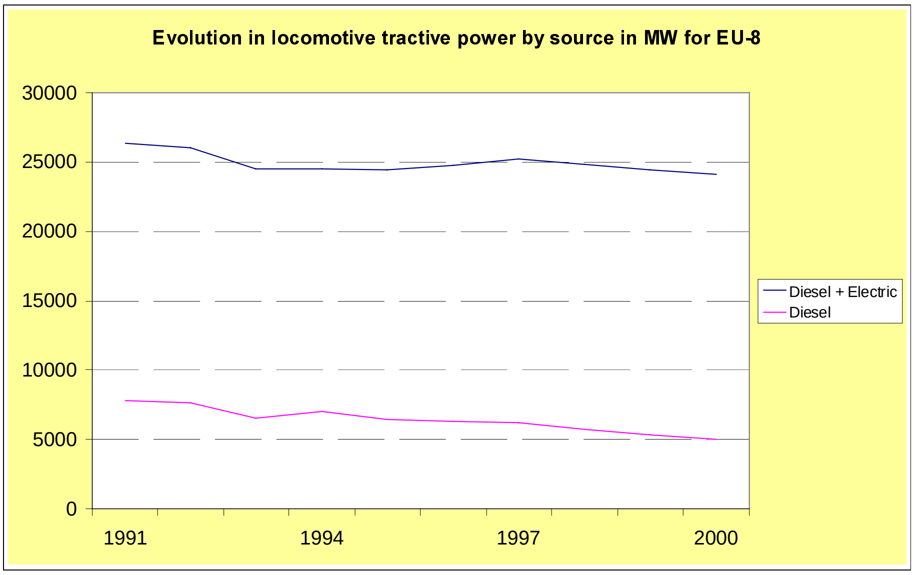
Where railway lines are not electrified there is a need for alternative traction. Diesel traction is the most common alternative. The fleet of diesel and electric locomotives differs considerably in character and has developed differently during the last decade. Figure 2 shows the development in the number and traction power of diesel and electric locomotives in 9 countries of the European Union. Since the statistical data for the entire EU locomotive fleet are far from complete, we can only show a selection. A complete overview of the available data is shown in Appendix A.

Figure 2 Development of the size of the locomotive fleet and average traction power of EU countries between 1991 and 2000



Note: EU-9 refers to Belgium, Germany, Spain, Finland, France, Greece, Ireland, Norway and Portugal.

Source: Eurostat (2002)



Note: EU-8 refers to Belgium, Germany, Spain, Finland, Greece, Ireland, Norway and Portugal.

Source: Eurostat (2002)

During the nineties, the total number locomotives decreased considerably. This is almost entirely caused by a decrease in the number of diesel locomotives. The decrease amounted on average about 40%. The number of electric locomotives remained more or less constant. In the beginning of the nineties, the number of diesel locomotives was twice as high as the number of electric locomotives. In 2000 the number of diesel and electric locomotives were almost equal, each at about 13,000 units throughout Europe. Table 3 gives an overview of the fleet size of each EU country for diesel locomotives.

Table 3 Absolute and relative numbers of diesel powered locomotives in 2000

	NO	CH	LU	NL	SE	BE	AT	IT	ES	FR	DE	FI	GB	DK	GR	IE	PT
%	48	19	76	63	39	58	40	36	51	60	48	78	86	81	96	100	65
Numbers	82	260	61	342	235	565	490	1,164	459	2,974	3,393	492	1,629	95	146	107	149

Note: Danish and Swedish numbers refer to 1999, Austrian numbers to 1997, Swiss numbers to 1996, numbers for the United Kingdom to 1994, Dutch numbers to 1993 and numbers from Luxembourg to 1992.

Source: Eurostat (2002)

From the above it appears that diesel traction, although declining over the past decade, is in relative and absolute terms still an important traction technique. Germany, France, the United Kingdom and Italy have the most diesel locomotives in operation.

Despite the large decrease in the number of locomotives, the total traction power remains more or less constant. This implies an increase of the power per locomotive during the past decades. The average power of a diesel locomotive in 2000 was about 1,000 kW. The average power of an electric locomotive nowadays is substantially higher: about 4,000 kW.

2.3 Types of diesel traction

Traction of diesel powered trains can be achieved by diesel-electric (DE) and diesel-hydraulic (DH) traction. In the case of DE traction, a diesel engine drives an electric generator, which supplies an electric engine. The electric engine drives the locomotive axles. In the case of DH traction, the diesel engine is connected to a hydraulic transmission. This transmission is connected to a drive shaft, which is connected to the drive wheels on the locomotive.

Generally, DH traction is used in railcars (for passenger transport) and in locomotives that are used for shunting. The traction power of DH locomotives is lower compared to DE traction, but DH traction needs less maintenance. DE traction is generally used in the traction of locomotives in medium and higher power ranges, which are the prime subject of this study.

2.4 Demand side: freight railway lines

A multitude of freight railway lines operates on the European track. Since third party access is available, the number of companies has increased from 464 in 1995 to 498 in 1999. However, the main freight railway companies are still the (former) national freight railways. Deutsche Bahn AG in Germany is by far the biggest freight railway company in Europe in terms of transport performance. Table 4 presents the performance of freight transport of the major European railway companies. For comparison, the performance of all EU-15 countries is 250 billion tonne-kilometres in 2000. So, the presented six companies represent about two-thirds of the rail freight market in the EU-15 area.

Table 4 Performance of main European railway companies in 2002

Freight railway line	Million tonnes	Billion tonne-km
DB AG (German State Railway)	199.5	67.0
SNCF (National French Railway Company)	95.3	50.0
ÖBB (Austrian Federal Railways)	63.8	17.6
FS Spa (Italian State Railways)	55.8	17.2
SNCB/NMBS (National Railway Company of Belgium)	38.5	7.2
Railion Benelux	18.4	3.6

Source: UIC Statistics

Since the 1970s, freight transport by rail declined. This continued until 1993, when the market for freight transport slowly started to grow again. This is shown in Figure 3. However, the share of rail transport in the total transport of freight across Europe shows a decline during the nineties because of the much larger growth of road transport (not shown).

Figure 3 Development of the freight transport volume by rail of the 15 EU Member States between 1970 and 2000

Source: European Commission (2002)

As mentioned in section 1.1.2, new railway companies mainly operate diesel locomotives. Examples of these are Shortlines and ACTS in the Netherlands. Their arguments for choosing diesel are:

- lack of electrification on (parts) of railways;
- lower initial investments;
- lack of interoperability across different electric systems within Europe;
- running costs that continue to decrease due to the improvements in fuel efficiency of diesel engines.

Diesel locomotives are mainly used for shunting operations, regional transport and for long distance transport on non-electrified lines. However, in general electric locomotives are cheaper to operate and railway companies stress that they would prefer to use electric locomotives, if operating conditions would allow. Therefore Railion, for example, collects its freight with diesel trains and composes a large train that is pulled by electric locomotives on an electrified shunting area.

In cross-border transport the use of electric locomotives could increase if technical barriers are cleared by harmonisation of standards (e.g. on voltage and safety systems).

2.5 Supply side: locomotive and engine manufacturers

The analysis of the European market for diesel locomotives is complicated by the relatively small size and secluded character of the market in comparison to the market for road engines and trucks. In addition, information on the market situation in Eastern Europe is extremely sparse. Furthermore, the diesel engines that are used for rail generally originate from engines that are developed for other modes, such as road and shipping. Therefore basically any engine manufacturer can claim (to be able) to supply the EU market for diesel engines for rail applications.

Of the manufacturers that build locomotives the largest are:

- Alstom;
- Bombardier;
- Siemens;
- Vossloh.

These manufacturers are responsible for 80% of the EU market. Major diesel engine manufacturers that are active on the EU market include:

- Caterpillar;
- Cummins;
- General Motors;
- MAN B&W;
- MTU Friedrichshafen;
- Pielstick.

For an indication of the number of manufacturers of possible (diesel-rail) engines that are active on the European market, the reader is referred to the website of the association of engine manufacturers, Euromot: http://www.euromot.org/.

There are currently approximately 13,000 diesel engine units present in the EU market. Across Europe the market share of diesels varies considerably, with countries such as Britain, Spain and Portugal overwhelmingly dominated by diesel (80% according an Euromot spokesperson). Whilst Germany, France and the Netherlands are overwhelmingly electrified (<10% diesel).

On the basis of the total number of locomotives, an average life span of 30 years, and the gradual decline in total number of diesel locomotives, it can be estimated that a few hundred diesel locomotives are sold annually in Europe. Usually new locomotives are ordered in batches that are delivered to the operator over the course of several years.

The market size is relatively small compared to the road transport market and this could hamper innovation due to the high costs per engine. Euromot for example argues that the market size does not allow the development of optimised engines for railway traction (Euromot, 2000). However, the engines that are used in diesel locomotives are not developed for application in locomotives only but have a broader application and market. The power range of these engines runs from 100’s of kW (truck engines) to over 3,000 kW (engines that are also used in marine applications). In addition, technology improvements for locomotive engines could benefit from the experiences that are gained in the development of cleaner engines for trucks.

The scale of retrofitting of new engines in existing locomotives must be considered significant concerning the quality and technological level of the diesel locomotives on the EU market. Information regarding retrofitting, in terms of percentage of the market and technology standard that is applied, is difficult to come by. However, from communication with DB Cargo and Alstom, it appeared that they jointly re-engine a substantial number of locomotives. Alstom indicated to give priority to re-engining programs for railway companies.

From discussions with various manufacturers it is believed that the Netherlands, Austria and Denmark are all considering significant purchases of new diesel locomotives in the near future to renew their existing fleet. If so, this means that the environmental performance of these particular fleets will improve.

2.6 Synthesis

The use of diesel- and electric locomotives is largely dependent on the degree of electrification of the railway lines and varies throughout Europe. The total number of locomotives has decreased during the last decade to about 13,000 in the year 2000. This decline is almost entirely cased by a reduction in the number of diesel locomotives. However, the traction power of the remaining diesel locomotives has increased to about 1,000 kW per unit for the year 2000. Germany, France, the United Kingdom and Italy have the most diesel locomotives in operation (about 9,000 units).

The total market for diesel locomotives is estimated at a few hundred per year. This is an average number, as new orders usually come in batches. Besides, re-engining is an important activity: providing old locomotives with new diesel engines. Figures on this activity are not available.
Engine manufacturers argue that the relatively small size of the market makes technological innovations costly. However, the market is probably larger with applications of engines in shipping and road transport as well. Moreover, the manufacturers can benefit from experiences in developing cleaner technology for truck engines.

In the EU-15 there are about 500 railway companies, with six (former) national freight railways responsible for two-thirds of the freight transport volume over rail. In general the operators prefer the use of electric locomotives, because operation cost are less. However, the initial investments of diesel locomotives are substantially lower and their usability is higher, as they can operate on non-electrified tracks.

3 Emissions form diesel locomotives

3.1 Introduction

In this chapter we give an overview of the emissions of diesel locomotives by describing their characteristics of use, as well as the most commonly used emission factors. In this chapter we also address noise. We start this chapter with an overview of existing relevant emission legislation.

3.2 Current emission legislation in the EU

At the moment the EU sets no emission standards for diesel locomotives. However, the Union International de Chemin des Fers (UIC) has recently set emission standards for the rolling stock of its members. These members are mostly the large (national) railway companies. Most of the small railway companies that have emerged on the market in the past few years do not have UIC membership. In the case of the Netherlands, only NS and Raillion are UIC member (both are the largest players in passenger and freight transport respectively).

In the 1980's, the UIC developed Leaflet 623 that describes the procedure for type testing diesel engines for railway applications and includes exhaust emission limit values. Since the first issue of the leaflet in 1984, the limits of exhaust gases permitted by the UIC have tightened, as shown in Table 5. However, since leaflet 623 is not mandatory not every UIC member complied with it.

In 2002, UIC published leaflet 624, which follows its predecessor 623 and gives mandatory emission standards for UIC members. However, there is no active checking mechanism on the compliance of the companies with these new UIC rules. Neither is there any sanction on non-compliance.

Table 5 UIC exhaust emission limit values (g/kWh)

		HC	CO	NO_X	PM_{10}
Limit value applicable from 01/1993		1.6	4	16	1.6
Limit value applicable from 01/1997		0.8	3	12	0.8
Limit value applicable from 01/2003	P≤ 560 kW	0.6	2.5	6	0.25
	P> 560 kW	0.8	3	N >1,000 rpm: 9.5 N ≤ 1,000 rpm: 9.9	0.25
Target objective limit value applicable from 01/2008 on		0.4	2.0	6	0.20

Note: For engines with a nominal power output above 2,200 kW, a particulate emission of 0.5g/kWh is accepted on an exceptional basis until 31 December 2004. However, it is recommended that the limit value of 0.25 will be observed. From 1 January 2005 a limit value of 0.25g/kWh shall be mandatory for all engines.

Source: UIC leaflet 624; Paukert (2001)

The above presented limit values apply to the ISO 8178/F testing cycle. The ISO 8178 standard has been designed for various non-road engine applications. The ISO 8178 is actually a collection of many steady-state test cycles (type C1, C2, D1, etc.). Each of these cycles represents a sequence of several steady-state modes with different weighting factors. Table 6 presents the different weighing factors of the cycle.

Table 6 Weighing factors of the ISO 8178/F cycle

Load	Weighing factor
Idling (5% of load)	60%
Intermediate (60-70% of nominal speed, full torque)	15%
Rated speed	25%

As was indicated in section 1.1 the EU has just proposed a set of emission standards that is based on the ISO 8178/F testing cycle and that is much stricter than the UIC standards. We will discuss these emission standards in greater detail in section 6.3.

3.3 Emission legislation outside the EU

The United States Environmental Protection Agency (US-EPA) has established emission standards for polluting emissions from diesel locomotives in 1997. Three separate sets of emission standards have been adopted, with applicability of the standards dependent on the date a locomotive is first manufactured. ‘Tier 0’ standards apply to locomotives built from 1973 trough 2001, ‘Tier 1’ standards apply to locomotives built from 2002 to 2004. The final set of standards (‘Tier 2’) apply to locomotives built from 2005 on. Table 7 presents the United States emission standards for freight transport by rail.

Table 7 US locomotive exhaust emission standards in g/kWh

Year built		Duty cycle	HC	CO	NO_X	PM_{10}
1973-2001	TIER 0	Line Haul	1.34	6.70	12.73	0.80
		Switch	2.81	10.72	18.76	0.96
2002-2004	TIER 1	Line Haul	0.74	2.95	9.92	0.60
		Switch	1.61	6.70	14.74	0.72
2005+	TIER 2	Line Haul	0.40	2.01	7.37	0.27

Note: The **line-haul duty-cycle** is weighted toward operation in the higher power notches and is typical of line-haul applications. The **switch duty-cycle** is typical of switch operations, with more emphasis on idle and low power notch emissions. Locomotives generally are required to meet the standards for both duty-cycles. However, Tier 0 dedicated switch locomotives rated at 2,300 hp or less are only required to meet the switch duty-cycle standard.

Tier 0 standards apply to all new production locomotives in the 2001 model year, as well as for any 1994 through 2001 model year freight locomotives remanufactured on or after Jan. 1, 2001. They also apply to all other 1973 through 2001 model year locomotives remanufactured on or after Jan. 1, 2002. Other phase-in options are also available for manufacturers (see 40 CFR 92 for more detail on phase-in options). All locomotives with a rated power less than 1,716 kW are classed as shunting locomotives.

Source: US Environmental Protection Agency (2003)

EPA will issue a proposal for the next tier emission standards for locomotives and marine engines by spring 2004.

The EPA have developed their own emission test cycles, as it considered the locomotive cycle of ISO 8178 not to be representative for the operating conditions of the locomotives in the US. Shunting locomotives are tested on a separate ‘switch cycle’ that represents shunting circumstances. Locomotives used for the transport of wagons have to comply with the ‘line-haul cycle’ as well as with the ‘switch cycle’.
A typical American diesel locomotive has 8 power switch notches, plus ‘idle’ and ‘dynamic brake’ positions. The test cycle represents precisely this situa-

tion, weighted for each notch. The Line-haul and 'shunting' test cycle are presented in Table 8.

Table 8 Weighing factors of the US-EPA line-haul and shunting test cycles

Notch	Line-haul (%)	Shunting (%)
Idle	38	59.8
Dynamic brake[1]	12.5	0
1	6.5	12.4
2	6.5	12.3
3	5.2	5.8
4	4.4	3.6
5	3.8	3.6
6	3.9	1.5
7	3.0	0.2
8	16.2	0.8

Considering the US locomotive emission standards and the UIC standards, one can conclude that the order of magnitude of emissions standards and their time schedule are roughly identical. The time between the introduction of new standards is smaller in the United States than with those prescribed by the UIC. It also can be noticed that reduction of NO_X-emissions is stressed by the American standards, whereas the UIC limits are tighter with respect to particle emissions. However, an accurate comparison between UIC limits and EPA limits is problematic since both test cycles are completely different.

3.4 Characteristics of diesel locomotive use

The characteristics of the use of diesel locomotives are important since the use of the locomotive determines the actual emissions. From the European Rail Research Institute (ERRI) we received information on measurements of the user pattern of locomotives of 3 railway companies (Table 9). This user pattern, however, is a pattern that applies to passenger and freight trains, and both electric and diesel traction. It should therefore be seen as a general use pattern.

Table 9 Use characteristics of railcars and locomotives from various railways (as percentage of time)

Railway	Idling (%)	Partial load (%)	Rated speed (%)
EWS (United Kingdom) locomotives	55	18	28
DB (Germany) railcars	58	20	22
DB (Germany) locomotives	48	41	11
NS (Netherlands) railcars	62	15	23
ISO 8178/F	60	15	25

Source: Paukert (2001)

From the table above we can observe a high percentage of idling. This can be explained by taking into account two factors: the first are the long periods

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[1] The 'dynamic brake' position refers to a situation in which an electric motor is used as generator to slow the train.

during which a main-line locomotive is waiting in a station or marshalling yard. As a second factor that contributes to the relatively high share of idling it is noted that a locomotive returns to idling even during running conditions. After an initial acceleration phase during the starting period of a train the throttle is often completely closed and the train maintains its speed for long periods of time due to its low rolling resistance (Paukert, 2001).
As a general conclusion we can state that the use patterns correspond rather well with the pattern of test cycle ISO 8178/F. However, substantial deviations are possible in practice and have been reported, especially between the load profiles of shunting and line-haul locomotives. Particularly the fraction of idling and intermediate load seems to be substantial higher for shunting locomotives than for line-haul locomotives (MTZ, 2002).

3.5 Emission factors

Emission factors from rail traffic have been extensively investigated in the European project “Methodologies for Estimating Air Pollutant Emissions from Transport” (MEET) within the fourth EU framework program. A report from this programme provides NO_X-emissions in the range of 1.2-1.5 grams of NO_X per MJ fuel. PM_{10}-emissions are in the range of 41 to 140 milligrams per MJ fuel, with an average of 76 mg/MJ. This corresponds to values of about 12-15 g/kWh for NO_X and 0.41-1.4 g/kWh for PM_{10}[2].

Recent measurements from a European operator for 3 different types of diesel engines are displayed in Table 10. These factors are weighted over different operating cycles and correspond well with the ranges mentioned above.

Table 10 Recent measurement of emission factors in g/kWh from a European operator

Type	Age	Size class (kW)	CO_2	SO_2	NO_X	HC	CO	PM_{10}
			[g/kWh]	[g/ kWh]	[g/ kWh]	[g/ kWh]	[g/ kWh]	[g/ kWh]
Locomotive	15-20	1,800-3,000	763.5	0.18	14.8	0.6	2.06	0.51
Locomotive	~20+	1,800-3,000	735	0.17	13.07	0.65	2.92	0.91
Railcar	15-20	<560	714.5	0.17	11.16	1.81	3.43	0.77

Source: Georgakaki (2003), processed by CE Delft

A German study that measured emissions from diesel locomotives of several ages on the German track that represent 80% of the German mileage of diesel locomotives, estimated the average NO_X-emissions over the ISO-F cycle at 11.3 g/kWh. The average cycle emissions of particulate matter were estimated at 0.40 g/kWh (MTZ, 2002).
Table 11 shows an overview of the different emission factors that were measured. It appeared from this study that the emissions from measuring point 1 of the ISO-F cycle (nominal power) form the largest fraction of the cycle emissions for all pollutants. For NO_X this fraction is on average 75%.

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[2] Assuming an engine efficiency of 36%.

Table 11 Emissions of NO_x and PM_{10} of different engines over the ISO 8178/F cycle

Manufacturer	Motor type	Rated Power (kW)	Years of construction	NO_X (g/kWh)			PM_{10} (g/kWh)		
MTU	GTO6A	460	1956 – 1964	15.4	11.9	13.8	0.34	0.50	0.33
MTU	12V652TZ10	810	1958 – 1964	7.7	8.3	8.6	0.21	0.17	0.18
MTU	12V652TB10	1,810	1964 – 1979	12.5	11.9	10.8	0.34	0.34	0.34
KAB	12KVD21AL-5	1,100	1967 – 1985	8.4	8.5	8.7	0.89	0.90	0.65
KOL	5D49	2,206	1973 – 1983	14.1	15.0	14.8	0.41	0.82	0.45
MTU	12V956TB11n/o	2,060	After 1995	12.4			0.10		
MTU	8V4000(1)	1,000	2003	7.0			0.086		
MTU	16V40000R40	2,000	After 1997	11.6			0.12		
CAT	3412EDI-TA	480	After 1998	8.4			0.10		

Note: MTU refers to Motoren- und Turbinen-Union Friedrichshafen GmbH, KAB refers to Kühlautomat Berlin, KOL refers to AG “Kolomnaer Werk”, Kolomna, Rußland. CAT refers to Caterpillar Inc., Peoria, USA.

(1) The information from the MTU 8V4000 was received from MTU. This engine is equipped with common rail injection system and an electronic engine management system. www.mtu-friedrichshafen.com

Source: MTZ (2002)

As can be seen from Table 11, there is no clear relation between the age of a locomotive and its pollutant emission factors. However, it seems that the emission factors differ between the different manufacturers and various types of engines. This is in line with comments made by ERRI (Paukert, 2003).

On the basis of the previous information we estimate 12 g/kWh for NO_X and 0.40 g/kWh for PM_{10} to be reasonable averages for the emissions factors of the current EU locomotive fleet. This means that the majority of the locomotives currently in operation do not comply with the current UIC emission standards for new locomotives. However, the most recent engines generally emit less than is required by the 2003 UIC limit values.

3.6 Noise

Noise from diesel locomotives is based on:

- speed, basically rolling noise;
- RPM, or the rotational speed of the engine and ancillary equipment, and can be described as engine or equipment noise;
- power, based on size of engine and therefore related to speed and RPM capacity;
- aerodynamics of engine and train, which influences power requirements and thus engine and equipment noise, as well as wind noise;
- the state of the engine: continuous running (idling, under load), accelerating, decelerating, etc.

The contribution of engine noise is small compared to the contribution from rail/wheel noise from carriages and wagons. Generally, rolling noise takes over above about 30-40 km/h. The most relevant noise emission is therefore that from train pass-bys, as this is experienced most frequently by residents along railway lines. Noise of stationary, braking, accelerating trains and shunting activities is mostly more localised.
According to the Green Paper on Future Noise Policy (COM (96) 540), approximately 7 million persons are exposed to a railway noise level of

65 dB(A) during daytime. This level is normally regarded as above an acceptable level.
Because rail/wheel noise dominates locomotive engine noise has received less attention until now. Possibly the most important source of engine noise (for both diesel and electric engines) is RPM. That is during acceleration RPM may be high, but at speed not. However, at cruising speed RPM may be low, but rolling noise and engine noise, including cooling fans, are high.

Noise emission limits have appeared only more recently in Austria, Finland and Italy, and are under consideration in other countries. Current efforts concerning noise and (diesel) locomotives at the EU level are contained within the Interoperability Directive, which covers both high speed and conventional trains. The basic objective of the Directive is to facilitate exchange across borders regarding trains. Within this Directive, noise limits are being set as described in the technical specifications for interoperability (TSI) which is included as an annex to the Directive. This annex has a section on exterior noise, including limits.
ISO 3095 is the relevant standard for exterior noise and measurement methods. However, it is currently subject to change, and in 2001 a draft was completed. The standard is meant to be finalised in 2003. Perhaps the most controvertible issue is that the load factor is not clearly defined. There are several tests in the standard: pass-by, stationary, and acceleration. The first, the pass-by test is considered the most important. The most important factor that determines the successfulness of the revision of ISO 3095 is agreement with industry on standards and limits.

Concerning noise from diesel locomotive engines there is an enormous spread in noise levels (15-20 dB) which makes setting limits and standards difficult. Therefore there is a need to coalesce the differences to within more manageable limits, making setting and enforcement of noise limits easier. The current approach towards setting limits for engine noise is based on differentiation by nominal power. However, it is probably far better to differentiate on both power and RPM. Manufactures are well aware of developments, possibilities, limits, etc. However, they are not forthcoming over the specifics and up to date information.

The concept of noise limits for not only diesel locomotives but for rail in general is relatively new. As such the industry is negotiating limits. In setting appropriate standards and therefore targets for manufacturers further difficulties are encountered due to the enormous spread and incomparability of data.

3.7 Synthesis

The characteristics of use largely determine the actual emissions from diesel locomotives. It is generally acknowledged by the rail industry that the ISO 8178/F test cycle represents the characteristics of use rather well. This cycle consists of 60% idling, 15% partial load, and 25% rated speed. However, substantial deviations are possible in practice and have been reported, especially between the load profiles of shunting and line-haul locomotives.

It is therefore that in the United States shunting and line-haul locomotives are tested over different cycles. In contrast to the European situation, the US-EPA has set legal standards for locomotive emissions. These standards are more or less comparable with the emission standards that the UIC has voluntarily set for the rolling stock of its members. However, compliance to these UIC standards is not enforced.

Emission factors for NO_X and PM_{10} differ and seem to mainly depend on the type of locomotive and manufacturer and not on age alone. Emission factors for NO_X vary on average from 10 to 15 g/kWh. Emission factors for PM_{10} vary between 0.10 and 0.50 g/kWh. A reasonable average for the emissions factors of the EU locomotive fleet seems to be 12 and 0.40 g/kWh for NO_X and PM_{10} respectively.

The contribution of engine noise is small compared to the contribution from rail/wheel noise from carriages and wagons. Generally, rolling noise takes over above about 30-40 km/h. The most relevant noise emission is therefore that from train pass-bys. Noise standards are relatively new to rail transport and are for the EU-level developed within the Interoperability Directive. Industry is negotiating limits. In setting appropriate standards further difficulties are encountered from the enormous spread and incomparability of data, as well as revision of the measurement procedure.

4 Rail emissions compared to other modes

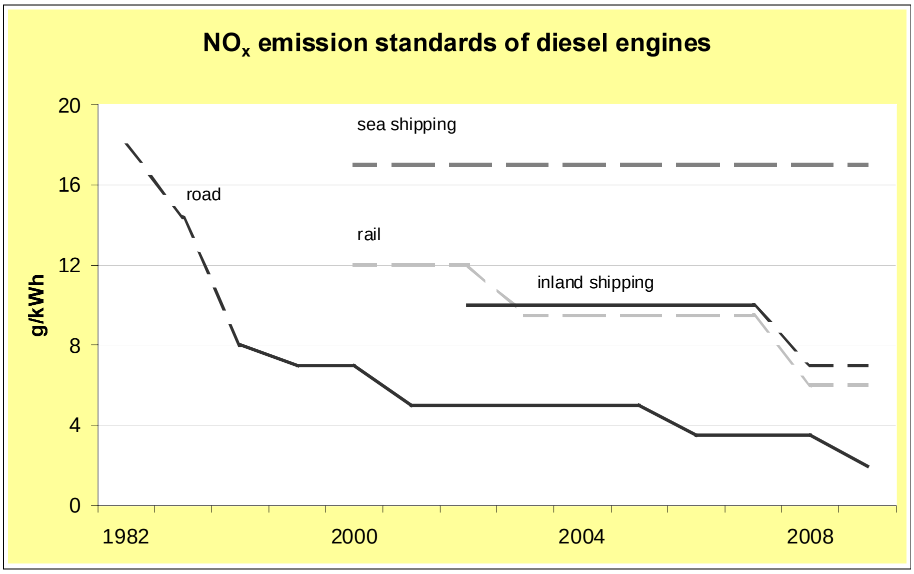
4.1 Introduction

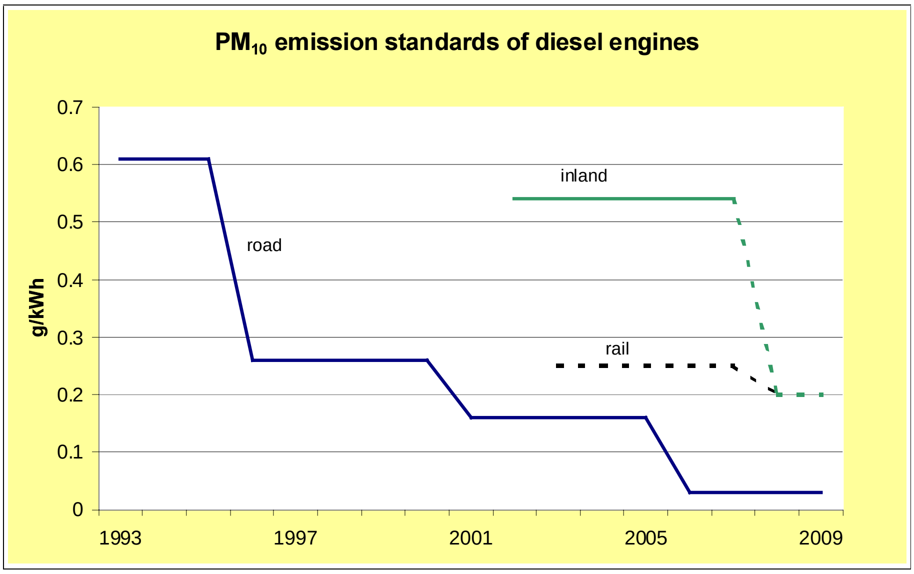
In this chapter we compare the emissions of diesel locomotives with other modes of transport. This chapter forms a key in the argumentation for the need to improve the environmental performance of diesel locomotives.

4.2 Improvements of the environmental performance of modes

During the past decades the environmental performance of transport has changed considerably. Particularly emission standards have contributed to the reduction of emissions, setting a limit to the emission levels of new vehicles. Some of these standards are legal EU standards, other are on a voluntary basis or not yet consolidated in legislation. Figure 4 shows the development for the different freight transport modes of the most important emission standards for diesel engines: NO_X and PM_{10}.

Figure 4 NO_x and PM_{10}-emission standards for different freight transport modes





Source: CE Delft (2002)

Dashed lines indicate standards without a legal status, either voluntary standards or proposed standards but not yet consolidated in legislation.

The above figure shows that the emissions standards are very different for the different transport modes. The environmental performance of road transport has strongly improved in the last decade and is expected to improve even more. The emissions from road trucks in 2009 are expected to be reduced by 90% since 1982 for NO_X and even by 95% for PM_{10} since 1993. Without these improvements, the total NO_X-emissions of road transport in 1998 would have been 50% higher than in 1993.
For rail and inland shipping progress is less distinct. For inland shipping there are no EU standards, but the CCR (Central Commission for Navigation on the Rhine) set the first emission standards a few years ago. These standards became effective at January 2002. At the moment the standards have very limited effects on the emissions because they reflect more or less the current technology. Moreover, they only apply to new engines, and with the long life span of ship engines (on average 30 years) the effects of emission standards will only slowly become visible in the environmental performance of the entire fleet.

For rail transport we need to distinguish between electric trains and diesel trains. The emissions of electric trains depend for a large part on the emissions of power plants.
For diesel trains EU emission standards are under development, as mentioned earlier. The emission standards that are voluntarily set by the UIC are less restrictive than the standards for road transport, but are expected to tighten in the future. For detailed information on the emission standards we refer to section 3.2.

Comparison of the emission standards does not tell us everything about the actual emissions, because standards only apply to new vehicles and ships, and the consumed energy per tonne-kilometre is not identical for the various modes. Furthermore, in modes with vehicles or ships that have a long life span and slow rate of renewal, the reduction of emissions will take much longer. However, emission standards give a good picture of the future progress of emission reduction. In the following section, the different modes will be assessed, taken into account their specific in-use characteristics.

4.3 Differences in environmental performance between modes

In this section, we make a comparison of the environmental impacts of different transport modes. Since the environmental performance of the different modes depends largely on specific situations, average figures lead to misunderstandings. Therefore, we present an overview of best and worst cases. We compare rail with its competitors on the market for long-distance transport. Several variables have influence on the bandwidth:

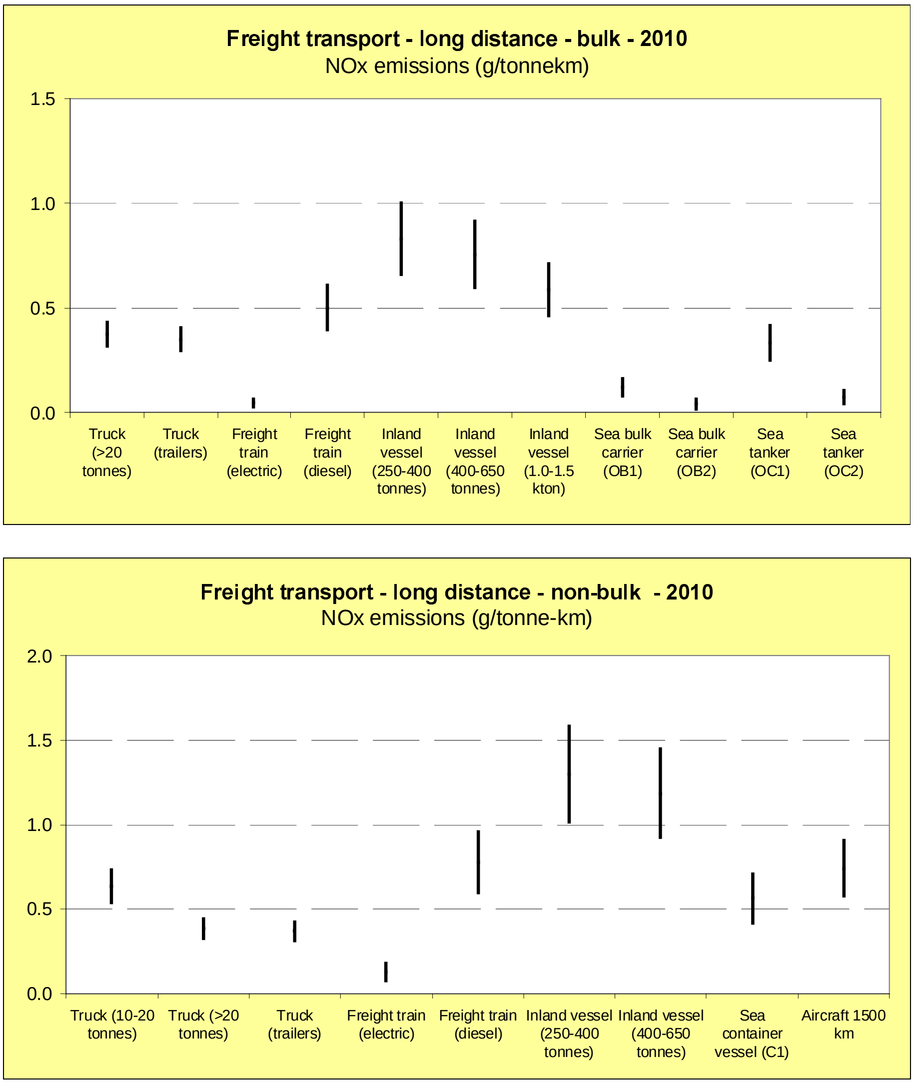
- load factor;
- detouring factor: since the rail network has a less fine structure than the road network, the distance by rail is generally longer. In the case of inland shipping, this factor is even larger;
- speed: increasing the speed of trains from 80 to 100 km/h increases the emissions of NO_X per tonne-kilometre with 30%. Decreasing the speed from 80 to 60 km/h reduces the emissions of NO_X with 30%;
- transport to and from loading points: in our comparison transport to and from loading points is assumed to go by truck.

In the next sections we will focus on the emissions of NO_X and PM_{10} of rail transport in comparison with road transport and inland shipping. However, since the environment debate is expected to focus on CO_2 in the coming decades, it is meaningful to address CO_2-emissions as well. In short, CO_2-emissions from diesel locomotives are generally lower than in road transport. In the case of container transport, the CO_2-emissions can be about a fourth lower. Bulk transport emits on average half of the emissions of road transport. These are average figures, the above mentioned variables have a major influence on emissions.

4.3.1 NO_x-emissions from various transport modes in 2010

Figure 5 shows the results for the bulk market and the container market. For each transport mode the whole range from best case to worst case has been plotted. The time frame is 2010.
As can be seen from this figure, the NO_X-emissions from rail freight transport strongly depend on the type of traction. Electric trains have much lower NO_X-emissions compared to diesel trains. In the case of bulk transport, the NO_X-emissions of diesel trains are more or less in the same range of that of road transport. Container transport by rail generally emits more NO_X per tonne-km than road transport. In general NO_X-emissions from container transport are higher (on a per tonne-km basis) because of the relatively low load factors.

Figure 5 NO_x-emissions per tonne-kilometre of different transport modes (bulk and container transport) in 2010 (g/tonne-km)



Note: The used differences between best case and worst case are:

For best case we assume no transport to and from loading points; for worst case, we assume 0% to 15% for bulk and 0% to 20% for non-bulk, depending on the mode. For all modes transport to and from loading points is assumed to go by large trucks (> 20 tons).

For best case we assume no detour factors; for worst case, we assume a detour factor of 0% to 10%, depending on the mode.

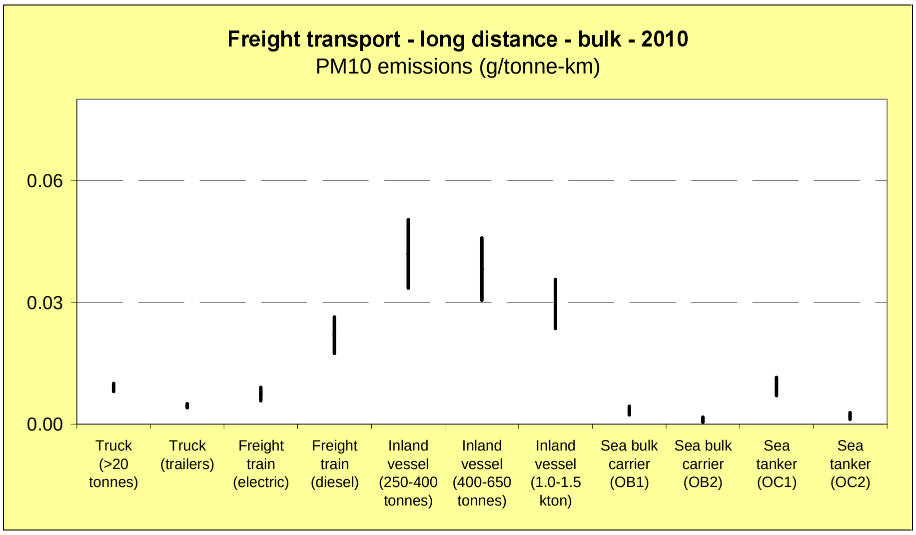
For utilisation factors (the product of the load factor and percentage productive rides) we use an uncertainty margin of 15%. For all modes, the best case is the average load factor multiplied with 1.15; the worst case is the average load factor multiplied with 0.85.

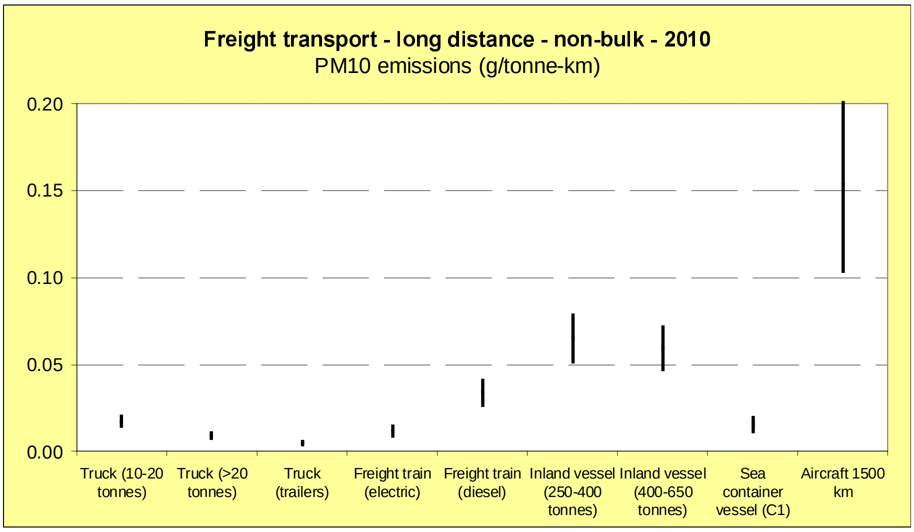
Source: CE Delft (2003)

4.3.2 PM_{10}-emissions from various transport modes in 2010

In this section we compare particulate emissions from various freight transport modes. An overview of best and worst cases, for bulk and container transport is presented in Figure 6.

Figure 6 PM$_{10}$-emissions from different transport modes (bulk and container transport) in 2010 (g/tonne-km)





Note: The used differences between best case and worst case are:

For best case we assume no transport to and from loading points; for worst case, we assume 0% to 15% for bulk and 0% to 20% for non-bulk, depending on the mode. For all modes transport to and from loading points is assumed to go by large trucks (> 20 tons).

For best case we assume no detour factors; for worst case, we assume a detour factor of 0% to 10%, depending on the mode.

For utilisation factors (the product of the load factor and percentage productive rides) we use an uncertainty margin of 15%. For all modes, the best case is the average load factor multiplied with 1.15; the worst case is the average load factor multiplied with 0.85.

Source: CE Delft (2003)

It appears from Figure 6 that particulate emissions from inland shipping are relatively high, compared to road and rail freight transport. PM$_{10}$-emissions from diesel powered freight trains are about a factor five higher than that of electric powered freight trains. Compared to road transport, diesel powered bulk freight transport on rail emits generally 2 to 5 times more particulate matter per tonne-km. With container transport, the differences are smaller.

4.4 Emissions of rail compared to road in 2000 and 2010 (freight)

In this section we make a rough estimate of the development of the emissions from freight transport with diesel locomotives in the EU-15, if no emission reduction measures are implemented. This development is then compared with the emissions from freight transport by road.

The emissions from rail transport can be estimated from the total diesel consumption. Data of the diesel consumption in the EU-15 region in recent years is included in Annex A. From (Jørgensen, 1997) it can be derived that throughout Europe about 50% of all diesel fuel consumed in the rail sector is consumed in freight transport. In the calculation of the total emissions we use the average emission factors that are mentioned in the previous chapter. Based on these figures and assumptions we estimate the NO_X-emissions from diesel locomotives in the EU-15 region in the year 2000 to amount 69 kton. PM_{10}-emissions from rail freight transport on diesel totalled 2.3 kton.

According to the IEA transportation projections in OECD regions, tonne-km on the EU track will increase yearly with 0.1% between 2000 and 2010. Fuel consumption will however decrease with 0.5% per year as a result of improved routing and logistics, reduction in stops and starts and increases in trip lengths. As a net result of these, we assume the emissions of NO_X and PM_{10} to decline with 0.5% yearly. We further assume that no emission reduction measures are implemented.

Table 12 shows the results of our experiment and presents an overview of the emissions of NO_X and PM_{10} for the EU-15 region for freight transport on rail and road.

Table 12 NO_x and PM_{10}-emissions from freight transport on rail and road for the EU-12 region in 2000 (data) and 2010 (estimated)

	Road 2000 (kton)	Road 2010 (kton)	Rail 2000 (kton)	Rail 2010 (kton)	Contribution of rail vs. Road and rail (%)	
					2000	2010
NO_X	1877	996	64	62	3.3	5.8
PM_{10}	180	74	2.1	2.0	1.2	2.7

Note: Emissions from road transport in 2000 and 2010 have been taken from TERM (2002). Total emissions from diesel trains (passenger + freight) in the EU-15 region were about 154 and 8.8 kton for NO_X and PM_{10} respectively in 2000.

Source: IEA Energy balances OECD countries; TERM (2002); Jørgensen (1997); IEA (2002)

From Table 12 it appears that emissions from freight transport on road are expected to decrease considerably in the 2000-2010 period. This is mainly due to the EURO-3, -4 and -5 emission standards that are in effect in that period. For rail transport the emissions from diesel locomotives will only slightly decrease in the coming decade. With slightly decreasing emissions from diesel locomotives and stronger decreasing emissions from road freight transport, the contribution of rail transport relative to road freight transport and diesel fuelled rail freight transport will double to about 6% in 2010 for NO_X and to about 3% for PM_{10}.

4.5 Synthesis

At the moment the emissions per tonne-km of diesel-powered rail transport are comparable (bulk, NO_X) or higher (container, NO_X and PM_{10}) than that of road transport. The emissions of CO_2 are generally lower, especially in bulk transport.

The environmental performance of road transport has been improved considerably during the last decades since EU standards have come into effect. The improvements in road transport will continue with the future Euro-4 and –5 standards that will in the end mean a reduction of 90 - 95% in emission factors during the 1982 - 2009 period. The success in road transport will cause a doubling of the share of emissions from rail transport if no emission reduction measures are implemented.

5 Technical options for emission reduction

5.1 Introduction

This chapter addresses the technical options for the improvement of the environmental performance of diesel locomotives. Section 5.2 examines solutions to improve in-engine conditions in order to lower emissions. In section 5.3 exhaust gas after treatment measures are discussed. Section 5.4 deals with the possibilities of fuel quality improvements to reduce emissions. In section 5.5 we give some estimates for the costs of the technical options.

5.2 In-engine measures

In former days, emission levels of engines applied in trucks and locomotives were similar. Today emissions per kW from locomotive engines are higher because no mandatory legislation calls for improvements. Theoretically, emission levels of truck engines should be feasible. An exemption is probably NO_X, since low speed engines produce more NO_X, as a result of the longer residence time of the fuel/air mixture in the cylinders.
The combustion in a diesel engine takes place as a result of fuel injection in compressed air. The time between the start of the injection of fuel and the actual combustion of this fuel is the so-called ignition delay. The premixed portion of the fuel (mixed during the ignition delay) that does not burn before the time of peak cylinder pressure is particularly important for NO_X-formation. At the moment of ignition, the accumulated fuel burns all at once, resulting in high rising temperatures. This high raised temperature increases the NO_X-formation in the cylinder. For this reason, techniques to control NO_X focus on this early phase of combustion. Unfortunately, most of these techniques resort to reducing combustion temperatures. In so doing, they lead to penalties in hydrocarbon emissions, particulate emissions, and fuel consumption.
It is common to refer to the NO_X/PM_{10} trade-off or the NO_X/fuel consumption trade-off in diesel engines. These expressions point in part to the admission that in-engine measures to reduce NO_X-emissions would invariably lead to increases in particulate emissions as well as fuel consumption, and vice versa.
In (TNO, 2000) an overview of measures to reduce emissions from diesel engines is shown. In the following sections we give the most relevant information.

5.2.1 Injection timing

The delay of fuel injection has a decreasing effect on the formation of NO_X because it prevents high temperatures in the cylinder that occur with early accumulation and combustion of fuel in the cylinder. The delay of fuel injection can reduce the NO_X-formation with 10 to 20%. However, a delayed fuel injection has the undesired effect of an increase in fuel consumption (1.5 – 2.5%), HC-emission and PM_{10}-formation. The PM_{10} increase can however be recovered by increasing the fuel injection pressure (TNO, 2000; Weaver, 1994).

5.2.2 Air intake improvements

Achieving a higher compression pressure in the cylinder at the moment of fuel injection can reduce the ignition delay, which is an important factor in NO_X-formation as we have seen above. A turbo charger can do just that. Besides this effect, the total mass of intake air increases, which results in a lower combustion temperature. These effects reduce the formation of both NO_X and PM_{10}-emissions.
A Turbo charger can be effectively combined with an inter-cooler that cools the air before it enters the cylinder. Due to the lowering of the temperature, the air mass flow into the cylinder can be increased (cold air has a higher density). The increased air mass flow and the lowering of the temperature cause for a reduction of NO_X-formation of about 10% (TNO, 2000).

5.2.3 Optimisation of the combustion system

The air in the cylinder must be used as effectively as possible for mixing in order to reduce the formation of HC and PM_{10}. Proper design of the cylinder bowl can enhance the air swirl created by the intake port, increase turbulence in the cylinder and reduce parasitic volumes (volumes of 'non-mixed' air).

Electronic engine control (or motor management unit) plays a vital role in the exhaust emission control from today's advanced diesel engines. From the emission perspective, the goal of the engine control system is to provide the demanded quantity of fuel, air, and EGR (see below) at the required time and in the required temperature and pressure state.
An electronic control system for diesel engines includes a set of sensors, a microprocessor, and a set of actuators. The sensors measure physical variables and pass the information in the form of electrical signals to the controller. Examples include crank speed, boost pressure, intake manifold temperature and pressure. The actuators perform mechanical actions as directed by signals from the microprocessor. Examples of actuators are EGR valves or variable geometry turbochargers.

5.2.4 Exhaust gas re-circulation (EGR)

(EGR) is a method that allows a significant NO_X-emission reduction from light- and heavy-duty diesel engines. However, the application of EGR is at a price: increased PM_{10}-, HC-, and CO-emissions and reduced fuel economy.

With EGR a part of the exhaust gas is recycled. EGR displaces a portion of the fresh intake air, and thus displaces a portion of the oxygen entrained into the engine. This causes a lower flame temperature in the cylinder during combustion. Since NO_X-formation is strongly flame temperature-dependent, it is suggested that reduced combustion flame temperature is the major reason for NO_X-reduction. Every percent of EGR decreases the NO_X-emission with 4%. With heavy-duty engines, EGR percentages up to 15% can be achieved, resulting in a reduction of the NO_X-emissions with 60% at high engine loads (TNO, 2002).
Without additional measures, the air excess with EGR is lower, increasing the formation of PM_{10}. The formation of PM_{10} is strengthened by the recirculation of exhaust particles that serve as nucleation sites for further particle growth. The fuel consumption also increases with the application of EGR, with 3 to 8%, depending on the application of injection delay (TNO, 2000).

The application of EGR benefits from low sulphur fuels because condensation of sulphuric acid causes corrosion and engine wear. Waste heat discharge of the engine is reduced by EGR, therefore extension and improvement of the cooling system is required.

5.3 Exhaust gas after treatment measures

In this section, we give an overview of technologies that reduce emissions of NO_X and PM_{10} by treatment of the engine exhaust gas. These options can be used in conjunction with the previously addressed in-engine options. To meet emission standards that go further than the proposed 2008 standards by the UIC and European Commission the application of exhaust after treatment systems as SCR (with optimisation for particles) or particle filters combined with EGR is expected (R. von Bischopink, MTU[3]).

5.3.1 Selective catalytic reduction (SCR)

A SCR system reduces NO_X that is present in the exhaust gas and uses urea as reducing agent. The urea degrades by injection in the catalyst to ammonia and carbon dioxide.
SCR systems have been utilised successfully in reduction of NO_X from power plants where they have achieved conversion efficiencies of 90% with the production of electricity. SCR systems will probably also be applied in heavy-duty trucks to meet Euro 4 (2005, 3.5 g/kWh) and 5 (2008, 2 g/kWh) standards. The oxidation catalyst of the system lowers the HC- and CO-emissions with 70 and 50% respectively.

Application of SCR systems could encounter the following problems:

- the installation of a SCR system on a locomotive can give *space problems*. The space necessary is estimated to be about half of the engine volume (R. von Bischopink, MTU);
- the catalyst conversion efficiency depends on the *exhaust temperature*. A SCR system requires exhaust gas temperatures of about 250 – 450°C. From an American study it appeared that exhaust temperatures in the lower notches is too low for NO_X-conversion. However, since NO_X-formation is generally higher with high loads, an overall conversion efficiency of about 70% is achievable. Restricting the intake air at light loads can further increase this conversion efficiency;
- the use of urea brings about *additional costs*, which are around 5% increase of fuel consumption (TNO, 2000; Weaver, 1994).

It is however expected that application of SCR in diesel locomotives can benefit from the (research) experience that is gained with the application in trucks and inland vessels. To our knowledge research into after-treatment technologies for diesel locomotives has been scarcely carried out.

5.3.2 NO_x-adsorber catalysts

The NO_X-adsorber catalyst is a further development of the three-way catalyst technology developed for gasoline powered cars more than a decade ago.
The NO_X-adsorber enhances the three-way catalyst function through the addition of storage materials on the catalyst surface that can adsorb NO_X

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[3] Information from telephone conversation with Rainer von Bischopink, MTU Friedrichshafen at 29-4-2003.

under oxygen-rich conditions. This enhancement means that a NO_X-adsorber can control NO_X-emissions under the lean burn (oxygen-rich) operating conditions that are typical for diesel engines. The adsorber then undergoes subsequent brief regeneration events where the NO_X is released and reduced across precious metal catalysts. The NO_X-storage period can be as short as 15 seconds and as along as 10 minutes, depending on NO_X-emission rates and exhaust temperatures. A number of methods have been developed to accomplish the necessary brief rich exhaust conditions necessary to regenerate the NO_X-adsorber, including e.g. late-cycle fuel injection and in-exhaust fuel injection.

The NO_X-adsorber catalyst for NO_X-control has shown to be highly effective (an effectiveness of about 90% for much of the temperature range of the diesel engine), but has a number of technical challenges associated with it. Primary among these is sulphur poisoning of the catalyst. Also NO_X-control during idle operation eventually diminishes after long periods when temperatures are under 150°C (EPA, 2003; www.dieselnet.com).

A clear advantage of the NO_X-adsorber catalyst is that is does not need a reducing agent as SCR does.

5.3.3 Particle filters

Diesel particle filters (DPF) have the possibility to decrease the emissions of PM_{10} with 80 – 90%. HC and CO-emissions are reduced by 90% since the particles consist of carbon (soot) with hydrocarbons and solid particles attached.

Particle filters have a negative influence on engine operation, since the back-pressure in the exhaust system could increase as the filter contaminates. As a consequence fuel consumption increases and the power output is reduced. Therefore particulate filters have to be regenerated to remove the filtered particles.

The exhaust gas and/or filter temperature is the most important parameter influencing filter regeneration. Self-regenerating particle filters will regenerate themselves automatically by achieving high enough exhaust gas temperatures. However, since the load profile of a locomotive shows high percentages of idling and intermediate power, exhaust gas temperatures can be too long under the limit for regeneration. To prevent this, a catalyst is used to lower the regeneration temperature from about 550°C to about 360°C. The catalyst can be applied as a catalytic coating on the filter or as a so-called fuel borne catalyst in the fuel.

A continuously regenerating trap (CRT) system is a two-stage passive filter. The principle in such a system is that PM_{10} is more easily oxidised by NO_2 than by O_2. With NO_2, the process occurs at temperatures as low as 250°C. The concentration of NO_X in the exhaust gas does not decrease, since NO is oxidised in the oxidation catalyst to NO_2, and reduced to NO again in the filter[4] (source: www.dieselnet.com).

The exhaust gas temperature could pose a problem for the application of a CRT particle filter, mainly at loads below 30-40% of maximum. However, according to Weaver (1994), restricting great quantities of excess air intake

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[4] $NO + \frac{1}{2} O_2 \rightarrow NO_2$ (oxidation) $NO_2 + C \rightarrow NO + CO$ (filter, main reaction)
$NO_2 + C \rightarrow \frac{1}{2}N_2 + CO_2$ (filter)
Where C represents the combustible portion of PM.

can increase the exhaust gas temperature. A temperature of 300°C should be reachable. This is sufficiently high for the application of a CRT system.

As with SCR systems, the application of a particulate filter may need a relatively large amount of space. The reality and gravity of this problem is as yet unclear.

The Swiss railways have positive experiences with the application of DPF systems on locomotives.

5.4 Fuel quality

The sulphur content has influence on the engine emissions, together with other characteristics as cetane number, aromatics, density and distillation characteristics. The influence of the sulphur content is, however, the most significant.

In an engine sulphur will be converted into sulphuric acid. With high fuel sulphur levels, the condensed acid will produce high levels of corrosion and wear in the engine. With application of EGR, the problems with high sulphur contents will further increase.

The current EU-limit for non-road applications is a maximum of 2,000 ppm. From 2008 on this value will be 1,000 ppm (Directive 99/32/EC). The European parliament has been pushing for non-road diesel fuel specifications that meet road vehicle fuel standards (50 ppm from 2005 on and 10 ppm from 2009). However, in conciliation the parliament failed in its bid to extent the current rules for road vehicles.
In the United States, a sulphur fuel limit of 500 ppm will be in effect from 2007 onwards for fuels that are used in non-road, locomotive and marine engines. In 2010, the sulphur content for non-road fuels will have to decrease to 15 ppm. However, this obligation for ultra low sulphur content will not apply to locomotive and marine fuels.

The industry association Euromot assumes only fuels with 50 ppm sulphur and less appropriate for after-treatment systems since the sulphate emissions are the main cause for high particulate emissions (Euromot, 2001):

- diesel particulate filters function better with a low sulphur fuel (10-50 ppm). In general, reduction of the fuel sulphur content minimises the storage of sulphate particles in the filter and the release of them to the environment. The application of low-sulphur fuel also decreases the temperature for regeneration. The long-term durability of a particulate filter is higher with such a low-sulphur fuel;
- a CRT filter is very sensitive to the sulphur content in the fuel. The reduction of the sulphur content from 50 to 10 ppm a) increases the filter efficiency because less sulphate particles are produced in the oxidation catalyst and b) lowers the temperature at which the filter functions efficiently. This is especially important in the case of application in locomotives, as discussed before;
- a SCR system is more or less insensitive to the sulphur content of the fuel, so there are no emission effects to be expected from a reduction of the fuel sulphur content. When the fuel gas contains sulphur, as is the case with diesel exhaust, SO_2 can be oxidised to SO_3 with the subsequent formation of H_2SO_4 upon reaction with H_2O. These reactions are the same as those occurring in the standard diesel oxidation catalyst.

All in all the sulphur-related PM_{10}-emission is estimated to be about 0.03 g/kWh for a sulphur content of 1,500 ppm and 0.04 g/kWh for a sulphur content of 2,000 ppm (Euromot, 2001). This is only about 5% of the PM_{10}-emission of an 'average' locomotive but amounts 30-40% for a state-of-the-art locomotive engine (see also section 3.5). Lowering the sulphur content of the fuel therefore significantly reduces particulate emissions and can be one of the most effective means once the current state-of-the-art locomotives become representative for the entire EU fleet.

A decrease of the content of aromatics, poly-aromatics, density and an increase of the cetane number can also have a positive effect on the emission of pollutants. For NO_X, the total aromatics content is a dominant parameter, whereas density and poly-aromatics are the most dominant in PM_{10}-formation. From the EPEFE study of the Auto/oil I program it appears that in general NO_X will be reduced by 4% if aromatics are reduced from 30% to 10%. A similar reduction is possible for PM_{10} with a reduction of poly-aromatics from 9% to 1%. However, their magnitude is less predictable and ambiguous than the influence of sulphur. An example of the combined effect of the above mentioned measures shows the application of Swedish class 1 fuel instead of the RF-73 reference fuel (Table 13).

Table 13 Influence of fuel quality on NO_x and PM_{10}-emission

Component	RF-73	SC-1	Improvement
NO_X	6.7 g/kWh	5.9	11.8%
PM_{10}	0.12 g/kWh	0.11	8.3%

Note: RF-73 fuel is the Euro II reference fuel and has the following characteristics: density 838 kg/m^3, cetane number 51, total aromatics 17.2% m/m, poly-aromatics 2.5% m/m and a sulphur content of 435 ppm. The Swedish class 1 fuel has density of 815 kg/m^3, 2.7% m/m total aromatics, 0.2% m/m poly-aromatics, a cetane number of 58 and a sulphur content of 10 ppm.

Source: Euromot (2001)

The EPA estimated the cost of producing 500 ppm fuel to be on average 2.5 cents per gallon. Average costs for 15 ppm fuel are estimated to be an additional 2.3 cents per gallon, for a combined cost of 4.8 cents per gallon, which is about 1.3 €ct per litre.

5.5 Costs and cost-effectiveness of measures

Due to the fact that reduction of emissions from locomotives was not high on the agenda until recently, not much information is available about the costs of more advanced engines (injection delay, motor management and high-pressure injection) and filters to reduce emissions of NO_X and particles. However, since the engine types that are installed in locomotives are also used in inland navigation vessels, information from the costs of emission reduction gives information about the costs for locomotives. Also information about the costs use of after treatment systems in non-road mobile machinery is useful. However, this information can only be used for rough estimates.

The additional costs of an engine with delayed injection, electronic engine-management, and high-pressure injection, that can reduce emissions of NO_X and PM_{10} with about 20 %, are about 10 – 15% of the initial purchasing costs. This is about 15,000 € for an engine of 1,000 kW. The operational

cost increase because of an increase of fuel consumption with 3 to 5%, which is about 3 € per MWh (1 hours for an engine of 1,000 kW).
The cost of a SCR system differs throughout various literature sources. The investment costs are estimated between 20 and 50 € per kW. However, this depends on the time and scale of installation (the costs will decrease in the future by wider application in larger volumes) and engine size. The additional operational costs, that consists of the costs of urea that is needed, amount about 3 € per MWh. The purchase costs of a diesel particle filter are in the same order of that of a SCR filter. (European Commission, 2002; Germanischer Lloyd, 2001; EPA, 2003).

Table 14 presents an overview of the cost-effectiveness of various measures and the annual cost, which consist of operational and investment cost. The calculations are further based on the assumption that an average diesel locomotive has a power rating of 1,000 kW and operates about 1,500 full power hours per year.
The investment costs have been depreciated over 20 for in-engine measures and over 5 years for exhaust gas filters. These depreciation periods are taken from a macro-economical point of view. For a private rail transport operator the depreciation period is under five years.
The operational costs are calculated using the data presented above. The environmental effects of the various measures are calculated on the basis of the average emission factors, as described in Chapter 3.

Table 14 An indication of cost-effectiveness of various measures to reduce NO_x and PM_{10}-emissions of diesel locomotives and lorries

	Annual costs (€/ locomotive)	Reduction %		Cost effectiveness (€/kg)	
		NO_X	PM_{10}	NO_X	PM_{10}
diesel locomotives					
Improved Combustion	~ 5,700	~20	~ 20	~ 1	~ 15
Selective Catalytic Reduction	~ 16,000	~70		~ 1.5	--
Diesel Particulate Filter	~ 11,200		~ 70	--	~ 25
Lorries					
EURO IV → EURO V lorries	~ € 700 per lorry	~40		~ 5 - 10	--

When we compare the cost-effectiveness of measures to reduce emissions from diesel locomotives with that of measures to reduce emissions from lorries, it seems very likely that measures in the rail sector have a better cost effectiveness than measures to reduce emissions from road.
For a locomotive that is operated for 1,500 hours per year or more, the cost-effectiveness of in-engine measures is higher than the cost effectiveness of the application of an SCR system or a DPF (particle filter).

5.6 Synthesis

A number of measures exists to reduce NO_X and PM_{10}-emissions. These measures can be divided into in-engine measures, after-treatment of exhaust gases and improvements in fuel quality. Information about the technical feasibility and costs of these measures is rather limited. However, estimates can be made on the basis of information that is available from the application of exhaust gas after treatment on inland navigation vessels and mobile machinery.

In-engine measures (injection retarding, electronic motor-management systems and turbo chargers) can achieve a reduction of NO_X-emissions compared to the current fleet emissions of over 50%.
The initial purchase costs increase by about 10 – 15% or about 15,000 € for an engine of 1,000 kW, compared with an engine that is currently available on the market without these emission reducing options. Such an engine can reduce emissions of NO_X and PM_{10} with about 20%. The operational cost increase because of an increase of fuel consumption with 3 to 5%, which is about 3 € per MWh.

To meet emission standards that go further than the proposed 2008 standards by the UIC and European Commission the application of exhaust after treatment systems as SCR (with optimisation for particles) or particle filters combined with EGR is expected. The estimated investment costs of a diesel particle filter and a SCR system range from 20 to 50 € per kW. For a SCR system the operational cost are about 3 € per MWh.

The fuel quality has a considerable influence on pollutant emissions. A decrease of the fuel sulphur content decreases the formation of particles significantly. Also other fuel characteristics as aromatics, poly-aromatics, cetane number and density have influence on the emissions of pollutants. The EPA estimated the cost of producing 15 ppm fuel to be about 1.3 €ct per litre.

And finally, it is very likely that measures to reduce emissions from diesel locomotives are much more cost effective than additional measures to reduce emissions from lorry engines. This is not very surprising, as the cheaper options to reduce lorry engine emissions have already been implemented.

6 Incentives for emission reduction

6.1 Introduction

In this chapter we describe incentives that would lead to the reduction of emissions. There are various measures to reduce emissions from diesel locomotives that have a different impact on environment, behaviour of hauliers and economics. In section 6.2, we shortly consider the most important criteria for the selection of options that reduce emissions. Section 6.3 deals with the setting of emission standards, such as currently in preparation by the Working Party Environment of the Council on emissions of non-road mobile machinery. In section 6.4, a description of effects of the increase of the fuel excise duty is given. Finally, we describe the effects of a system of differentiated user charges in section 6.4.

6.2 Criteria for selecting options to reduce emissions

From a theoretical point of view, several criteria can be used to select the most appropriate instrument to reduce emissions from diesel locomotives. The most important criteria are:

- *effectiveness.* It is clear that a policy instrument should be effective in achieving its intended objectives (i.e. reduction of air pollution from diesel locomotives);
- *cost-effectiveness.* Cost-effectiveness is another key-criterion, which requires an instrument that is able to achieve a predefined target at minimum costs. This criterion selects economically efficient solutions;
- *distribution effects.* Considerations of fairness play a major role in devising policies. Principles such as ‘the polluter pays’ are widely accepted and refer to the distribution issue.

In the following sections, we will use the above criteria to discuss three options to reduce pollutant emissions from diesel powered railway transport:

1. Emission standards.
2. Introduction (or increase) of an excise duty on diesel.
3. A differentiation of the user charge for railway infrastructure.

6.3 Setting emission standards

While writing this report, the Working Party Environment of the Council, in reaction to the Commission proposal, included emission standards for locomotive engines in their proposal for amendment of Directive 97/68/EC. According to this proposal, not only new locomotives have to comply with these standards, but also locomotives that undergo a major engine conversion. The limit values of this proposal are shown in Table 15.

The Committee on the Environment, Public health and Consumer Policy, with reporter Mr. Bernd Lange, made amendments on the Commission proposal for a first reading by the European Parliament. This Parliament proposal includes, at some points, tighter limit values than the Council Working Party proposal does.

Table 15 Proposal for legal emissions standards by the Working Party Environment of the Council of 4 June 2003

Class nom. power in kW	CO in g/kWh	HC in g/kWh	NO_X in g/kWh	PM_{10} in g/kWh	Date for placing on the market for new or replaced engines
130 < P< 560 kW	3.5	4.0		0,2	31-12-2006
560 kW < P	3.5	0,5	6,0	0,20	31-12-2008
2,000 kW < P and swept volume > 5 l/cylinder	3.5	0.4	7.4	0.27	31-12-2008
130 kW < P	3.5	4.0		0,025	31-12-2011

Note: We estimate that the 4.0 grams of HC+ NO_X consist of 3.6 grams of NO_X and 0.4 grams of HC.

According to the Council proposal, the UIC standards that are planned for 2008 will be made mandatory in that year for locomotives with an engine power under 2,000 kW. For locomotives with an engine power above 2,000 kW, the limit values are somewhat less strict. The 2008 emission standards roughly correspond with those for an Euro II truck. At the end of 2011 the emission limits will be further tightened for all locomotives. This will give engine manufacturers an incentive and necessary time to develop appropriate technologies.

The basis for the proposed emission standards for now will be the existing ISO 8178/F test cycle. However, the Working Party Environment of the Council that deals with the revision of the emission standards for non-road mobile machinery recommends that this test cycle be adjusted and improved in the future. This adjustment will likely be co-ordinated with the US-EPA, in order to achieve identical, or at least comparable, global emission standards.

While the effects of emission standards can be considerable (see the results for trucks) the cost-effectiveness of emission standards is generally considered to be lower than that of a user charge (see section 6.5). The reason for this is that an emission standard gives an incentive to apply the cheapest measures that reduce the emissions to just under the prescribed standard. The cheapest measures can however be less cost-effective than more expensive measures that more rigorously reduce emissions.

From the point of view of equity emission standards can be judged as sub-optimal because they do not make a difference between a sparsely used small shunting locomotive and a big line-haul locomotive. The latter yearly emits a multitude of the emissions of the first, but the shunting locomotive has to be fitted with the same technical measures[5].

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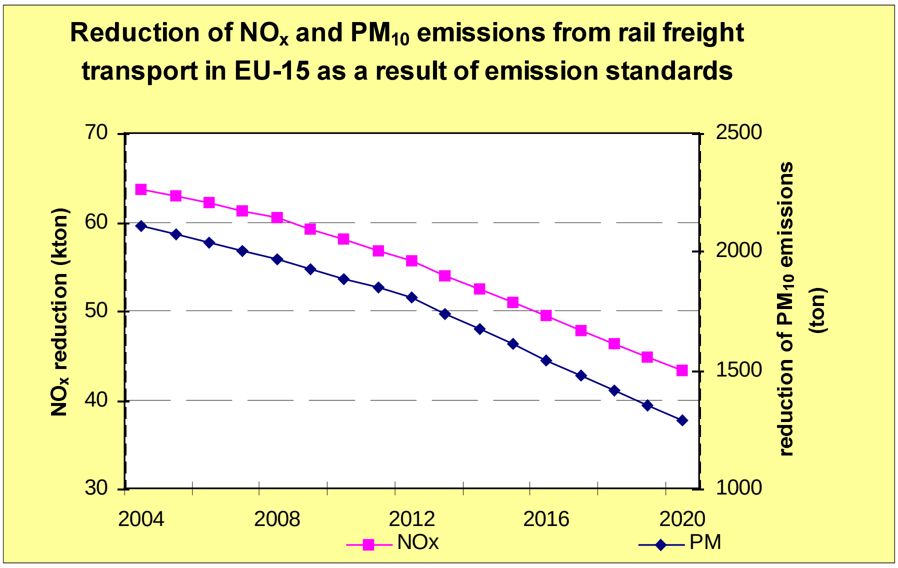
[5] This is true when emission standards are expressed in grams of emittants per unit of engine power such as is the case for the existing standards for trucks and the proposed standards for diesel locomotives. In contrast, the existing emissions standards for passenger cars are expressed in gram/km. In that case cars with smaller engines could comply to the standards by applying cheaper options that reduce less (but enough) than the more rigorous options that are needed for larger cars.

Figure 7 Reduction of NO_x and PM_{10}-emissions in the EU as a result of the introduction of the proposed standards in 2003, 2008 and 2011



The introduction of the proposed standards will in the year 2020 result in about 12% of the locomotives meeting only the 2008 standards and about 24% of the locomotives also meeting the 2012 standards[6]. The emission characteristics of the rest (64%) of the locomotives will not be affected by the proposed regulation until 2020. Figure 7 presents the decrease in emissions as a result of the tightened emission standards in 2003, 2008 and 2011.

The introduction of tightened emission standards result in a decrease of about 27% of the NO_X-emissions and 35% of the PM_{10}-emissions, compared to the reference scenario. The reference scenario is based upon estimations of the IEA (IEA, 2002). They estimate a yearly growth of 0.1% in tonne-km on European rail and a decrease in energy consumption of 0.6%. This implies a 5%-emission reduction in 2010 and a 10% reduction of diesel fuel consumption in 2020.

6.4 Introduction (or increase) of excise duty on diesel

At the moment, the fiscal treatment of diesel fuel for the carriage of goods by rail varies greatly among the EU-15 countries. For example, in Germany, the excise duty is 0.47 €/l, while in the Netherlands this level is about 0.05 €/l and in Belgium diesel fuel for rail applications is exempt from fuel taxes.
In general, the introduction of excise duty on diesel fuel for rail transport would have the following effects:
- an increase in efficiency of rail freight transport by higher load factors, improved routing, and more efficient engines. This reduces the environmental impact of rail transport on a per tonne-km basis;
- a shift towards electric locomotives, which reduces primarily NO_X and PM_{10}-emissions of rail transport;
- a reduction in demand for rail transport, leading to either a net loss of demand, or a shift towards road or waterway transport.

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[6] When we assume that each year 3% of all locomotives is replaced.

When considering the effectiveness of an excise duty on the reduction of emissions of NO_X and PM_{10}, one can show that the effectiveness of (an increase of) an excise duty is lower than setting emission standards and the differentiation of the user charge. While the latter two directly affect the actual emissions, an introduction of an excise duty only stimulates to avoid costs (fuel savings), not to reduce pollutant emissions. The introduction of an excise duty therefore is an effective means to reduce CO_2-emissions, since these are, unlike NO_X and PM_{10}, directly linked to fuel consumption. For the same reasons the cost-effectiveness of the introduction of an excise duty for the reduction of NO_X and PM_{10} is not high from a theoretical point of view.

As an example, we will estimate the effects of a harmonisation of the excise duty in the EU-15 for diesel fuel that is used in rail transport at the current minimum excise duty for road transport (0.30 € per litre in 2004 and 0.33 € per litre in 2010). This introduction (or increase) of the excise duty increases the costs per diesel train-km for hauliers with about 5%[7]. As a reaction on this cost increase, we expect that hauliers are able to absorb one-third of the extra costs by efficiency improvements and a shift to electric locomotives. The increase of the cost for shippers will then be about 3%. Given that the price elasticity[8] ranges between –0.4 and –1.2 and the cross elasticity for the shift towards road transport is about –0.1 to –0.2, the EU-15 demand for rail freight transport decreases roughly with 2.5%. The demand for road freight transport then increases with about 0.5% of the rail tonne-km, equalling about 1.2 billion tonne-km for the EU-15 region. This totals to 3% in 2010 and 8% in 2020, when the measure is introduced in 2005. However, these numbers can only be seen as indicative. Since many tracks are not electrified, the shift will not exceed this 8% before 2020, we expect.
The effects of the introduction of an excise duty on diesel on the reduction of emissions are in the order of 10% for both NO_X and PM_{10}. However, we note that the basis for this calculation is the assumption that no excise duty was paid before the introduction of the measure. As we indicated previously, this is not entirely true, since some EU Member States already apply an excise duty on diesel for rail transport. An exact overview of the fiscal regimes of all Member States is lacking, but it is safe to assume that the effects of introduction of an EU wide excise duty will probably be lower than estimated here[9]. The introduction of an excise duty for rail freight transport will therefore more likely reduce the emissions of NO_X and PM_{10}-emissions therefore with 5% than with 10%.

6.5 Differentiation and increase of the user charge

The EU has set itself the objective to reach more sustainable transport by a.o. the introduction of fair and efficient pricing. Internalisation of external costs of all transport modes encourages the use of the most environmentally friendly means of transport. EU Directive 2001/14/EG provides the opportu-

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[7] Rail freight transport cost about 3-4 €ct per tonne-km. For an average train load of 350 tonnes this equal about 14 € per trainkm. With a tax increase of 0.30 €/l, the cost increase is about 5%, when we further assume that half of all rail transport is carried out by diesel locomotives.

[8] Information on the price elasticity of rail freight transport is extremely scarce and inconsistent, therefore the results from these calculations must be taken with caution. They merely serve to show the order of magnitude of the effects.

[9] We estimate the effects of the introduction of the excise duty to be at least 20% lower than calculated, since Germany already levies taxes on locomotive fuel. Germany consumes about one fifth of all locomotive fuel sold in the EU.

nity to take environmental performance into account when setting charges for infrastructure use.

An overview of current user charges in Europe is shown in Table 16. As can be seen from this table, these charges differ considerably over Europe.

Table 16 User charges for freight trains in Europe in 2002

country	Infrastructure charges in € per train km	
	Conventional trains	Heavy trains
Netherlands	0.22	0.22
Belgium	1.30	1.50
France	0.70	0.70
Germany	2.80	2.80
Switzerland	6.50	6.50
Italy	2.05	2.10
Austria	4.30	6.70
Poland	4.20	7.50
Czech Republic	0	0

Source: The Dutch Ministry of Transport, Public Works and Water Management

When the environmental costs of train exploitation are internalised by differentiation of the user charge to emission performance, hauliers would be stimulated to operate low emission locomotives. Ideally, every locomotive would be charged, based upon its actual environmental performance. However, this is not feasible. As an alternative, the different UIC and (proposed) EC standards (sections 3.2 and 6.3) can be used to differentiate the user charge.

The differentiation of the user charge is considered to be the most effective means to reduce emissions, since it allows for measures to be taken over the whole chain of operational activities (also logistics, load factors) in response. In contrast the setting of emission standards only stimulates to reduce the emission level of locomotive engines.
For the same reasons the cost-effectiveness of a differentiation of the user charge is higher than the cost-effectiveness of setting emission standards.
The financial effects of the (revenue neutral) differentiation of the user charge for the entire rail transport sector are zero, since it generates no net profits. However, there is a shift in the distribution of the ‘burden’ among the members of the sector, where the ‘polluter pays principle’ makes sure that everyone pays their fair share.
Based on the annual investment costs for emission reducing technologies and the reduction potential that are presented in chapter 5, measures to reduce NO_X and PM_{10}-emission are under 2.5 €/kg NO_X and 35 €/kg PM_{10}[10]. These incentive levels are under the environmental cost to society that are between 70 and 300 €/kg for PM_{10} and between 7 and 12 €/kg for NO_X (depending on location). This means that a differentiation of the user charge based on these incentive levels will bring about more profits than cost to society.

On the basis of the presented incentive levels, the user charges per train-km can be calculated for the different emission classes. The charges for the different emission classes of NO_X and PM_{10} are shown in Table 17.

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[10] For 1,000 kW locomotives that are operated for more than 1,000 full power hours per year.

We have chosen to use UIC 1997 emission characteristics as a reference level, since emission characteristics from locomotives that are older than 1997 are most probably not available. All locomotives from 1997 or before are therefore treated the same[11].

Table 17 Proxies for effective emission-based charges for rail infrastructure use, relative to UIC 1997 levels

Emission class	emissions, in g/kWh		charge for infrastructure use (€/train km)
	NO_X	PM_{10}	
UIC 1997	12	0.8	reference level (RL)
UIC 2003	9	0.25	RL - 0.39
UIC 2008	6	0.2	RL - 0.53
EC 2012	3.6	0.025	RL - 0.71
Electric	1	0.0015	RL - 0.82

We can see that a differentiation up to € 0.8 per train km is required to provide effective incentives to operators. However, the current user charge in some countries (e.g. Netherlands and Czech Republic) is currently too low to allow for the needed differentiation range. To make differentiation possible, the user charges therefore first need to be lifted in these countries.

The effects of a differentiated user charge on locomotive emissions depend on the implementation of clean diesel locomotives and the replacement of diesel locomotives by electric locomotives. The effect can only be based on estimations, since the behaviour of hauliers is not predictable. Many factors play a role in this. Based on an estimate[12] for the Dutch situation, emissions of NO_X and PM_{10} could decrease in the order of 50% by the year 2020.

Finally, we want to note that infrastructure charges can also be differentiated on the basis of noise (differentiation based on location and noise levels), which is also a problem that arises from train operation. A simultaneous differentiation on the basis of emissions and noise is complicated because of the possibility of undesired interference.

6.6 Synthesis

While the effects of emission standards on the emissions of NO_X and PM_{10} can be large, the cost-effectiveness of emission standards is generally lower than that of a user charge. One reason for this is that an emission standard gives an incentive to apply the cheapest measures that reduce the emissions to just under the prescribed standard. These cheapest measures can however be less cost-effective than more expensive measures that more rigorously reduce emissions. From the point of view of equity emission stan-

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[11] Another possibility is to differentiate the user charge around a base level resulting in no net revenues (revenue-neutral charge). In that case there will be no reduction in demand for rail freight transport, since there is on average no cost increase. The base level (neutral) will have to be determined based on the average emission factors for the current locomotive fleet and progresses with time as these emission factors decline. As an example the UIC 2003 standards could be used as a start for the base level.

[12] We estimate a shift to electric locomotives of 4% in 2010 and a shift of 21% in 2020. The use of EC 2012 locomotives (3.6 g/kWh NO_x and 0.025 g/kWh PM_{10}) is estimated to be 12% in 2010 and 42% in 2020.

dards can be judged as sub-optimal because they do not discriminate between large polluters and small ones.

The effectiveness (reduction of emissions of NO_X and PM_{10}) of an excise duty is lower than setting emission standards or a differentiation of the user charge. While the latter two directly affect the actual emissions, an introduction of an excise duty only stimulates to avoid costs (fuel savings), not to reduce pollutant emissions. For the same reasons the cost-effectiveness of an excise duty is not high.

The differentiation of the user charge is considered to be the most effective means to reduce emissions, since it allows for measures to be taken over the whole chain of operational activities (also logistics, load factors) in response to the charge. In contrast emission standards only stimulate to reduce the emission level of locomotive engines. For this reason the cost-effectiveness of a differentiation of the user charge is higher than the cost-effectiveness of setting emission standards. The financial effects of the (revenue neutral) differentiation of the user charge for the entire rail transport sector are zero, since it generates no net profits. However, there is a shift in the distribution of the ‘burden’ among the members of the sector, where the ‘polluter pays principle’ makes sure that everyone pays their fair share.

On the basis of examples for each of the options we have indicated that in 2020 NO_X and PM_{10}-emissions from diesel locomotives can be reduced by about 5% when an excise duty on diesel is introduced and about 30% when emission standards are set. A differentiated infrastructure user charge may even result in a reduction of NO_X and PM_{10}-emissions of up to 50% in 2020. The actual effects however depend on the incentive levels and can deviate from the given examples.

7 Conclusions

7.1 Introduction

In this chapter we present the key findings of this study and give recommendations for policy makers on how to improve the environmental performance of rail transport and diesel locomotives in particular.

7.2 Key findings

Market for diesel locomotives

- the total number of locomotives in the EU-15 is about 13,000 in the year 2000. Germany, France, the United Kingdom and Italy have the most diesel locomotives in operation (about 9,000 units). Average traction power is about 1,000 kW per unit;
- with an average life span of 30 years the market size of new diesel locomotives is on average about 400 units yearly. Retrofitting of new engines in existing locomotives seems to be an important activity for the manufacturers of locomotives, but the exact scale is unknown;
- the market is probably larger than indicated above with applications of engines in shipping and road transport as well. This makes investments in cleaner technology easier. Moreover, the manufacturers can benefit from experiences in developing cleaner technology for truck engines;
- in the EU-15 there are about 500 railway companies, with six (former) national freight railways responsible for two-thirds of the freight transport volume over rail. In general the operators prefer the use of electric locomotives, because operation cost are less. However, the initial investments of diesel locomotives are substantially lower and their usability is higher, as they can operate on non-electrified tracks.

Emissions

- it is generally acknowledged by the rail industry that the ISO 8178/F test cycle represents the characteristics of use rather well. This cycle consists of 60% idling, 15% partial load, and 25% rated speed. However, substantial deviations are possible in practice and have been reported, especially between the load profiles of shunting and line-haul locomotives;
- in the United States shunting and line-haul locomotives are tested over different cycles. In contrast to the European situation, the US-EPA has set legal standards for locomotive emissions. These standards are more or less comparable with the emission standards that the UIC has voluntarily set for the rolling stock of its members. However, compliance to these UIC standards is not enforced;
- emission factors for NO_X and PM_{10} differ and seem to mainly depend on the type of locomotive and manufacturer and not on age alone. Emission factors for NO_X vary on average from 10 to 15 g/kWh. Emission factors for PM_{10} vary between 0.10 and 0.50 g/kWh. A reasonable average for the emissions factors of the EU locomotive fleet seems to be 12 and 0.40 g/kWh for NO_X and PM_{10} respectively.

Environmental performance compared to other modes

- today emissions per tonne-km of diesel-powered rail transport are comparable (bulk, NO_X) or higher (container, NO_X and PM_{10}) than that of road transport. The emissions of CO_2 are generally lower, especially in bulk transport;
- the environmental performance of road transport has been improved considerably during the last decades since EU standards have come into effect. The improvements in road transport will continue with the future Euro-4 and –5 standards that will in the end mean a reduction of 90 - 95% in emission factors during the 1982 - 2009 period. The success in road transport will cause a doubling of the share of emissions from rail transport if no emission reduction measures are implemented.

Options for cleaner technology

- there exist a number of measures that can be used to reduce NO_X and PM_{10}-emissions. These measures can be divided into in-engine measures, after treatment of exhaust gases and improvements in fuel quality. The information about the technical feasibility and costs of these measures is rather limited. However, estimates can be made on the basis of information that is available from the application of exhaust gas after treatment on inland navigation vessels and mobile machinery;
- in-engine measures (injection retarding, electronic motor-management systems and turbo chargers) can achieve a reduction of NO_X-emissions compared to the current fleet emissions of over 50%. The extra purchasing costs of an advance engine are about 10 – 15% or about 15,000 € for an engine of 1,000 kW, relative to a nowadays base-engine without these features. An advanced engine has about 20% lower NO_X and PM_{10}-emissions than a base-engine. The operational cost increase because of an increase of fuel consumption with 3 to 5%, which is about 3 € per MWh;
- to meet emission standards that go further than the proposed 2008 standards by the UIC and European Commission the application of exhaust after treatment systems as SCR (with optimisation for particles) or particle filters combined with EGR is expected. The estimated investment costs of a diesel particle filter and a SCR system range from 20 to 50 € per kW. For an SCR system the operational cost are higher, about 3 € per MWh;
- fuel quality has a considerable influence on pollutant emissions. A decrease of the fuel sulphur content decreases the formation of particles significantly. Also other fuel characteristics as aromatics, poly-aromatics, cetane number and density have influence on the emissions of pollutants. The EPA estimated the cost of producing 15 ppm fuel to be about 1.3 €ct per litre.

Assessment of options to reduce locomotive emissions

- differentiation of the rail infrastructure user charge with respect to emission class is considered to be the most effective as well as cost-effective means to reduce emissions. This option allows for measures to be taken over the whole chain of operational activities (also logistics, load factors) in response to the charge. The financial effects of the (revenue neutral) differentiation of the user charge for the entire rail transport sector are zero, since it generates no net profits. However, there is a shift in the distribution of the ‘burden’ among the members of the sector, where the ‘polluter pays principle’ makes sure that everyone pays their fair share;
- emission standards can be very effective but only give an incentive to take measures at new locomotive engines. Cost-effectiveness will therefore be lower than that of a user charge differentiation. Another

cause for this is that an emission standard gives an incentive to apply the cheapest measures that reduce the emissions to just under the prescribed standard. These cheapest measures can however be less cost-effective than more expensive measures that more rigorously reduce emissions. From the point of view of equity emission standards can be judged as sub-optimal because they do not discriminate between large polluters and small ones;

- the last option considered is the introduction of a minimum fuel tax for diesel locomotives. Currently, fuel taxes in EU Member States vary from zero to 0.47 €/litre, leading to substantial distortions in international rail competition. The environmental effectiveness of an excise duty is lower than setting emission standards or a differentiation of the user charge. While the latter two directly affect the actual emissions, an introduction of an excise duty only stimulates to avoid costs (fuel savings), not to reduce pollutant emissions. For the same reasons the cost-effectiveness of an excise duty is not high;
- on the basis of examples for each of the options we have indicated that NO_X and PM_{10} emissions from diesel locomotives can be reduced by about 5% when an excise duty on diesel is introduced and about 30% when emission standards are set. A differentiated user charge may even result in a reduction of NO_X and PM_{10}-emissions of up to 50% in 2020. The actual effects however depend on the incentive levels and can deviate from the given examples.

7.3 Recommendations for policy

A couple of arguments exist to take measures to reduce NO_X and PM_{10}-emissions from diesel locomotives:

- environmental effectiveness. the share of diesel locomotives in total transport emissions is likely to rise quickly as a result of EU enlargement, liberalisation of the rail market, and emission reductions in road transport;
- cost effectiveness: it appears highly likely that measures to reduce diesel locomotive emissions are much cheaper than measures that are being taken in road transport;
- fairness: excluding one transport mode from emission reduction obligations may reduce support for measures in other modes;
- sector image: if nothing is done, rail transport runs the risk of losing its image as environmentally friendly mode of transport.

Based on these arguments as well as the key findings of this study we strongly recommend:

- to introduce two stages of emission standards for all new diesel locomotive engines sold, including those over 560 kW, at EU level;
- to accelerate actual usage of cleaner locomotives by differentiating existing user charges for rail infrastructure on the basis of the emission standards mentioned. This would give an incentive to operators to optimise the environmental performance of the entire range of operational activities.

And finally, it may be considered to set a EU minimum level for the fuel tax for diesel locomotives, in order to reduce competitive distortions that currently exist, to stimulate usage of electric locomotives, and to reduce fuel consumption and CO_2-emissions.

References

CE Delft, 2002
Towards a more sustainable transport indicator – Critical assessment of the modal split as an indicator for the EU Sustainability strategy, CE Delft, September 2002

CE Delft, 2003
To shift or not to shift, that is the question – The environmental performance of the principal modes of freight and passenger transport in the policy-making context
CE Delft & RIVM, March 2003

EPA, 2003
Draft Regulatory Impact Analysis
Assessment and Standards Division Office of Transportation and Air Quality, U.S. Environmental Protection Agency, EPA420-R-03-008, April 2003. www.epa.gov/nonroad

Euromot, 2000
Consideration on exhaust emission optimisation of diesel engines for rail traction, Contribution to the railway energy efficiency conference of International Union of Railways (UIC) 10/11 May 2000, The European Association of Internal Combustion Engine Manufacturers, Paris

Euromot, 2001
Considerations on diesel fuel quality required for non-road mobile machinery
The European Association of Internal Combustion Engine Manufacturers, 2001.

Euromot, 2002
Proposal for a Directive of the European Parliament and Council Amending Directive 1997/68/EC (NRMM NonRoad Mobile Machinery)COM(2002)765– The Euromot Position, The European Association of Internal Combustion Engine Manufacturers, 2003

European Commission, 2002
EU Transport in figures - statistical pocketbook 2002, European Commission Directorate General for Energy and Transport in co-operation with Eurostat. Brussels, Belgium

European Commission, 2002b
Proposal for a Directive of the European Parliament and of the Council amending directive 97/68/ec on the approximation of the laws of the member states relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery, Brussels, 2002

Eurostat, 2002
Common questionnaire on transport statistics–EU and EFTA data 1990 – 2000
Eurostat, Luxembourg

Germanischer Lloyd, 2001
Erarbeitung vor Verfahtren zur Ermittlung de Luftschadstoffemissionen von betrieb befindlichen Binnenschiffsmotoren
2001

IEA, 2003
Transportation projections in OECD regions
May 2002

Jørgensen, 1997
Estimating Emissions from Railway Traffic
Jørgensen M, Sorenson SC (1997)
MEET Deliverable 17

Mönch, 2001
Schadstoffemissionen von Lokomotiven, triebwagen und rangierlokomotieven mit Dieselmotor, UBA, Berlin, Mai 2001

Paukert, 2001
Diesel emissions of European railway vehicles, the envrionmental policy of the UIC
*C*ontribution to the ASME Spring Conference, Pihiladelphia 01/02 May 2001

Paukert, 2003
Personal communication with Hans Paukert, locomotive diesel engine technologist, European Rail Research Institute (ERRI), Utrecht, March 2003

TNO, 2000
Inventarisatie van opties voor stille, schone en zuinige aandrijving van goederentreinen op de Betuweroute
TNO Wegtransportmiddelen, TNO Rapport 00.OR.VM.054.2/JVL, 28 Juli 2000, Delft

TERM, 2002
Transport Environment Reporting Mechanism of the European Environment Agency (EEA), www.eea.eu.int.

Weaver, 1994
Emissions control technology for locomotives
Weaver, C.S., Mc Gregor, D.B
SAE (Society of automotive engineers) Paper no. 940453

WTZ, 2002
Ermittlung von basisemissionsdataten des betriebenen Schienenverkehrs
Wissenschaftlich-Technisches Zentrum für Motoren- und Maschinenforschung Roßlau gGmbH im auftrag des Umweltbundesambtes, Januar 2002

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Clean on track

Reducing emissions from diesel locomotives

Annexes

Report

Delft, July 2003

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A Size, composition and diesel consumption of the European locomotive fleet

Total number of locomotives in European countries; diesel+electric

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Austria	1,232	1,263	1,277	1,245	1,360	1,333	1,327	1,328	:	:	:
Belgium	1,040	1,040	1,031	1,040	963	977	967	950	943	939	969
Switzerland	1,435	1,430	1,469	1,488	1,495	1,454	1,393	:	:	:	:
Germany	:	11,580	11,319	10,528	10,028	8,985	8,814	8,589	7,897	7,449	7,054
Denmark	328	312	296	290	271	:	143	123	117	117	:
Spain	1,287	1,230	1,192	1,148	1,128	1,081	981	974	935	928	899
Finland	682	692	671	670	665	663	648	654	640	639	632
France	5,654	5,667	5,664	5,390	5,285	5,295	5,246	5,157	5,125	5,006	4,983
United Kingdom	2,242	2,102	2,026	1,895	1,887	:	:	:	:	:	:
Greece	233	233	234	234	234	234	234	234	260	163	157
Ireland	126	126	156	112	112	114	114	113	110	110	107
Italy	:	:	:	:	:	3,268	3,202	3,113	3,144	3,195	3,270
Luxembourg	80	80	80	:	:	:	:	:	:	:	:
Netherlands	522	486	505	545	532	526	495	395	330	309	305
Norway	326	324	323	300	269	235	201	199	197	185	172
Portugal	320	324	261	267	269	275	272	260	251	249	229
Sweden	1,015	912	784	723	701	671	636	583	613	607	:

Source: Eurostat (2002)

Total number of locomotives in European countries; diesel

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Austria	489	498	507	492	548	539	532	530	525	450	490
Belgium	659	660	653	663	587	601	591	575	571	556	565
Switzerland	277	273	281	269	271	262	260	:	:	:	:
Germany	3,417	7,516	7,278	6,666	6,310	5,356	5,108	4,820	4,071	3,722	3,393
Denmark	318	302	286	268	261	:	121	101	95	95	:
Spain	694	638	622	580	580	580	498	500	483	479	459
Finland	572	582	561	559	554	552	535	530	511	509	492
France	3,356	3,360	3,354	3,140	3,082	3,085	3,027	3,006	2,999	2,982	2,974
United Kingdom	1,964	1,839	1766	1,635	1,629	:	:	:	:	:	:
Greece	233	233	234	234	234	234	234	234	260	152	146
Ireland	126	126	126	112	112	114	114	113	110	110	107
Italy	:	:	:	:	:	1,167	1,168	1,167	1,165	1,165	1,164
Luxembourg	61	61	61	:	:	:	:	:	:	:	:
Netherlands	376	345	339	342	:	:	:	:	:	:	:
Norway	177	177	177	159	131	120	100	104	105	93	82
Portugal	266	270	207	207	198	194	190	178	169	168	149
Sweden	386	359	300	271	251	245	241	213	237	235	:

Source: Eurostat (2002)

Total tractive locomotive power; diesel+ electric (1,000kW)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Austria	2,557	2,645	2,747	2,777	:	:	:	:	:	:	:
Belgium	1,508	1,591	1,580	1,562	1,549	1,548	1,545	1,523	1,511	1,607	1,709
Switzerland	3,297	3,336	3,482	3,803	3,950	3,953	3,935	:	:	:	:
Germany	11,431	20,165	19,979	18,448	*22,502*	18,283	18,734	19,104	18,719	18,506	18,162
Denmark	367	:	371	400	395	:	:	330	321	:	:
Spain	2,517	2,495	2,348	2,413	2,397	2,359	2,302	2,301	2,217	2,206	2,171
Finland	747	770	758	759	758	751	750	813	814	817	802
France	9,555	9,686	9,562	9,457	9,431	9,523	9,633	:	:	:	:
United Kingdom	:	:	:	:	1,543	:	:	:	:	:	:
Greece	340	340	351	351	351	351	351	351	405	222	216
Ireland	116	116	116	114	114	144	144	143	141	141.3	141
Italy	:	:	:	:	:	7,063	7,124	7,247	7,312	7,598	7,813
Luxembourg	98	98	98	:	:	:	:	:	:	:	:
Netherlands	:	:	:	:	:	:	:	:	:	:	:
Norway	536	532	530	515	507	467	454	527	516	491	465
Portugal	344	344	333	374	430	481	482	474	464	463	448
Sweden	2,133	1,984	1,742	1,679	1,654	1,610	1,546	1,448	1,498	1,492	:

Note: The 1990 and 1994 numbers for Germany are assumed as too high and too low respectively.

Source: Eurostat (2002)

Total tractive locomotive power; diesel (1,000kW)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Austria	268	276	294	304	:	:	:	:	:	:	:
Belgium	446	531	528	512	501	498	495	478	470	458	474
Switzerland	95	96	99	96	96	94	108	:	:	:	:
Germany	1,677	5,367	5,183	4,230	4,755	4,210	4,075	3,986	3,536	3,427.6	3,141.2
Denmark	327	:	331	312	307	:	:	242	233	:	:
Spain	761	742	790	598	599	566	545	557	533	529	513
Finland	406	429	417	415	414	407	394	391	359	356	341
France	1,965	1,979	1,961	1,915	1,906	1,903	1,876	:	:	:	:
United Kingdom	2,560	2,939	:	:	1,285	:	:	:	:	:	:
Greece	340	340	351	351	351	351	351	351	405	190	183
Ireland	116	116	116	114	114	144	144	143	141	141.3	141
Italy	:	:	:	:	:	603	604	603	601	601	601
Luxembourg	49	49	49	:	:	:	:	:	:	:	:
Netherlands	167	:	:	:	:	:	:	:	:	:	:
Norway	92	92	92	85	81	77	77	114	107	82	60
Portugal	216	216	205	205	200	196	191	184	174	173	160
Sweden	271	255	230	181	180	178	178	168	193	190	:

Source: Eurostat (2002)

Total diesel fuel consumption by rail (ktoe)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Austria	56	52	51	50	51	47	42	42	42	43	49
Belgium	71	108	83	84	82	79	76	62	64	65	61
Germany	946	973	838	818	787	745	712	693	640	600	585
Denmark	97	98	105	109	98	99	98	96	81	76	75
Spain	217	228	238	228	259	295	362	414	466	497	501
Finland	64	60	60	66	69	63	55	56	55	53	49
France	396	438	442	465	327	395	348	428	466	382	378
United Kingdom	636	653	677	634	621	624	599	492	501	480	457
Greece	65	51	49	50	54	45	47	43	43	41	41
Ireland	48	51	57	57	60	50	79	82	105	118	127
Italy	203	203	200	195	197	199	178	199	197	144	142
Luxembourg	0	8	7	4	1	2	2	5	5	8	7
Netherlands	38	38	37	36	38	36	32	33	31	31	36
Norway	33	32	34	35	37	32	26	27	21	21	18
Portugal	57	60	60	55	55	56	51	55	49	52	58
Sweden	40	38	37	37	39	40	40	36	17	8	25
EU15	2967	3091	2975	2923	2775	2807	2747	2763	2783	2619	2609

Note: 1 toe corresponds with 41.8 GJ

Source: IEA Energy balances OECD countries, www. iea.org