Rail Diesel Study
Work Package 4

Draft Final Report

Possible emission reduction strategies that could be applied to diesel traction units across the "EU Railway 27"

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March 2006

Title	Rail Diesel Study, WP4 Draft Interim Report: Possible Emission Reduction Strategies that could be applied to Diesel Traction Units across the "EU Railway 27"
Customer	UIC
Customer reference	
Confidentiality, copyright and reproduction	
File reference	ED05010
Report number	ED05010/WP4/R02
Report status	Final v4

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1 Introduction

1.1 Overview

Work Package 4 of the Rail Diesel Study was concerned with the development of strategies that could be applied to the wider European fleet to reduce emissions of NOx and PM_{10} from diesel rail vehicles across Europe. The objective was to use the outputs from Work Packages 1, 2, and 3 to develop possible strategies that could be applied to pre-1990 and post-1990 railcars, mainline locomotives and shunting locomotives. Cost-benefit analysis (CBA) of the proposed strategies was carried out to provide initial estimates of the costs of implementing different Europe-wide strategies, and the monetary value of emissions benefits associated with each strategy. These benefits have been quantified using the recently published Clean Air For Europe (CAFE) cost-benefit methodology that provides damage costs per tonne of emission for a range of different air pollutants. It must be stressed that the cost–benefit analysis that has been carried out as part of this work package provides **initial, indicative results** only. Further, more detailed work, outside the scope of this study will be required to quantify in detail the costs and benefits associated with different specific emission reduction strategies.

This document describes the development of possible strategies that could be applied to the European diesel rail fleet, based on the outputs from WP1, WP2 and WP3. Three different types of strategies have been developed, as follows:

1) A series of general technical strategies for tackling emissions from the **existing** diesel fleet have been developed;
2) Technical Strategies for ensuring that **future** diesel traction units and engines meet the Stage IIIA and Stage IIIB limit values have also been developed. (However, it should be noted that the Stage IIIB limit values will be subject to review by the end of 2007);
3) Strategies for tackling emissions from railway locations that could significantly contribute to **air quality hotspots** have also been developed. These strategies include both technical and operational options.

The remainder of this report is structured as follows:

Section 2 provides details of the development of strategies to reduce emissions from the existing fleet.

Section 3 discusses the development of strategies to reduce emissions from the future fleet.

Section 4 describes the development of strategies for tackling emissions from potential railway contributors to air quality hot spots.

Section 5 provides full details of the cost-benefit analysis methodology that has been used in this study.

Section 6 presents the CBA results for the strategies for the existing fleet.

Section 7 presents the CBA results for the strategies for the future fleet.

Section 8 presents the CBA results for the strategies for tackling railway contributors to air quality hot spots.

Section 9 presents the conclusions of this study.

Section 10 presents recommendations for further work.

2 Development of strategies for reducing emissions from the existing fleet

2.1 Characterisation of the existing fleet based on vehicle age

The results from Work Package 2 indicated that a limited selection of technical options could be applied to the existing fleet to reduce emissions of NOx and PM_{10}. In developing strategies that could be applied more widely across the existing fleet, it was decided that only locomotive engines dating from 1975 onwards should be included in any of the strategies, whilst for railcar engines, only those dating from 1980 were included. The reason for this is that pre-1975 locomotives and pre-1980 railcars are usually close to the end of their lives, and it would not normally be cost-effective to apply emissions abatement options to such vehicles.

The analysis carried out for WP2 looked at vehicles that fall into two different age categories – pre-1990 vehicles and those built after 1990. For the purposes of developing strategies, it was first necessary to identify how many existing traction units and engines fall into various age categories. Much of this work was carried out as part of WP1, based on submissions received from individual railway operators on the numbers of different traction engines that fall into different age categories. These data are presented in the table below.

Table 2.1: Estimates of the numbers of locomotive and railcar engines in various age categories in 2005

Age category	Number of Locomotive engines	Number of Railcar engines
Pre-1970	6,072	954
1970-1974	2,984	1,013
1975-1979	2,984	1,013
1980-1989	2,940	3,315
1990-1994	867	1,808
1995-1999	734	2,718
2000 onwards	2,399	3,491
TOTAL	**18,980**	**14,313**

The table has been colour-coded to show how each age category was treated. Grey shading indicates that these engines were not included in the development of strategies to reduce emissions, yellow shading indicates that these engines were included in strategies and were be treated as the “Pre-1990” fleet. Blue shading also indicates that these engines were included in the development of strategies, and were treated as the “Post-1990” fleet. The data presented in this table shows that around 48% of locomotive engines date from before 1975, whilst only 21% of railcar engines date from before 1980.

Whilst this data provided useful information on the numbers of engines that fall into different age categories, it did not provide any data on what proportion of locomotive engines are mainline locomotive engines as opposed to shunting engines. This information was not collected directly from railway operators, and hence it was necessary to make use of the detailed fleet data that is available in the European Railway Stock List published on the www.railfaneurope.net website. The data included in this stock list is very detailed, and it was possible to calculate the split between mainline and shunting locomotives for each of the age categories of interest. This data was combined with the data on the total number of locomotive engines presented in Table 2.1 to estimate the number of mainline and shunting locomotive engines in each age category (see Table 2.2 below).

Table 2.2: Estimated split between mainline and shunting locomotives for each age category

Age category	Percentage of locomotives that are mainline locomotives	Percentage of locomotives that are shunting locomotives
Pre-1975	61% *(5517 engines)*	39% *(3539 engines)*
1975-1989	45% *(2675 engines)*	55% *(3249 engines)*
1990-2004	79% *(3160 engines)*	21% *(840 engines)*
TOTAL	**11352 engines**	**7628 engines**

Based on all of this data, and on the assumption that only locomotive engines from 1975 onwards and only railcar engines from 1980 onwards would be included in any of the proposed strategies, it was possible to estimate the theoretical maximum number of traction unit engines that could be included in any emissions reduction strategies. These data are presented in Table 2.3 below.

Table 2.3: Theoretical maximum number of diesel traction engines that could be included in any strategies for reducing emissions from the diesel rail sector

Age category	Railcar engines	Mainline locomotive engines	Shunting locomotive engines
Pre-1990	3315	2675	3249
Post-1990	8017	3160	840
TOTAL	**11332**	**5835**	**4089**

Note: For this table, pre-1990 railcar engines include only those that came into service between 1980 and 1989. Pre-1990 locomotive engines are those that entered service between 1975 and 1989

The figures in the table above relate to the estimated number of existing railcar engines and locomotives in the European fleet at the end of 2005, and based on the projections for the existing fleet, it was anticipated that these numbers will decrease in future years as older engines and vehicles are removed from service. Strategies for reducing emissions would in reality never be applied to all of the relevant fleet in one year. In practice, such strategies would be implemented over a number of years, starting with preparative engineering work first. To take this into account, the emission reduction strategies were developed on the basis of being applied to a proportion of the **2010 fleet** rather than the 2005 fleet, and furthermore, each strategy was assumed to be implemented over the five-year period between 2006 and 2010 inclusive. Estimates for the number of existing traction engines in operation in 2010 are given in the table below.

Table 2.4: Projected maximum number of existing traction unit engines in 2010 that could be included in strategies for reducing emissions

Age category	Railcar engines	Mainline locomotive engines	Shunting locomotive engines
Pre-1990	1473	1794	2179
Post-1990	8017	3160	840
TOTAL	**9490**	**4954**	**3019**

2.2 Summary of the most suitable technical options for reducing emissions from the existing fleet

The analysis carried out in WP2 identified the most suitable technical options that could be applied to each different type of traction unit, differentiated according to which age category the traction unit falls into. These findings are presented in the box below:

Box 1: Summary of findings from WP2 for applying technical options to railcars and locomotives

Pre-1990 traction units

WP2 identified the main options that could be used to reduce emissions from pre-1990 traction units as follows:

1) *Open channel Diesel Particulate Filters (DPFs) could be fitted to railcars and mainline locomotives (although in some cases, fitting open channel DPFs may lead to maximum allowed axle loads being exceeded).*
2) *Re-engining with modern engines is possible in certain cases (although it should be noted that fitting new engines may require significant changes in off-engine support systems or modifications to the vehicle car-body that may make re-engining impractical or infeasible)*
3) ***Shunting locomotives only:** closed channel DPFs could be fitted after significant modifications have been made to the vehicle – may exceed allowed axle loads.*
4) ***Shunting locomotives only:** SCR + closed channel DPF could be fitted after modifications have been made to the vehicle – may exceed allowed axle loads.*

Post-1990 traction units

1) *DPF with active trap regeneration. This would allow Stage IIIB PM emission limits to be met (but not NOx limits)*
2) *SCR system could be accommodated if modifications to the vehicle are made (however, these modifications may mean that maximum axle loads are exceeded).*
3) *SCR + DPF system could be accommodated if modifications to the vehicle are made (however, these modifications may mean that maximum axle loads are exceeded).*

For each type of traction unit (railcar, mainline locomotive, and shunting locomotive) it can be seen that the options available for the post-1990 fleet are the same, and that the same general limitations apply. It may be possible to fit closed channel DPFs, SCR systems, or a combined SCR + DPF system, but it is likely that significant modifications to vehicles would need to be made in order to accommodate such equipment. There is also the distinct possibility that maximum allowed axle loads would be exceeded if these types of emissions abatement equipment were to be fitted. It should be noted that the use of sulphur-free diesel (maximum sulphur content of 10 ppm) would be required if SCR equipment is to be used on rail vehicles. Other exhaust after-treatment equipment also requires the use of sulphur-free diesel.

For the pre-1990 fleet, it was generally found from WP2 that re-engining with a newer design of engine (when this is technically feasible) would be the most suitable option for reducing emissions. Closed channel DPFs or a combined SCR + closed channel DPF could probably be fitted to shunting locomotives after significant modifications have been made to the vehicles. At this point in time, it appears that these types of equipment cannot be fitted to pre-1990 mainline locomotives or railcars, but in some cases there is the possibility of fitting open channel DPFs. Open channel DPFs would only enable a 30-40% reduction in PM_{10} emissions to be achieved, whilst there would be no reduction in NOx emissions.

2.3 Proposed strategies for reducing emissions from the existing diesel rail fleet

Taking into account the findings from WP2 described in the previous section, a series of proposed strategies for reducing NOx and PM emissions from the existing fleet were developed. Each strategy consisted of applying a particular technology to a percentage of the projected 2010 fleet of diesel traction units. For each proposed strategy, two scenarios were developed: a low uptake scenario and a high uptake scenario. These scenarios reflect the uncertainty that exists with regard to the potential application of these technologies on rail vehicles. Furthermore, even if an option can technically be applied to all types of traction unit, this is no guarantee that in practice the technology will be applied across the board. The results from Work Package 2 showed that the feasibility of applying technical options to existing traction units must be assessed individually for each different type of vehicle. It was beyond the scope of this study to investigate the exact proportion of the European fleet for which retrofitting emissions abatement equipment, or re-engining would be feasible, and hence the percentage uptake values for each proposed strategy presented in this section of the report are hypothetical values only, that have been used to provide initial indications of the range of costs and benefits. In some cases it is possible that the high uptake percentage scenarios may be greater than what can be achieved in reality.

For each proposed strategy, the low-uptake scenario was set to 10% of the existing fleet that is projected to still be in service in 2010. The high-uptake scenarios vary depending on the types of vehicles and the specific technology options. For example, for pre-1990 vehicles, re-engining was identified as the most suitable option, and there are many examples of where re-engining with a newer design of engine has been carried out in the past. For this reason, the high-uptake scenario for re-engining has been set to a relatively high value of 50%. By contrast, for the post-1990 fleet, the WP2 analysis showed that there are many potential difficulties in trying to apply exhaust after-treatment equipment. In particular, there are space and weight limitations that may or may not be possible to overcome. The implications of these findings are that it is unlikely that a large proportion of these newer vehicles can be retrofitted with emissions abatement equipment. For this reason, lower estimates (typically ranging from 30% to 40%) were made with regard to the proportion of the fleet that could be equipped with exhaust after-treatment equipment. It should also be noted that different uptake rates were applied for each different type of exhaust after-treatment technology. The reason for this was that the analysis carried out for WP2 indicated that certain technical options could be fitted to traction units more easily than other options. For example, it was found that open channel DPFs could be fitted more easily than closed channel DPF systems, and that both of these individual options could be accommodated more easily than an SCR system. A combined SCR+DPF system was found to be the most difficult system to fit to traction units. The proposed high uptake scenarios that include these options, attempt to take these findings into account.

The strategies that were examined for each type of traction unit (including the low and high uptake scenarios), are presented in the tables below.

Table 2.5: Proposed strategies for applying technical options to the pre-1990 DMU railcar fleet

Strategy code	Strategy option	Proportion of the 1980-1990 DMU railcar fleet to which the strategy could be applied	
		Low uptake scenario	High uptake scenario
R1	Retrofit open channel DPF to existing railcars	10% *(147 railcars)*	50% *(737 railcars)*
R2	Re-engine railcars with improved engine	10% *(147 railcars)*	50% *(737 railcars)*

Table 2.6: Proposed strategies for applying technical options to the post-1990 DMU railcar fleet

Strategy code	Strategy option	Proportion of the post-1990 DMU railcar fleet to which the strategy could be applied	
		Low uptake scenario	High uptake scenario
R3	Retrofit closed-channel DPF to existing railcars	10% *(802 railcars)*	40% *(3207 railcars)*
R4	Retrofit SCR to existing railcars	10% *(802 railcars)*	35% *(2806 railcars)*
R5	Retrofit SCR + closed channel DPF to existing railcars	10% *(802 railcars)*	30% *(2405 railcars)*

Table 2.7: Proposed strategies for applying technical options to the pre-1990 mainline locomotive fleet

Strategy code	Strategy option	Proportion of the 1975-1990 mainline locomotive fleet to which the strategy could be applied	
		Low uptake scenario	High uptake scenario
M1	Retrofit open channel DPF to existing mainline locomotives	10% *(179 locos)*	50% *(897 locos)*
M2	Re-engine mainline locomotives with improved engines	10% *(179 locos)*	50% *(897 locos)*

Table 2.8: Proposed strategies for applying technical options to the post-1990 mainline locomotive fleet

Strategy code	Strategy option	Proportion of the post-1990 mainline locomotive fleet to which the strategy could be applied	
		Low uptake scenario	High uptake scenario
M3	Retrofit closed-channel DPF to existing mainline locomotives	10% *(316 locos)*	40% *(1264 locos)*
M4	Retrofit SCR + closed channel DPF to existing mainline locomotives	10% *(316 locos)*	30% *(948 locos)*

Table 2.9: Proposed strategies for applying technical options to the pre-1990 shunting locomotive fleet

Strategy code	Strategy option	Proportion of the pre-1990 shunting locomotive fleet to which the strategy could be applied	
		Low uptake scenario	High uptake scenario
S1	Retrofit closed-channel DPF to existing shunting locomotives	10% *(218 locos)*	30% *(654 locos)*
S2	Retrofit SCR + closed channel DPF to existing shunting locomotives	10% *(218 locos)*	20% *(436 locos)*
S3	Re-engine shunting locomotives with improved engines	10% *(218 locos)*	50% *(1089 locos)*

Table 2.10: Proposed strategies for applying technical options to the post-1990 shunting locomotive fleet

Strategy code	Strategy option	Proportion of the post-1990 shunting locomotive fleet to which the strategy could be applied	
		Low uptake scenario	High uptake scenario
S4	Retrofit closed-channel DPF to existing shunting locomotives	10% *(84 locos)*	40% *(336 locos)*
S5	Retrofit SCR to existing shunting locomotives	10% *(84 locos)*	35% *(294 locos)*
S6	Retrofit SCR + closed channel DPF to existing shunting locomotives	10% *(84 locos)*	30% *(252 locos)*

3 Development of strategies for reducing emissions from the future fleet

3.1 Overview

Work Package 2 also included an investigation of the possible options that could be used to reduce emissions from future vehicles. The results from this investigation were used to develop possible strategies for reducing emissions from the future fleet, and to carry out an initial assessment of the possible costs and benefits associated with these strategies.

3.2 Characterisation of the future fleet

As part of Work Package 1, three scenarios were produced to set out the possible manner in which the diesel rail fleet across Europe might develop between 2005 and 2020. The most realistic of these scenarios (Scenario A), examined the likely change in the number and profile of traction units across Europe, taking into account the average ages at which traction units are decommissioned, as well as likely changes in annual traffic. Estimates were made with regard to the number of new traction units joining the fleet from 2005 onwards, and this data effectively sets out the theoretical maximum number of traction units that could be fitted with emissions abatement technology to meet the Stage IIIA and/or Stage IIIB limit values. The projected total numbers of new, post-2004 traction units estimated to be in service for each year between 2005 and 2020 are set out in Table 3.1 and Table 3.2. It should be noted that the figures in these tables are **not** the number of new engines that will enter service in each year.

Table 3.1: Projected estimates for the cumulative total number of post-2004 diesel rail engines in service in each year from 2005 to 2012

	2005	2006	2007	2008	2009	2010	2011	2012
Estimated total number of post-2004 DMU railcar engines	775	1549	2325	3100	3877	4653	5430	6207
Estimated total number of post-2004 mainline locomotive engines	635	1272	1911	2553	3197	4020	4846	5674
Estimated total number of post-2004 shunting locomotive engines	419	839	1261	1684	2109	2652	3197	3743

Table 3.2: Projected estimates for the cumulative total number of post-2004 diesel rail engines in service in each year from 2013 to 2020

	2013	2014	2015	2016	2017	2018	2019	2020
Estimated total number of post-2004 DMU railcar engines	6985	7763	8203	8644	9086	9527	9969	11292
Estimated total number of post-2004 mainline locomotive engines	6504	7336	7364	7395	7427	7462	7498	7464
Estimated total number of post-2004 shunting locomotive engines	4291	4840	4859	4879	4900	4923	4947	4925

3.3 Proposed strategies for reducing emissions from the future diesel rail fleet

As it will be a requirement for new engines to meet the Stage IIIA and Stage IIIB limit values, it was not necessary to develop low uptake and high uptake scenarios for each technology. Instead, it was assumed that in future years 100% of new engines will have to meet either the Stage IIIA or Stage IIIB limit values, depending on which year the engine comes into service. For Stage IIIA, all new railcar engines must meet the limit values from the beginning of 2006 onwards. For lower power locomotive engines (130 to 560 kW), new engines must meet the limit values from the beginning of 2007 onwards, whilst for high power locomotive engines (those greater than 560 kW), the Stage IIIA limits must be met from the beginning of 2009 onwards. For Stage IIIB as it currently stands, all new engines must meet the limit values from the beginning of 2012 onwards. It should be noted that the Stage IIIB limit values will undergo a technical review that is to be completed by the end of 2007, and the outcomes from the review process may possibly lead to modifications to the limit values. However, for the purposes of this study, it has been assumed that the current Stage IIIB limit values will be introduced as planned. The Stage IIIA and Stage IIIB limit values are presented below in Table 3.3.

Table 3.3: Stage IIIA and Stage IIIB limit values for rail traction units

	Stage IIIA limits (g/kWh)		Stage IIIB limits (g/kWh)	
	NOx	PM_{10}	NOx	PM_{10}
Railcars	4.0	0.2	2.0	0.025
Locomotives (130-560 kW)	4.0	0.2	4.0	0.025
Locomotives (560-2000 kW)	6.0	0.2	4.0	0.025
Locomotives (>2000 kW)	7.4	0.2	4.0	0.025

It was assumed that emissions abatement options will only be applied to new engines from the point in time that the individual emission limit values come into force. So, for example, it was assumed that no railcar engines will be fitted with emissions abatement equipment to meet Stage IIIA before 2006, but from the beginning of 2006 onwards (i.e. the point at which the emissions limits apply to railcar engines), all new railcar engine will meet the Stage IIIA limits.

The analysis carried out in WP2 indicated that in order to meet the Stage IIIA limit values, only internal engine design measures would be required, and no exhaust after-treatment options would be necessary. Box 2 below summarises the findings for meeting Stage IIIA limits.

For both the Stage IIIA and Stage IIIB emissions limits, **initial estimates** of the costs and benefits of applying the relevant technical options to all affected new diesel traction engines were made, based on the cost data collated as part of WP2. It must be stressed that more detailed analysis to more accurately quantify the costs and benefits associated with implementing the Stage IIIA and IIIB limits for the rail sector will be required after this project has been completed.

Box 2: Summary of findings from WP2 for applying technical options to new railcar and locomotive engines to meet the Stage IIIA limit values

Likely technical options that will enable new engines to meet the Stage IIIA limit values

WP2 identified the main options that could possibly be used to ensure that new engines meet the Stage IIIA limits

1) *Modern diesel combustion technology*
2) *The use of improved charging and injection technology*
3) *Optimised air cooling*
4) *Possible use of Exhaust Gas Recirculation*

It should be noted that there is still some uncertainty with regard to which are the most suitable options. Sulphur-free diesel (10 ppm maximum sulphur content) will be required for all of these options

The findings for meeting the Stage IIIA limit values contrast strongly with the findings for meeting the Stage IIIB limits. In this latter case, the investigations carried out in WP2 strongly indicated that these limit values will only be achieved if exhaust after-treatment options are applied to new engines.

Box 3: Summary of findings from WP2 for applying technical options to new railcar and locomotive engines to meet the Stage IIIB limit values

Likely technical options that will enable new engines to meet the Stage IIIB limit values

WP2 identified the main options that could possibly be used to ensure that new engines meet the Stage IIIB limits:

1) *Further development of the internal engine design measures detailed above for meeting the Stage IIIA limits will be required to meet the Stage IIIB NOx limits*
2) *SCR exhaust after-treatment technology could be used to abate NOx emissions*
3) *Many of the options examined included the use of a Diesel Particulate Filter to control PM_{10} emissions*

It should be noted that at this stage there is a high level of uncertainty with regard to which are the final levels and measures to achieve Stage IIIB. Proposals will come out of the 2007 feasibility study. Sulphur-free diesel (10 ppm maximum sulphur content) will be required for all of these options

4 Strategies for tackling emissions from potential railway contributors to air quality hotspots

4.1 Overview

WP3 focused on examining the potential contributions of different types of railway locations to concentrations of air pollutants. The objective of this work was to identify whether any particular types of railway operation could possibly be significant contributors to air quality hot spots. For the purposes of this study, such hot spots have been defined as areas where the concentrations of NO_2 or PM_{10} exceed 40 µg/m^3 (40 µg/m^3 is currently the maximum allowed yearly pollutant concentration for PM_{10}, and this value will also come into force for NO_2 from 2010, as specified in Directive 99/30/EC).

Three different types of railway operation were investigated to understand whether they contribute to hot spots or not. These operations were very busy line sections where large numbers of diesel trains operate on a daily basis, shunting yards with diesel shunting locomotives, and busy terminal stations where large numbers of diesel traction units operate. The air quality modelling work carried out in WP3 indicated that none of these types of railway operations would ever on their own generate an air quality hotspot, but that under certain circumstances, emissions from some of these types of locations could be significant contributors to hot spots generated by combinations of different sources such as road transport, industrial emissions and railway emissions. Furthermore, the results also indicated that the potential contribution to hot spots was limited to NO_2 hotspots; railway contributions to PM_{10} at all three types of location would be too low to be considered as a significant contributor to any PM_{10} hotspots. The results also showed that not all of the three types of location examined would contribute to NO_2 hotspots. Potential contributions from very busy line sections were found to be insignificant, but contributions from shunting yards and busy terminal stations could play an important part in the generation of NO_2 hotspots.

Bearing all of this in mind, it was clear that any strategies for tackling railway emissions at potential air quality hotspots should focus specifically on options that reduce NOx emissions, and options that can reduce emissions from shunting locomotives operating in shunting yards, and traction units that are idling whilst stationary at busy terminal stations. In some countries, there has been a focus on trying to reduce emissions of PM_{10} at potential hotspots. For this reason, the strategies also included options for reducing PM_{10} emissions.

4.2 Possible strategies for reducing NOx emissions from shunting yards

The strategies that were investigated focused on trying to identify the costs and benefits associated with reducing emissions from a busy shunting yard that could potentially contribute to air quality hotspots. For shunting yards, the solutions are likely to be based around technical options that could reduce NOx emissions from shunting locomotives. In particular, the costs and benefits associated with re-engining, or applying combined SCR+DPF technology were examined. Furthermore, as there is much interest at the moment in reducing PM_{10} emissions at sensitive locations, the use of DPF technology was also examined.

Box 4: Strategies for reducing emissions at shunting yards that contribute to air quality hotspots

Proposed possible strategies for reducing emissions at shunting yards
Examine the costs and benefits of applying the following options to shunting locomotives at a typical busy shunting yard that could contribute to pollutant concentrations:

1) *Closed channel DPF*
2) *SCR + DPF exhaust after-treatment technology*
3) *Re-engining*

4.3 Possible strategies for reducing NOx emissions from busy terminal stations

There is much less certainty regarding how significant the contribution of emissions from diesel traction units at busy terminal stations is to local air quality hot spots. This is because the dispersion modelling that was used in WP3 is not able to model the semi-enclosed environment of such stations. The modelling carried out in WP3 assumed that terminal stations are completely unenclosed environments, and this factor means that the contribution of idling diesel rail engines to ambient pollutant concentrations tends to be overestimated, whilst the contribution to concentrations inside the station tends to be underestimated. Nevertheless, it was thought possible that a small number of busy stations across Europe could be significantly contributing to air quality hotspots.

The strategies attempted to examine the costs and benefits associated with applying technical or operational measures to a busy terminal station where a high proportion of diesel traction units are in operation, but in practice robust cost data for these strategies was not available. The strategies that were examined as part of this work are set out in the box below.

Proposed strategies for reducing emissions at busy terminal stations
Identify busy terminal stations that have a high proportion of diesel traffic and that could contribute to NO_2 hotspots. For these stations, examine the costs and benefits of applying the following options:

1) *Idling policies*
2) *SCR + DPF exhaust after-treatment technology*
3) *Closed channel DPF*
4) *Re-engining*

5 Cost benefit analysis methodology and assumptions

5.1 Overview

Sections 5.2 to 5.6 below provide details of all of the assumptions that were used to estimate the costs and reductions in emissions associated with each strategy option, whilst Section 5.8 provides details of the CAFE pollutant damage cost values that were used to value the emissions benefits associated with each strategy option.

5.2 Representative vehicles included in the analysis

In order to remain consistent with the work carried out as part of Work Package 2, it was decided that the same set of representative vehicles should be used to assess the possible costs and emissions benefits of adopting emission reduction strategies. This was necessary as it was not feasible within the scope and resources available for this study to assess the costs and benefits of applying emissions reduction strategies to all of the different designs of traction units that are in operation across the EU Railway 27. The approach used was based on assuming that a small number of traction unit designs are representative of the whole European fleet in terms of the following parameters:

- ability to fit emissions abatement equipment or to re-engine the traction units
- costs of fitting emissions abatement equipment or of re-engining
- average fuel consumption
- average annual distance travelled
- average NOx and PM_{10} emission factors

Hence, many of the assumptions used in Work Package 2 were carried through and used in Work Package 4. The existing (pre-2005) diesel rail fleet was represented by the following designs of traction unit.

Table 5.1: Representative traction units used in the cost benefit analysis

Type of traction unit	Age category	Representative traction unit used in the analysis of emission reduction strategies
Diesel railcar	1980-1989	CD VT810
	1990-2004	DB VT612
	1990-2004	DB VT642
Mainline locomotive	1975-1989	DB Class 232
	1990-2004	DB Class 218
Shunting locomotive	1975-1989	CD Class 742
	1990-2004	DB Class 290

For the purposes of the cost benefit analysis, the traction units presented in the table above were used as proxy vehicles to represent the whole European fleet. Hence the VT810 railcar was assumed to be representative of all railcars in the 1980 to 1989 age category, and the Class 290 locomotive was assumed to be representative of all shunting locomotives in the 1990 to 2004 age category. For post-1990 railcars, two representative traction units were included; it was assumed that two thirds of the post-1990 fleet was represented by the Class

642 (typically used for regional services), whilst the remaining one third was represented by the Class 612 (typically used for intercity services).

5.3 Baseline emission factors used for the representative vehicles

The assessment of the emissions benefits associated with each strategy was based on estimating the total NOx and PM_{10} emissions from all included diesel traction units across Europe under a baseline (i.e. no action) scenario, and then estimating the effect of each strategy on the baseline values. In order to estimate the baseline emissions and the resultant reduction in emissions related to each scenario, it was necessary to use a set of representative baseline emission factors for each type of traction unit in conjunction with activity data that represents the operational performance of diesel traction across Europe. As part of the data collected during Work Package 1, UIC member railway operators were asked to supply data on the emissions performance of their fleets. These data were used to calculate average emission factors for each type of vehicle. These emission factors were used in the cost benefit analysis as the baseline factors for each type of existing traction unit (see Table 5.2 below).

Table 5.2: Assumed emission factors used for analysis of the existing diesel rail fleet

Type of traction unit	Age category	Assumed average emission factors (based on WP1 survey data) (g/kWh)	
		NOx	PM_{10}
Diesel railcar	1980-1989	13.70	0.53
	1990-2004	7.00	0.14
Mainline locomotive	1975-1989	15.40	0.34
	1990-2004	10.70	0.16
Shunting locomotive	1975-1989	12.60	0.55
	1990-2004	11.90	0.27

For the future (post-2005) fleet, the baseline emission factors against which the Stage IIIA and Stage IIIB limits have been compared are shown below in Table 5.3. It was assumed that the baseline future NOx emission factors are the same as the UIC II limits for NOx, whilst Euromot provided data on the baseline PM_{10} emissions performance of new traction units. The Stage IIIA and Stage IIIB limit values are presented in Table 5.4.

Table 5.3: Assumed baseline emission factors for the new fleet prior to the introduction of the Stage IIIA or Stage IIIB limits (based on UIC II limits for average NOx emission factors and performance of current new traction units for PM_{10})

Type of traction unit	Age category	Assumed average emission factors (g/kWh)	
		NOx	PM_{10}
Diesel railcar	post 2004	6.00	0.10
Mainline locomotive (560 kW to 2000 kW)	post 2004	9.90	0.10
Mainline locomotive (above 2000 kW)	post 2004	9.90	0.10
Shunting locomotive (130 kW to 560 kW)	post 2004	6.00	0.10
Shunting locomotive (560 kW to 2000 kW)	post 2004	9.90	0.10

Note: NOx emission factors are the UIC II limit values. PM_{10} emission factors are the typical emission factors for current new traction units (PM_{10} emission factor data supplied by Euromot)

Table 5.4: Stage IIIA and Stage IIIB limit values

Type of traction unit	Age category	Assumed average emission factors (g/kWh)			
		Stage IIIA		Stage IIIB	
		NOx	PM_{10}	NOx	PM_{10}
Diesel railcar	Stage IIIA: 2006-2011 Stage IIIB: from 2012	4.00	2.00	0.2	0.025
Mainline locomotive (130 kW to 560 kW)	Stage IIIA: 2007-2011 Stage IIIB: from 2012	4.00	4.00	0.2	0.025
Mainline locomotive (560 kW to 2000 kW)	Stage IIIA: 2009-2011 Stage IIIB: from 2012	6.00	4.00	0.2	0.025
Mainline locomotive (above 2000 kW)	Stage IIIA: 2009-2011 Stage IIIB: from 2012	7.40	4.00	0.2	0.025
Shunting locomotive (130 kW to 560 kW)	Stage IIIA: 2007-2011 Stage IIIB: from 2012	4.00	4.00	0.2	0.025
Shunting locomotive (560 kW to 2000 kW)	Stage IIIA: 2009-2011 Stage IIIB: from 2012	6.00	4.00	0.2	0.025
Shunting locomotive (above 2000 kW)	Stage IIIA: 2009-2011 Stage IIIB: from 2012	7.40	4.00	0.2	0.025

5.4 Activity data for calculating total baseline emissions from diesel rail traction

In order to calculate total baseline NOx and PM_{10} emissions, it was necessary to combine the average emission factor data for each type of traction unit with representative average activity data for the corresponding traction unit types, and with data on the total numbers of rail engines in the European fleet. Total baseline emissions were calculated using the following equation:

$$\text{Total baseline emissions} = \sum_{1}^{n} \text{Number of engines}_n \times \text{Emission Factor}_n \times \text{Energy output}_n$$

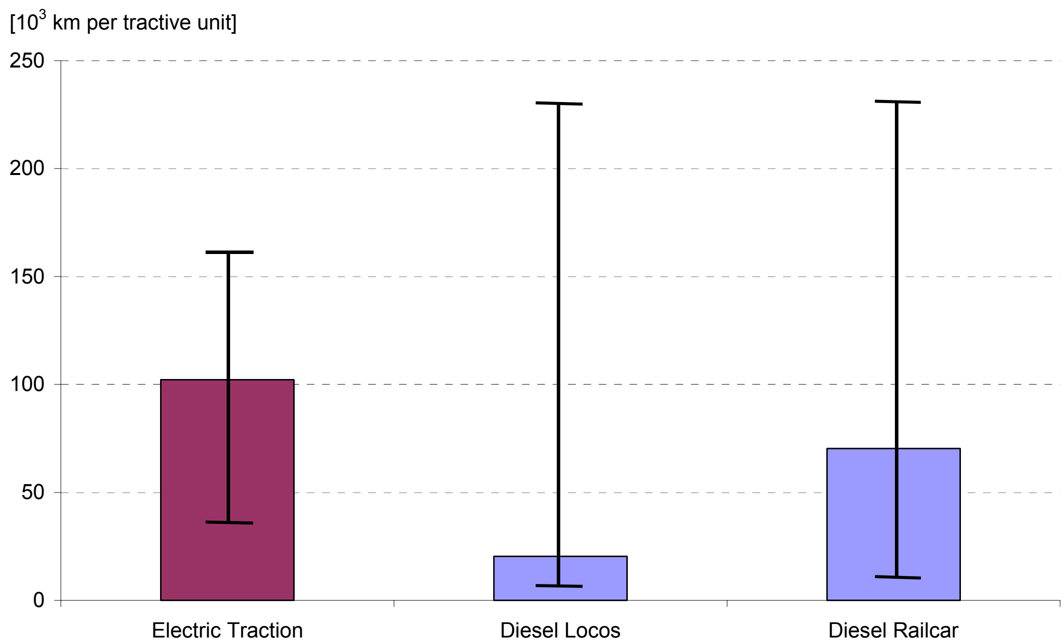
where n = the type of traction unit.

(Note: Energy output = Energy consumption x Average Thermal Efficiency Factor)

For this study, the emission factor data was available in units of grams of pollutant per kWh energy output, and hence the data required to complete the above equation was the average total annual energy output associated with each type of traction unit, based on train activity data. Total annual energy output can be estimated by taking annual fuel consumption data for each type of traction unit, converting these values into units of energy, and then multiplying the resultant value by the average value for the thermal efficiency of a diesel internal combustion engine. For the purposes of this study, it was assumed that the average thermal efficiency of all rail diesel engines is 40%. However, in order to estimate the total annual fuel consumption associated with each different type of traction unit, a number of assumptions had to be made with regard to annual train kilometre and average fuel consumption data.

Over the course of this study, a range of different types of train activity data have been collated and, to date, these data have been presented in the Work Package 1 and Work Package 2 final reports. As part of WP1, UIC members were surveyed and were asked to provide data on the average annual train-kilometres travelled by each traction unit, disaggregated into railcars and locomotives. As part of WP2, average fuel consumption (in litres per 100 km or litres per hour for shunting locomotives) and annual train-kilometre data (or annual operating hours for shunting locomotives) were provided for each of the representative traction units described in Section 5.2 of this report. These data are presented below in Figure 5.1 and Table 5.4.

Figure 5.1: Estimated average annual activity data (train kilometres) for different types of traction units, as presented in the WP1 final report



As can be seen from Figure 5.1 above, the possible range of annual train kilometres that were collected as part of WP1 varies very significantly, indicating the spread of values provided by different railway operators. For diesel locomotives, the average annual activity was calculated to be 20,000 train kilometres per year, whilst for diesel railcars, the average annual activity was calculated as being 70,000 train kilometres. It should be noted that the figure for diesel locomotives includes shunting locomotives, which do not travel far (but which are obviously used quite intensively). Consequently the annual activity data for locomotives given above is likely to significantly underestimate the average annual distance travelled by mainline locomotives, whilst annual train-kilometre data is not a suitable metric for shunting locomotives.

Table 5.5 below provides details of the fuel consumption data and train kilometre activity data that were included in Work Package 2 for the selected representative traction units. These data indicate that annual railcar train kilometres range from 68,000 kilometres per year to 200,000 kilometres per year, whilst for mainline locomotives, the range is from 47,500 kilometres per year to 125,000 kilometres per year. For shunting locomotives, average activity data was reported in terms of annual operating hours, which is a much more appropriate measure for these types of traction units.

Table 5.5: Average fuel consumption factors and activity data for the representative traction units, as presented in the WP2 final report

Representative traction unit	Age category	Fuel consumption factor	Annual average train kilometres (operating hours for shunting locomotives
VT810 railcar	1980-1989	35 litres/100 km	68000 kilometres/year
VT612 railcar	1990-2004	65 litres/100 km	200000 kilometres/year
VT642 railcar	1990-2004	43.5 litres/100 km	120000 kilometres/year
Class 232 mainline locomotive	1980-1989	350 litres/100 km	47500 kilometres/year
Class 218 mainline locmotive	1990-2004	250 litres/100 km	125000 kilometres/year
Class 742 shunting locomotive	1980-1989	35 litres/hour	2500 hours/year
Class 290 shunting locomotive	1990-2004	45 litres/hour	3500 hours/year

However, whilst the WP2 train activity data presented in Table 5.5 may be an accurate reflection of the average fuel consumption and annual distances travelled by these particular types of vehicles, detailed analysis and assessments made using these figures indicated that they were not fully representative of intensively used traction units across Europe that might in the future be considered for re-engining or for retrofitting with emissions abatement equipment. It is for economic reasons that only intensively used traction units are likely to be considered for re-engining or retrofitting. As each of the railcars and locomotives listed in the table is supposed to be more widely representative of pre-1990 and post-1990 existing railcars and locomotives across Europe, it was felt necessary to develop a set of more realistic average fuel consumption and train kilometre activity data that could be used to inform the development and analysis of the proposed emissions reduction strategies. Following detailed discussions with UIC, UNIFE, and Euromot, the following set of activity data was proposed in place of the WP1 and WP2 activity data discussed above (Table 5.6).

Table 5.6: Train activity data used in the cost-benefit analysis

Representative traction unit	Age category	Fuel consumption factor	Annual average train kilometres (operating hours for shunting locomotives)
VT810 railcar	1980-1989	35 litres/100 km	120000 kilometres/year
VT612 railcar	1990-2004	65 litres/100 km	200000 kilometres/year
VT642 railcar	1990-2004	43.5 litres/100 km	120000 kilometres/year
Class 232 mainline locomotive	1980-1989	300 litres/100 km	100000 kilometres/year
Class 218 mainline locmotive	1990-2004	300 litres/100 km	100000 kilometres/year
Class 742 shunting locomotive	1980-1989	35 litres/hour	3500 hours/year
Class 290 shunting locomotive	1990-2004	45 litres/hour	3500 hours/year

5.5 Emissions abatement performance of technical measures

As part of the analysis carried out in Work Package 2, estimates for the emissions abatement performance of each technical measure were supplied by equipment manufacturers, and additional research was also carried out to understand the possible impacts of each measure on NOx and PM_{10} emissions. The emissions abatement assumptions presented in the Work Package 2 final report were carried through to the Work Package 4 analysis. A summary of these assumptions is presented in the table below.

Table 5.7: Assumed emissions abatement performance of strategy options for the existing fleet

Option	Assumed percentage emissions abatement performance	
	NOx	PM_{10}
Open channel Diesel Particulate Filter		30%
Closed channel Diesel Particulate Filter		90%
Selective Catalytic Reduction (SCR)	80%	20%
Selective Catalytic Reduction (SCR) + Diesel Particulate Filter	60%	85%
Exhaust Gas Recirculation (EGR) + Diesel Particulate Filter	60%	85%
Re-engining	35%	35%

Table 5.8: Assumed emissions abatement performance of strategy options for the future fleet

	Assumed emissions abatement performance	
Option	**NOx**	**PM_{10}**
Stage IIIA options Optimised diesel combustion technology and air cooling Exhaust Gas Recirculation + Open channel Diesel Particulate Filter	All options assumed to meet Stage IIIA NOx limits	All options assumed to to meet a value of 0.1 g/kWh
Stage IIIB options Improved charging and injection technology (e.g. HCCI) + fitment of a DPF Selective Catalytic Reduction + Closed Channel DPF	All options assumed to meet Stage IIIB NOx limits	All options assumed to meet Stage IIIB PM_{10} limits

5.6 Costs and technical life-times of emissions abatement options

5.6.1 Measures for the existing fleet

As part of the analysis carried out for Work Package 2, a life-cycle cost assessment was carried out to estimate the additional annual costs of different emissions abatement options. These cost assessments were carried out by using data supplied by equipment manufacturers on the costs of exhaust after-treatment options and engine control measures, along with estimates for any additional operating and maintenance costs that would be incurred due to the use of these types of equipment. Capital costs were annualised using the methodology specified in the EC's Impacts Assessment Guidelines (see Annex 1). For the purposes of this study, all costs (regardless of the year in which they would be incurred) were quoted in 2005 prices and in Euros. Cost and technical life-time data for each strategy option for the existing fleet are presented in Annex 3 (Tables A3.1 to A3.7). It must be stressed that the costs provided in the tables in Annex 3 are **indicative costs only;** installation and system integration costs, in particular, will vary depending on the number of traction units that are fitted with the particular type of emissions abatement technology. In addition to cost data, the tables in Annex 3 also provide details of the technical life times of each type of emissions abatement equipment.

An important point that should be noted is that whilst most of the cost and technical life-time data for all retrofit emissions abatement equipment were taken directly from the analysis carried out for Work Package 2, no data of this nature were available for re-engining options. In the lack of detailed cost data on re-engining, some initial estimates of the capital costs and reductions in operating and maintenance costs associated with re-engining have been made. It should therefore be noted that the cost data used for re-engining is likely to be less robust than the cost data for emissions abatement equipment.

5.6.2 Measures for the future fleet

The analysis carried out in Work Package 2 to assess the costs and feasibility of applying measures to the future fleet was carried out on a slightly different basis. Detailed cost information was not available for the individual options that could be used for the future fleet, and hence in Work Package 2 it was necessary to provide estimates on the basis of the likely percentage increases in capital costs, operating costs and maintenance costs associated with each vehicle type. These percentage cost increases were used in conjunction with estimates for the current purchase cost of railcars and locomotives in order to estimate the monetary (rather than percentage) increases in costs associated with each strategy option. It must be stressed that the estimates for the baseline costs of future railcars and locomotives **are only indicative costs at this stage.** It should be noted that all costs for measures that could be applied to the future fleet are quoted in Euros in 2005 prices.

Table 5.9: Estimates for the purchase costs of future traction units

	Lower estimate for purchase cost	Upper erstimate for purchase cost	Average cost (used in the analysis)
Future railcar	€1.5 million	€3.5 million	**€2.5 million**
Future mainline locomotive	€2.0 million	€3.0 million	**€2.5 million**
Future shunting locomotive	€1.0 million	€2.0 million	**€1.5 million**

For fuel consumption and annual activity data (train kilometres), it has been assumed that the baseline values for the future fleet will be the same as those for the 1990-2004 existing fleet. For future railcar engines, it has been assumed that low power engines will have the same fuel consumption and annual activity as the VT642 railcar engine, whilst high power railcar engines will have the same fuel consumption and activity as the VT612 railcar. Similar assumptions were made for future mainline and shunting locomotives. For future mainline locomotives, it was assumed that baseline fuel consumption and annual activity data will be the same as for the DB Class 218 locomotive, whilst for future shunting locomotives, it was assumed that the baseline fuel consumption and annual activity data will be the same as for the DB Class 290 locomotive. These assumptions have allowed estimates for the total annual fuel cost associated with each of the main traction unit categories in the future fleet to be made (see Table 5.10 below). It should be noted that the data for railcars is presented on the basis of fuel consumption **per engine**. As with the purchase cost data, it must be stressed that the data presented in this table are indicative values only.

Table 5.10: Estimated fuel consumption and fuel costs for the future fleet

	Assumed baseline fuel consumption	Assumed baseline annual operating performance	Estimated annual fuel cost (based on cost of €0.75 per litre)
Future railcar engine (low power)	43.5 litres/100 km	120000 km	€ 39,150
Future railcar engine (high power)	65 litres/100 km	200000 km	€ 97,500
Future mainline locomotive	300 litres/100 km	100000 km	€ 225,000
Future shunting locomotive	45 litres/hour	3500 hours	€ 118,125

Some of the options analysed include the use of SCR equipment; such equipment requires a urea solution to be injected into the exhaust stream of the traction units. Whilst the consumption and costs of this urea solution have been taken into account in the analysis, it should be noted that the analysis has not included an assessment of the costs of setting up urea distribution infrastructure for the rail industry.

The baseline maintenance costs for new rail vehicles were obtained from railway operators. These costs are the annual maintenance costs for modern traction units prior to the introduction of the Stage IIIA and Stage IIIB limits. The analysis carried out in Work Package 2 identified the percentage increase in maintenance costs associated with meeting Stage IIIA and Stage IIIB; the baseline costs given in the table below have been used in conjunction with these estimated percentage cost increases in order to calculate the absolute values of the additional maintenance costs of Stage IIIA and Stage IIIB vehicles.

Table 5.11: Estimated baseline annual maintenance costs for the future fleet

	Estimated annual maintenance costs (€ per engine per year)
Future railcar engine	€ 20,000
Future mainline locomotive	€ 35,000
Future shunting locomotive	€ 25,000

5.6.3 Additional unit costs associated with emissions reduction strategies for the future fleet

The baseline vehicle and operating costs discussed in the previous sections were used as the basis for estimating the absolute costs (rather than percentage cost increases) associated with the various strategies for meeting the Stage IIIA and Stage IIIB limit values. These absolute costs are summarised in the tables below. As for the existing fleet, it should be noted that whilst the costs of the urea additive necessary for SCR technology have been included in the figures presented below for Stage IIIB, the additional costs of setting up a urea supply and distribution infrastructure are not included in these figures.

5.6.3.1 Additional costs for meeting Stage IIIA limits

Table 5.12: Estimated additional capital costs to meet Stage IIIA limits

	Estimated percentage change in total vehicle capital costs associated with meeting Stage IIIA limits	Estimated monetary change in total vehicle capital costs associated with meeting Stage IIIA limits
Future railcar	+3% to +7%	+€ 75,000 to +€ 175,000
Future mainline locomotive	+3% to +15%	+€ 75,000 to +€ 375,000
Future shunting locomotive	+3% to +15%	+€ 45,000 to +€ 225,000

Table 5.13: Estimated additional fuel costs to meet Stage IIIA limits

	Estimated percentage change in fuel consumption associated with meeting Stage IIIA limits	Estimated change in annual fuel consumption costs (per engine) associated with meeting Stage IIIA limits
Future railcar (low power)	+4% to +6%	+€ 1,045 to +€ 1,567
Future railcar (high power)	+4% to +6%	+€ 1,621 to +€ 2,431
Future mainline locomotive	+4% to +6%	+€ 6,253 to +€ 9,380
Future shunting locomotive	+4% to +6%	+€ 3,152 to +€ 4,728

Table 5.14: Estimated additional maintenance costs to meet Stage IIIA limits

	Estimated percentage change in maintenance costs associated with meeting Stage IIIA limits	Estimated change in annual maintenance costs (per engine) associated with meeting Stage IIIA limits
Future railcar (low and high power)	+0% to +5%	+€ 0 to +€ 1,000
Future mainline locomotive	+5% to +10%	+€ 1,750 to +€ 3,500
Future shunting locomotive	+5% to +10%	+€ 1,250 to +€ 2,500

5.6.3.2 Additional costs for meeting Stage IIIB limits

Table 5.15: Estimated additional capital costs to meet Stage IIIB limits

	Estimated percentage change in total vehicle capital costs associated with meeting Stage IIIB limits	Estimated monetary change in total vehicle capital costs associated with meeting Stage IIIB limits
Future railcar	+8% to +9%	+€ 200,000 to +€ 225,000
Future mainline locomotive	+8% to +20%	+€ 200,000 to +€ 500,000
Future shunting locomotive	+8% to +20%	+€ 120,000 to +€ 300,000

Table 5.16: Estimated additional fuel costs to meet Stage IIIB limits

	Estimated percentage change in fuel consumption associated with meeting Stage IIIB limits	Estimated change in annual fuel consumption costs (per engine) associated with meeting Stage IIIB limits
Future railcar (low power)	0% to +5%	€ 0 to +€ 1,306
Future railcar (high power)	0% to +5%	€ 0 to +€ 2,026
Future mainline locomotive	-5% to +9%	-€ 7,816 to +€ 14,070
Future shunting locomotive	-5% to +9%	-€ 3,940 to +€ 7,093

Table 5.17: Estimated annual costs of urea additive for meeting Stage IIIB limits

	Estimated urea consumption (as a percentage of fuel consumption) required to meet Stage IIIB limits	Estimated annual cost of urea consumption requierd to meet Stage IIIB limits
Future railcar (low power)	+2% to +3%	+€ 279 to +€ 418
Future railcar (high power)	+2% to +3%	+€ 432 to +€ 648
Future mainline locomotive	3% to +4%	+€ 2,501 to +€ 3,335
Future shunting locomotive	3% to +4%	+€ 1,261 to +€ 1,681

Note: costs associated with urea supply and distribution infrastructure are not included in these figures

Table 5.18: Estimated additional maintenance costs to meet Stage IIIB limits

	Estimated percentage change in maintenance costs associated with meeting Stage IIIB limits	Estimated change in annual maintenance costs (per engine) associated with meeting Stage IIIB limits
Future railcar	+0% to +5%	+€ 0 to +€ 1,000
Future mainline locomotive	+5% to +10%	+€ 0 to +€ 3,500
Future shunting locomotive	+5% to +10%	+€ 0 to +€ 2,500

5.7 Monetary value of the damage caused by pollutant emissions (CAFÉ values)

The European Commission's Clean Air For Europe (CAFE) programme included the development of new values for the external damage costs associated with air pollution. These damage costs relate to the monetary value of the environmental impacts of air pollution (e.g. the costs of damage to human health, crops, buildings, and ecosystems). These damage cost values are quoted in terms of Euros per tonne of pollutant emitted. More details on the impact categories included in the CAFE values can be found in Appendix 2 of this report. Two sets of CAFE damage cost values (low and high) were used in this study, and these values are presented below in Table 5.19.

Table 5.19: CAFE pollutant damage cost values for NOx and PM emissions used in the analysis

EU25 (excluding Cyprus) averages		
	Low estimate of damage costs	**High estimate of damage costs**
NOx	€4,400 per tonne	€12,000 per tonne
PM emissions (94% $PM_{2.5}$, 6% PM_{10})	€25,453 per tonne	€73,422 per tonne

6 Results for the existing fleet

6.1 Overview

The following sections present the results of the cost-benefit analysis (CBA) of strategy options for the existing fleet. This analysis has been carried out at the macro-economic level, and the estimated costs of each strategy are those that would in the first instance be borne by the railway industry, whilst the benefits are the wider benefits to society as a whole. The CBA results have been used to identify the strategy options that are likely to have net costs associated with them and the options that are likely to lead to net benefits. In all cases, the costs and benefits have been estimated over the 2005 to 2020 time period, and all costs are presented in Euros in 2005 prices. Each of the tables below provides the following information for specific strategy options:

- Total reduction in NOx emissions between 2005 and 2020
- Total reduction in PM_{10} emissions between 2005 and 2020
- Total implementation costs (sum of capital costs and the change in operating costs) between 2005 and 2020
- Total monetary value of emissions benefits between 2005 and 2020 (calculated using the CAFE damage cost values for NOx and PM_{10})
- Net costs or net monetary value of benefits between 2005 and 2020 (the difference between implementation costs and the monetary value of emissions benefits)

For the calculation of net costs or benefits associated with each option, net costs are indicated by a **positive** monetary value, whilst net benefits are indicated by **negative** values.

It should be noted that all of the analysis carried out for the existing fleet has been based on the assumption that the fleet will run on sulphur-free diesel (sulphur content of 10 ppm). Sulphur-free diesel is a necessary pre-requisite for many of the retrofit emissions abatement technologies assessed in this study, and hence it will be necessary for the whole European diesel railway fleet to use this fuel in the near future if emissions reductions are to be achieved.

6.2 Results for railcars

6.2.1 Pre-1990 railcars

Table 6.1 and Table 6.2 below present the cost-benefit analysis results for pre-1990 railcars.

Table 6.1: Analysis results for pre-1990 railcars (using LOW CAFE DAMAGE COSTS)

Strategy code	Strategy description	Uptake scenario	Reduction in NOx emissions (2005 to 2020)	Reduction in PM_{10} emissions (2005 to 2020)	NPV of total implementation costs (2005 to 2020)	NPV of combined NOx and PM_{10} benefits - low CAFE damage costs	Net costs (positive) or net benefits (negative) (2005 to 2020)
R1	Retrofit open channel DPF to existing railcar engines	**R1a:** 10% of the 2010 fleet (147 railcar engines)	0 tonnes	19 tonnes	€ 2 million	-€ 0.4 million	**€ 2 million**
		R1b: 50% of the 2010 fleet (736 railcar engines)	0 tonnes	95 tonnes	€ 12 million	-€ 2 million	**€ 10 million**
R2	Re-engine railcars with improved engine	**R2a:** 10% of the 2010 fleet (147 railcar engines)	1651 tonnes	64 tonnes	-€ 3 million	-€ 6 million	**-€ 9 million**
		R2b: 50% of the 2010 fleet (736 railcar engines)	8257 tonnes	319 tonnes	-€ 14 million	-€ 30 million	**-€ 45 million**

Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

Table 6.2: Analysis results for pre-1990 railcars (using HIGH CAFE DAMAGE COSTS)

Strategy code	Strategy description	Uptake scenario	Reduction in NOx emissions (2005 to 2020)	Reduction in PM_{10} emissions (tonnes)	NPV of total implementation costs (2005 to 2020)	NPV of combined NOx and PM_{10} benefits - high CAFE damage costs	Net costs (positive) or net benefits (negative) (2005 to 2020)
R1	Retrofit open channel DPF to existing railcar engines	**R1a:** 10% of the 2010 fleet (147 railcar engines)	0 tonnes	19 tonnes	€ 2 million	-€ 1.1 million	**€ 1 million**
		R1b: 50% of the 2010 fleet (736 railcar engines)	0 tonnes	95 tonnes	€ 12 million	-€ 6 million	**€ 6 million**
R2	Re-engine railcars with improved engine	**R2a:** 10% of the 2010 fleet (147 railcar engines)	1651 tonnes	64 tonnes	-€ 3 million	-€ 17 million	**-€ 20 million**
		R2b: 50% of the 2010 fleet (736 railcar engines)	8257 tonnes	319 tonnes	-€ 14 million	-€ 84 million	**-€ 98 million**

Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

The analysis results clearly show that only re-engining would give net benefits for pre-1990 railcars. Using the low CAFE damage cost values, net benefits would range from €9 million to €45 million, whilst with the high CAFE damage cost values, the net benefits would range from €20 million to €98 million. The results presented in the two tables above also indicate that the savings in operational costs would be larger than the capital costs of the new engines as the total implementation costs are negative.

As of January 2006, if any railcars are re-engined, they must be fitted with engines that meet the Stage IIIA limits; at this point in time, information provided by railway operators and engine manufacturers has indicated that only a very limited number of railcar engines are available that meets these emissions limits. Hence, it is clear that at the moment there would be significant limitations in attempting to re-engine pre-1990 railcars.

6.2.2 Post –1990 railcars

Table 6.3: Analysis results for post-1990 railcars (using LOW CAFE DAMAGE COSTS)

Strategy code	Strategy description	Uptake scenario	Reduction in NOx emissions (2005 to 2020)	Reduction in PM_{10} emissions (2005 to 2020)	NPV of total implementation costs (2005 to 2020)	NPV of combined NOx and PM_{10} benefits - low CAFE damage costs	Net costs (positive) or net benefits (negative) (2005 to 2020)
R3	Retrofit open-channel DPF to existing railcars	**R3a:** 10% of the 2010 fleet (802 railcar engines)	0 tonnes	179 tonnes	€ 42 million	-€ 3 million	**€ 38 million**
		R3b: 40% of the 2010 fleet (3206 railcar engines)	0 tonnes	717 tonnes	€ 166 million	-€ 13 million	**€ 154 million**
R4	Retrofit SCR to existing railcars	**R4a:** 10% of the 2010 high speed railcar fleet (267 Class 612 railcar engines - SCR not examined for Class 642)	19895 tonnes	0 tonnes	€ 31 million	-€ 61 million	**-€ 30 million**
		R4b: 35% of the 2010 high speed railcar fleet (935 Class 612 railcar engines - SCR not examined for Class 642)	69632 tonnes	0 tonnes	€ 109 million	-€ 213 million	**-€ 104 million**
R5	Retrofit SCR + closed channel DPF to existing railcars	**R5a:** 10% of the 2010 fleet (802 railcar engines)	17917 tonnes	508 tonnes	€ 66 million	-€ 64 million	**€ 2 million**
		R5b: 30% of the 2010 fleet (2405 railcar engines)	53751 tonnes	1523 tonnes	€ 197 million	-€ 191 million	**€ 6 million**

Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

Table 6.4: Analysis results for post-1990 railcars (using HIGH CAFE DAMAGE COSTS)

Strategy code	Strategy description	Uptake scenario	Reduction in NOx emissions (2005 to 2020)	Reduction in PM_{10} emissions (2005 to 2020)	NPV of total implementation costs (2005 to 2020)	NPV of combined NOx and PM_{10} benefits - high CAFE damage costs	Net costs (positive) or net benefits (negative) (2005 to 2020)
R3	Retrofit open-channel DPF to existing railcars	**R3a:** 10% of the 2010 fleet (802 railcar engines)	0 tonnes	179 tonnes	€ 42 million	-€ 9 million	**€ 32 million**
		R3b: 40% of the 2010 fleet (3206 railcar engines)	0 tonnes	717 tonnes	€ 166 million	-€ 37 million	**€ 130 million**
R4	Retrofit SCR to existing railcars	**R4a:** 10% of the 2010 high speed railcar fleet (267 Class 612 railcar engines - SCR not examined for Class 642)	19895 tonnes	0 tonnes	€ 31 million	-€ 166 million	**-€ 135 million**
		R4b: 35% of the 2010 high speed railcar fleet (935 Class 612 railcar engines - SCR not examined for Class 642)	69632 tonnes	0 tonnes	€ 109 million	-€ 582 million	**-€ 472 million**
R5	Retrofit SCR + closed channel DPF to existing railcars	**R5a:** 10% of the 2010 fleet (802 railcar engines)	17917 tonnes	508 tonnes	€ 66 million	-€ 176 million	**-€ 110 million**
		R5b: 30% of the 2010 fleet (2405 railcar engines)	53751 tonnes	1523 tonnes	€ 197 million	-€ 527 million	**-€ 330 million**

Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

For post-1990 railcars, if the low CAFE damage cost values are used, the analysis results indicated that there would only be net benefits if retrofit SCR equipment was used to reduce pollutant emissions. The CBA results indicate that the net benefits associated with retrofit SCR equipment could range from €30 million to €104 million. If the high CAFE damage cost values are used, the CBA results indicate that both SCR and combined SCR+DPF equipment would give net benefits. Under this scenario, the net benefits of SCR equipment were estimated to range from €135 million to €472 million, whilst the net benefits of combined SCR+DPF equipment were estimated to range from €110 million to €330 million. It must be stressed that at this point in time, it is not clear how feasible or practical it would be to retrofit SCR technology to existing railcars, and hence these figures must be seen as initial indicative values only.

6.3 Results for mainline locomotives

6.3.1 Pre-1990 mainline locomotives

Table 6.5: Results for pre-1990 mainline locomotives (using LOW CAFE DAMAGE COSTS)

Strategy code	Strategy description	Uptake scenario	Reduction in NOx emissions (2005 to 2020)	Reduction in PM_{10} emissions (2005 to 2020)	NPV of total implementation costs (2005 to 2020)	NPV of combined NOx and PM_{10} benefits - low CAFE damage costs	Net costs (positive) or net benefits (negative) (2005 to 2020)
M1	Retrofit open channel DPF to existing mainline locomotives	**M1a:** 10% of the 2010 fleet (179 locomotives)	0 tonnes	145 tonnes	€ 29 million	-€ 3 million	**€ 27 million**
		M1b: 50% of the 2010 fleet (897 locomotives)	0 tonnes	724 tonnes	€ 147 million	-€ 14 million	**€ 133 million**
M2	Re-engine mainline locomotives with improved engines	**M2a:** 10% of the 2010 fleet (179 locomotives)	16144 tonnes	356 tonnes	€ 24 million	-€ 55 million	**-€ 31 million**
		M2b: 50% of the 2010 fleet (897 locomotives)	80719 tonnes	1782 tonnes	€ 118 million	-€ 275 million	**-€ 156 million**

Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

Table 6.6: Results for pre-1990 mainline locomotives (using HIGH CAFE DAMAGE COSTS)

Strategy code	Strategy description	Uptake scenario	Reduction in NOx emissions (tonnes)	Reduction in PM_{10} emissions (tonnes)	NPV of total implementation costs (2005 to 2020)	NPV of combined NOx and PM_{10} benefits - high CAFE damage costs	Net costs (positive) or net benefits (negative) (2005 to 2020)
M1	Retrofit open channel DPF to existing mainline locomotives	**M1a:** 10% of the 2010 fleet (179 locomotives)	0 tonnes	145 tonnes	€ 29 million	-€ 8 million	**€ 21 million**
		M1b: 50% of the 2010 fleet (897 locomotives)	0 tonnes	724 tonnes	€ 147 million	-€ 41 million	**€ 107 million**
M2	Re-engine mainline locomotives with improved engines	**M2a:** 10% of the 2010 fleet (179 locomotives)	16144 tonnes	356 tonnes	€ 24 million	-€ 151 million	**-€ 127 million**
		M2b: 50% of the 2010 fleet (897 locomotives)	80719 tonnes	1782 tonnes	€ 118 million	-€ 754 million	**-€ 636 million**

Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

As with pre-1990 railcars, it can be seen that for pre-1990 mainline locomotives, only re-engining would lead to net emissions benefits. Using the low CAFE damage cost values, net benefits were estimated to range from €31 million to €156 million; with the high CAFE damage cost values, net benefits were estimated to range from €127 million to €636 million.

In contrast to railcars, the assumed high capital costs of re-engining mainline locomotives were estimated to be greater than the reductions in operational costs – i.e. there would be net costs to the railway industry associated with re-engining mainline locomotives. It has to be noted that the costs and savings could vary significantly from railway to railway depending on the number of vehicles being re-engined and the assumed annual mileages. In many cases railway operators re-engine part of their diesel fleet for economic reasons as company investment calculations indicate that there would be overall cost reductions.

6.3.2 Post-1990 mainline locomotives

Table 6.7: Results for post-1990 mainline locomotives (using LOW CAFE DAMAGE COSTS)

Strategy code	Strategy description	Uptake scenario	Reduction in NOx emissions (2005 to 2020)	Reduction in PM_{10} emissions (tonnes)	NPV of total implementation costs (2005 to 2020)	NPV of combined NOx and PM_{10} benefits - low CAFE damage costs	Net costs (positive) or net benefits (negative) (2005 to 2020)
M3	Retrofit closed-channel DPF to existing mainline locomotives	**M3a:** 10% of the 2010 fleet (316 locomotives)	0 tonnes	757 tonnes	€ 48 million	-€ 13 million	**€ 35 million**
		M3b 40% of the 2010 fleet (1264 locomotives)	0 tonnes	3029 tonnes	€ 193 million	-€ 53 million	**€ 140 million**
M4	Retrofit SCR + closed channel DPF to existing mainline locomotives	**M4a:** 10% of the 2010 fleet (316 locomotives)	33762 tonnes	715 tonnes	€ 66 million	-€ 114 million	**-€ 49 million**
		M4b 30% of the 2010 fleet (948 locomotives)	101286 tonnes	2146 tonnes	€ 197 million	-€ 343 million	**-€ 146 million**

Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

Table 6.8: Results for post-1990 mainline locomotives (using HIGH CAFE DAMAGE COSTS)

Strategy code	Strategy description	Uptake scenario	Reduction in NOx emissions (2005 to 2020)	Reduction in PM_{10} emissions (2005 to 2020)	NPV of total implementation costs (2005 to 2020)	NPV of combined NOx and PM_{10} benefits - high CAFE damage costs	Net costs (positive) or net benefits (negative) (2005 to 2020)
M3	Retrofit closed-channel DPF to existing mainline locomotives	**M3a:** 10% of the 2010 fleet (316 locomotives)	0 tonnes	757 tonnes	€ 48 million	-€ 38 million	**€ 10 million**
		M3b 40% of the 2010 fleet (1264 locomotives)	0 tonnes	3029 tonnes	€ 193 million	-€ 153 million	**€ 40 million**
M4	Retrofit SCR + closed channel DPF to existing mainline locomotives	**M4a:** 10% of the 2010 fleet (316 locomotives)	33762 tonnes	715 tonnes	€ 66 million	-€ 314 million	**-€ 248 million**
		M4b 30% of the 2010 fleet (948 locomotives)	101286 tonnes	2146 tonnes	€ 197 million	-€ 942 million	**-€ 745 million**

Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

For post-1990 mainline locomotives, it can be seen that combined SCR+DPF equipment would give net emissions benefits of between €49 million and €146 million over the 2005-2020 time period, using the low CAFE damage costs values; these benefits would range from €248 million to €745 million if the high CAFE damage costs are used.

6.4 Results for shunting locomotives

6.4.1 Pre-1990 shunting locomotives

Table 6.9: Results for pre-1990 shunting locomotives (using LOW CAFE DAMAGE COSTS)

Strategy code	Strategy description	Uptake scenario	Reduction in NOx emissions (2005 to 2020)	Reduction in PM_{10} emissions (2005 to 2020)	NPV of total implementation costs (2005 to 2020)	NPV of combined NOx and PM_{10} benefits - low CAFE damage costs	Net costs (positive) or net benefits (negative) (2005 to 2020)
S1	Retrofit closed-channel DPF to existing shunting locomotives	**S1a:** 10% of the 2010 fleet (218 locomotives)	0 tonnes	349 tonnes	€ 21 million	-€ 7 million	**€ 14 million**
		S1b: 30% of the 2010 fleet (654 locomotives)	0 tonnes	1046 tonnes	€ 63 million	-€ 20 million	**€ 43 million**
S2	Retrofit SCR + closed channel DPF to existing shunting locomotives	**S2a:** 10% of the 2010 fleet (218 locomotives)	5326 tonnes	329 tonnes	€ 30 million	-€ 24 million	**€ 6 million**
		S2b: 20% of the 2010 fleet (436 locomotives)	10653 tonnes	659 tonnes	€ 61 million	-€ 49 million	**€ 12 million**
S3	Re-engine shunting locomotives with improved engines	**S3a:** 10% of the 2010 fleet (218 locomotives)	6551 tonnes	286 tonnes	€ 9 million	-€ 25 million	**-€ 16 million**
		S3b: 50% of the 2010 fleet (1089 locomotives)	32757 tonnes	1430 tonnes	€ 45 million	-€ 124 million	**-€ 79 million**

Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

Table 6.10: Results for pre-1990 shunting locomotives (using HIGH CAFE DAMAGE COSTS)

Strategy code	Strategy description	Uptake scenario	Reduction in NOx emissions (2005 to 2020)	Reduction in PM_{10} emissions (2005 to 2020)	NPV of total implementation costs (2005 to 2020)	NPV of combined NOx and PM_{10} benefits - high CAFE damage costs	Net costs (positive) or net benefits (negative) (2005 to 2020)
S1	Retrofit closed-channel DPF to existing shunting locomotives	**S1a:** 10% of the 2010 fleet (218 locomotives)	0 tonnes	349 tonnes	€ 21 million	-€ 20 million	**€ 1 million**
		S1b: 30% of the 2010 fleet (654 locomotives)	0 tonnes	1046 tonnes	€ 63 million	-€ 59 million	**€ 4 million**
S2	Retrofit SCR + closed channel DPF to existing shunting locomotives	**S2a:** 10% of the 2010 fleet (218 locomotives)	5326 tonnes	329 tonnes	€ 30 million	-€ 68 million	**-€ 37 million**
		S2b: 20% of the 2010 fleet (436 locomotives)	10653 tonnes	659 tonnes	€ 61 million	-€ 135 million	**-€ 74 million**
S3	Re-engine shunting locomotives with improved engines	**S3a:** 10% of the 2010 fleet (218 locomotives)	6551 tonnes	286 tonnes	€ 9 million	-€ 68 million	**-€ 59 million**
		S3b: 50% of the 2010 fleet (1089 locomotives)	32757 tonnes	1430 tonnes	€ 45 million	-€ 341 million	**-€ 297 million**

Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

For pre-1990 shunting locomotives, the analysis results indicated that only re-engining would give net emissions benefits if the low CAFE damage cost values are used. Under this scenario, net benefits would range from €16 million to €79 million. Using the high CAFE damage cost values, the results indicated that both re-engining and combined SCR+DPF would give net emissions benefits. The net benefits associated with re-engining were estimated to range from €59 million to €297 million, whilst the net benefits associated with SCR+DPF were estimated to range from €37 million to €74 million.

6.4.2 Post-1990 shunting locomotives

Table 6.11: Results for post-1990 shunting locomotives (using LOW CAFE DAMAGE COSTS)

Strategy code	Strategy description	Uptake scenario	Reduction in NOx emissions (2005 to 2020)	Reduction in PM_{10} emissions (2005 to 2020)	NPV of total implementation costs (2005 to 2020)	NPV of combined NOx and PM_{10} benefits - low CAFE damage costs	Net costs (positive) or net benefits (negative) (2005 to 2020)
S4	Retrofit closed channel DPF to existing shunting locomotives	**S4a:** 10% of the 2010 fleet (84 locomotives)	0 tonnes	178 tonnes	€ 13 million	-€ 3 million	**€ 9 million**
		S4b: 40% of the 2010 fleet (328 locomotives)	0 tonnes	713 tonnes	€ 50 million	-€ 12 million	**€ 38 million**
S5	Retrofit SCR to existing shunting locomotives	**S5a:** 10% of the 2010 fleet (84 locomotives)	6984 tonnes	40 tonnes	€ 10 million	-€ 21 million	**-€ 11 million**
		S5b: 35% of the 2010 fleet (294 locomotives)	24443 tonnes	139 tonnes	€ 37 million	-€ 74 million	**-€ 37 million**
S6	Retrofit SCR + closed channel DPF to existing shunting locomotives	**S6a:** 10% of the 2010 fleet (84 locomotives)	5238 tonnes	168 tonnes	€ 18 million	-€ 19 million	**-€ 1 million**
		S6b: 30% of the 2010 fleet (252 locomotives)	15713 tonnes	505 tonnes	€ 54 million	-€ 56 million	**-€ 3 million**

Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

Table 6.12: Results for post-1990 shunting locomotives (using HIGH CAFE DAMAGE COSTS)

Strategy code	Strategy description	Uptake scenario	Reduction in NOx emissions (2005 to 2020)	Reduction in PM_{10} emissions (2005 to 2020)	NPV of total implementation costs (2005 to 2020)	NPV of combined NOx and PM_{10} benefits - low CAFE damage costs	Net costs (positive) or net benefits (negative) (2005 to 2020)
S4	Retrofit closed channel DPF to existing shunting locomotives	**S4a:** 10% of the 2010 fleet (84 locomotives)	0 tonnes	178 tonnes	€ 13 million	-€ 9 million	**€ 4 million**
		S4b: 40% of the 2010 fleet (328 locomotives)	0 tonnes	713 tonnes	€ 50 million	-€ 36 million	**€ 14 million**
S5	Retrofit SCR to existing shunting locomotives	**S5a:** 10% of the 2010 fleet (84 locomotives)	6984 tonnes	40 tonnes	€ 10 million	-€ 57 million	**-€ 47 million**
		S5b: 35% of the 2010 fleet (294 locomotives)	24443 tonnes	139 tonnes	€ 37 million	-€ 201 million	**-€ 164 million**
S6	Retrofit SCR + closed channel DPF to existing shunting locomotives	**S6a:** 10% of the 2010 fleet (84 locomotives)	5238 tonnes	168 tonnes	€ 18 million	-€ 52 million	**-€ 34 million**
		S6b: 30% of the 2010 fleet (252 locomotives)	15713 tonnes	505 tonnes	€ 54 million	-€ 155 million	**-€ 101 million**

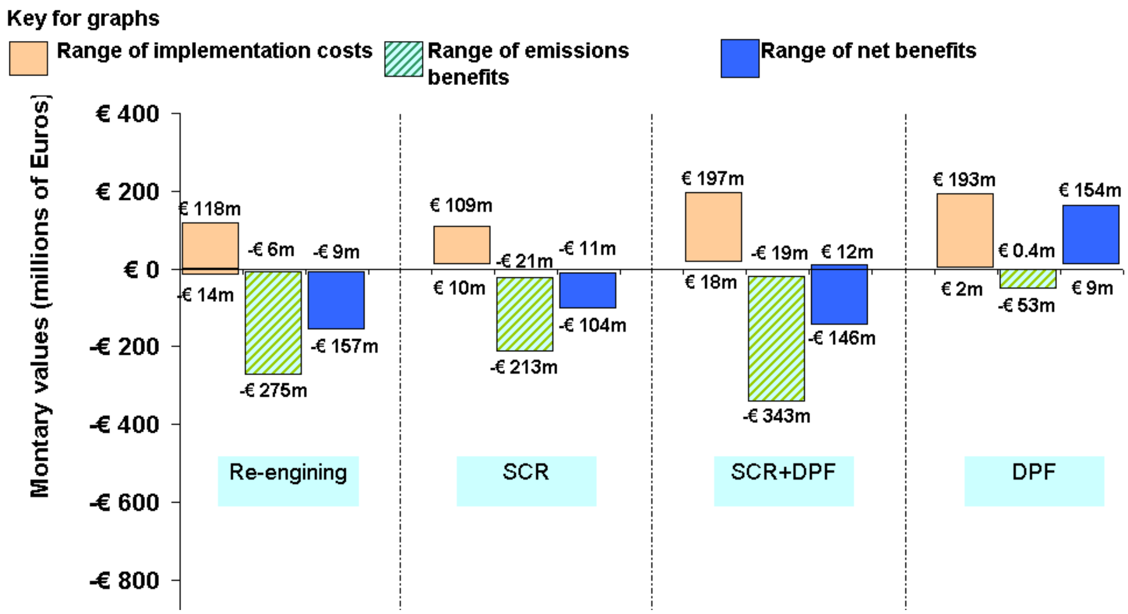
Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

For post-1990 shunting locomotives, the results indicated that both SCR and combined SCR+DPF equipment would give net benefits. Using the low CAFE damage values, the net emissions benefits of SCR equipment were estimated to range from €11 million to €37, rising to a range of €47 million to €164 million if the high CAFE values are used. For combined SCR+DPF equipment, the analysis indicated that net benefits ranging from €1 million to €3 million could be achieved, based on the low CAFE damage cost values, whilst this would rise to range from €34 million to €101 million if the high CAFE damage cost values are used.

6.5 Summary of cost-benefit analysis results

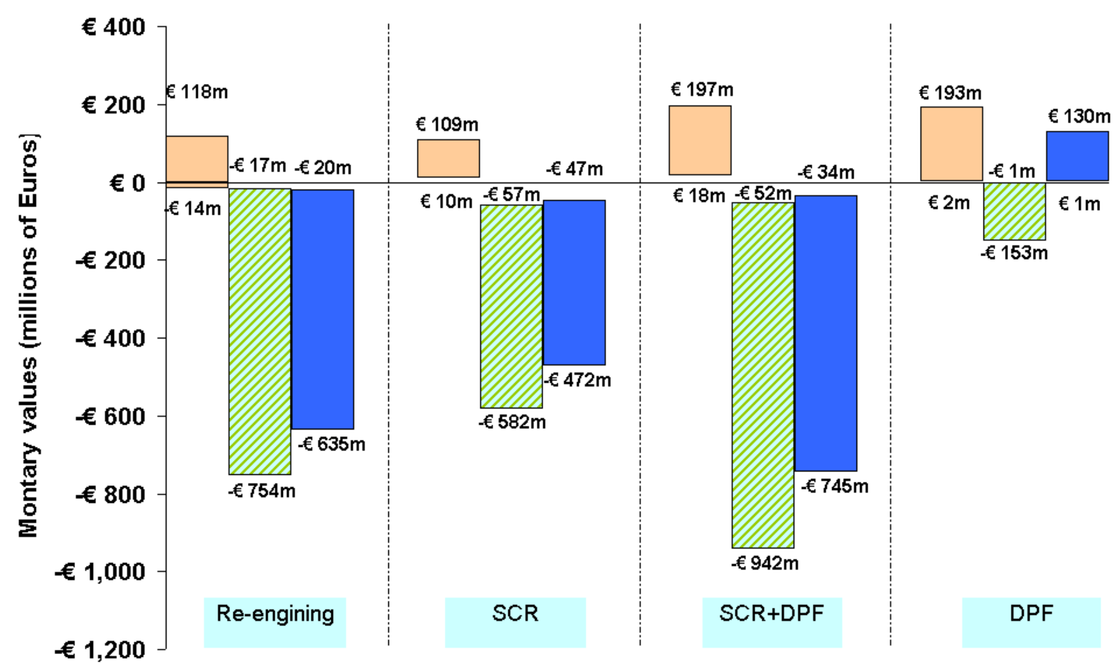
The cost benefit analysis results indicated that re-engining, SCR equipment, and combined SCR+DPF equipment could lead to net emissions benefits when applied to the existing fleet. The ranges of costs, emissions benefits, and net benefits associated with the different strategies are presented below in Figure 6.1 and Figure 6.2 below.

Figure 6.1: Initial estimates of the range of costs and benefits associated with the most promising strategies for the existing fleet (2005-2020 – LOW CAFE DAMAGE COSTS)



Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

Figure 6.2: Initial estimates of the range of costs and benefits associated with the most promising strategies for the existing fleet (2005-2020 – HIGH CAFE DAMAGE COSTS)



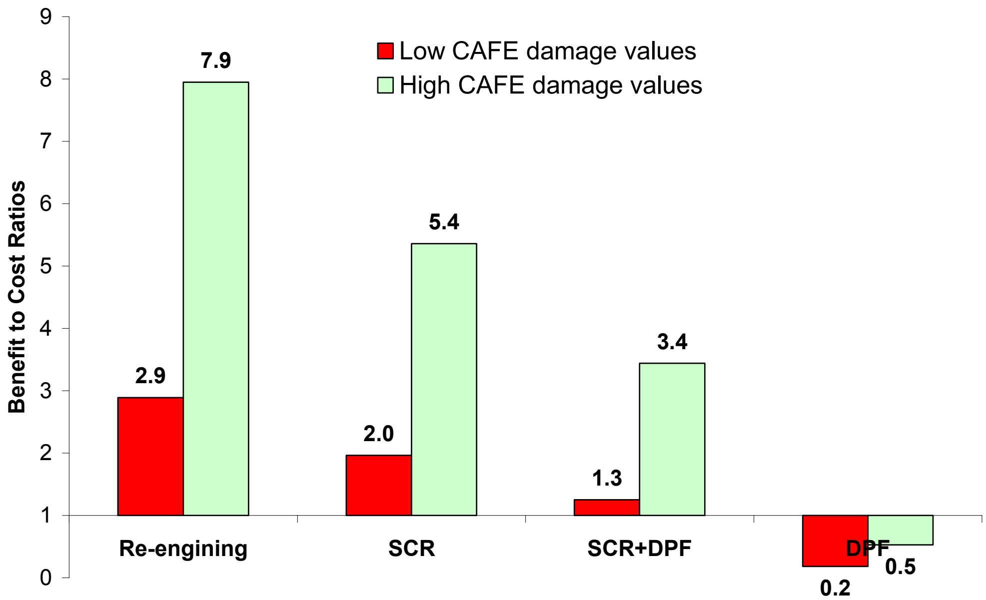
Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

As can be seen from the figures above, if the low CAFE damage cost values are used, the analysis has shown that re-engining options potentially give rise to the greatest net benefits, with estimated net benefits ranging from €9 million to €156 million over the 2005-2020 time period. A further benefit of re-engining is that under the assumptions made, for railcars the overall implementation costs were found to be less than zero – i.e. there would not be any net costs to railway operators, but there could be net reductions in costs (between €3 million and €14 million between 2005 and 2020) due to reduced operating and maintenance costs. By contrast, for locomotives, the capital costs associated with re-engining were anticipated to be greater than the reductions in operating costs due to reduced fuel consumption and maintenance costs, and hence there would be additional costs to the railway industry associated with re-engining locomotives. Primarily, this difference between railcars and locomotives is due to the much greater capital costs associated with re-engining locomotives compared to the costs for railcars. Using the low CAFE values, the analysis showed that all strategies based on the use of retrofit SCR would lead to net benefits, and some (but not all) of the strategies based around combined SCR+DPF technology would also lead to net benefits (the application of SCR+DPF technology to mainline and post-1990 shunting locomotives was found to give net benefits, whilst application to railcars and pre-1990 shunting locomotives would give net costs). It is clear from the results that none of the strategies based on only fitting DPF equipment to traction units would lead to net benefits – in all cases, the results indicate that net costs would be incurred, as the monetary value of emissions benefits is not enough to outweigh the implementation costs.

Using the high CAFE damage costs, Figure 6.2 indicates that combined SCR+DPF systems would give the greatest net benefits (ranging from €34 million to €745 million over the 2005-2020 time period. However, it should be borne in mind that the implementation costs associated with achieving these net benefits were estimated to total €197 million over the same time period. Under this scenario, re-engining would also lead to relatively large net benefits, whilst again, DPF equipment on its own would lead to net costs.

Further analysis was also carried out to quantify the average benefit-to-cost ratios (BCRs) for each of the technologies assessed. The results from this analysis are presented below in Figure 6.3. BCR values greater than 1 indicate that there would be net benefits associated with an option, whilst ratios that are less than 1 indicate that there would be net costs.

Figure 6.3: Average benefit-to-cost Ratios for strategy options for the existing fleet



As can be seen from the figure above, it is clear that re-engining is the option that has the highest benefit to cost ratio regardless of whether the low or high CAFE damage values are used.

Whilst the results presented above provide initial indications of the net costs, net benefits and benefit-to-cost ratios associated with different strategy options, it should also be highlighted that another important finding from the study is that there are no standard solutions that can be applied to all types of vehicles; in each case, detailed individual analysis would need to be carried out to assess the costs, benefits, and technical feasibility of applying a particular technical solution to specific types of traction units.

6.6 Other factors for consideration

6.6.1 Technical feasibility of re-engining and retrofitting emissions abatement equipment

It must be reiterated that the analysis carried out to assess the costs and benefits associated with strategies for the existing fleet has assumed that it will be possible to re-engine traction units with improved engines, or to retrofit emissions abatement technology such as SCR equipment or diesel particulate filters to existing railcars and locomotives. However, at this point in time there is almost no practical experience of using emissions abatement equipment on rail vehicles. Based on the results from Work Package 2 of this study, it is very likely that there will be practical limitations to the numbers of traction units that can be modified to accept exhaust after-treatment equipment. In many cases, there may not be space available to fit exhaust after-treatment, or the additional weight incurred by such equipment may lead to maximum axle loads being exceeded. Furthermore, some DPF equipment may lead to excessive increases in exhaust back-pressure. With regard to re-engining, requirements for major modifications to off-engine support systems may mean that it is not feasible to re-engine certain types of traction units. Taking all of these factors into account, it is again necessary to stress that a detailed engineering design and modification assessment would be required for each individual class of traction unit before proceeding with retrofitting exhaust after-treatment equipment or re-engining. It must also be reiterated that in order to use exhaust after-treatment such as SCR, it will be necessary for rail vehicles to run on sulphur-free diesel (10 ppm maximum sulphur content).

6.6.2 Emissions of CO_2, hydrocarbons, and carbon monoxide

The scope of this study was concerned with assessing the costs and benefits associated with reducing emissions of NOx and PM_{10}, and hence the quantification and monetisation of emissions benefits has focused on these two pollutants. However, it should also be taken into account that many of the options assessed for the existing fleet will also have an effect on carbon dioxide (CO_2), carbon monoxide (CO) and hydrocarbon (HC) emissions. It was outside the scope of this study to quantify these impacts, but a qualitative assessment of the impacts of different strategies on these pollutants has been carried out.

CO_2 emissions are directly proportional to fuel consumption, and hence strategies that reduce fuel consumption also lead to reductions in CO_2 emissions. Re-engining was assumed to lead to a 10% reduction in fuel consumption, and hence it can be assumed that re-engining would also lead to a 10% reduction in CO_2 emissions from those vehicles fitted with improved engines. The information gathered during Work Package 2 indicated that SCR technology does not lead to any changes in fuel consumption, and hence there would be no CO_2 benefits or additional impacts associated with the use of this technology on its own. However, some types of diesel particulate filters lead to increases in fuel consumption (some designs use fuel to regenerate the particulate trap). This additional fuel consumption has been estimated to be in the order of 2% to 3%, and any strategies that include the use of DPFs are likely to also incur CO_2 penalties of 2% to 3%. Combined SCR+DPF systems would also be affected by this factor.

During this study, no analysis has been carried out to quantify the impacts of each technology on CO and HC emissions, but it is anticipated that re-engining would lead to reductions in both of these pollutants.

6.6.3 Costs associated with re-engining

As mentioned in Section 5.6.1, the assumptions used in this study for the capital costs and changes in operating/maintenance costs associated with re-engining are less robust than the cost assumptions used for emissions abatement equipment (no data on the costs associated with re-engining was available during Work Package 2). It is known that railway operators often re-engine railcars and locomotives for economic reasons as in many cases the reduced operating and maintenance costs rapidly offset the capital costs associated with re-engining. It is therefore thought that further work will be required outside the scope of this study to assess in greater detail the costs and benefits associated with re-engining existing rail vehicles.

7 Results for the future fleet

7.1 Overview

For the future fleet, a similar methodology has been employed to assess the costs and emissions benefits associated with the strategy options that could be used to achieve the NRMM Stage IIIA and Stage IIIB emissions limits. As with the analysis carried out for the existing fleet, the costs and benefits have been estimated over the 2005 to 2020 time period, and all costs are presented in Euros in 2005 prices. Each of the tables in the following sections below provides the following information for specific strategy options:

- Total reduction in NOx emissions between 2005 and 2020
- Total reduction in PM_{10} emissions between 2005 and 2020
- Total implementation costs (sum of capital and additional operating costs) between 2005 and 2020
- Total monetary value of emissions benefits between 2005 and 2020 (calculated using the CAFE damage costs)
- Net costs or net monetary value of benefits between 2005 and 2020 (implementation cost minus monetary value of emissions benefits)

For the calculation of net costs or benefits associated with each option, net costs are indicated by **positive** monetary values, whilst net benefits are indicated by **negative** values. It should be noted that at this point in time there is considerable uncertainty with regard to which technologies will be used for meeting both the Stage IIIA and Stage IIIB limit values, and what the costs associated with these technologies will be. For these reasons, the results presented in this section should be viewed only as initial, indicative results that provide rough estimates of the costs and benefits associated with meeting Stage IIIA and Stage IIIB limits. In particular, it was not possible to accurately quantify the costs of emissions abatement technology for future rail vehicles as there is no experience of using this technology at this point in time. It should also be noted that the cost estimates presented in this section are not consistent with the cost estimates for retrofitting emissions abatement equipment to existing vehicles; this is because the data for the existing fleet was based on detailed information for specific types of traction units provided by suppliers of emissions abatement equipment, whilst the estimates for the future fleet, are initial estimates developed by representatives from Euromot and UNIFE. Furthermore, it should be noted that the Stage IIIA limits will apply to engines that enter service between 2006 and the end of 2011, whilst the Stage IIIB limits will only come into effect from 2012. For Stage IIIB, this means that only the costs and benefits associated with those engines entering service between 2012 and 2020 have been taken into account in the analysis. As the implementation costs have been annualised, the full implementation costs associated with engines that enter service between 2012 and 2020 are not taken into account; only the proportion of annualised costs estimated to be incurred over this time period have been taken into account and set against the value of benefits over the same time period. This ensure that costs and benefits are always compared on a similar basis.

As with the existing fleet, the analysis carried out for the future fleet has been based on assuming that all future vehicles will use sulphur-free diesel (10 ppm sulphur content). For many of the technical options that will be used to meet Stage IIIB, sulphur-free diesel is a necessary pre-requisite.

7.2 Results for Stage IIIA

Table 7.1: Results for Stage IIIA (using LOW CAFE DAMAGE COSTS)

Options included in the strategy	Traction unit type	Reduction in NOx emissions (2005 to 2020)	Reduction in PM_{10} emissions (2005 to 2020) (tonnes)	NPV of total implementation costs (2005 to 2020)	NPV of combined NOx and PM_{10} benefits - LOW CAFE DAMAGE COSTS	Net costs (positive) or net benefits (negative) (2005 to 2020)
A range of options could be used to meet the Stage IIIA limits including: (a) Improved diesel combustion performance, (b) Improved charging and injection technology, (c) Optimised air cooling, (d) possible use of Exhaust Gas Recirculation	Railcars	38,927 tonnes	N/A	€ 428 million to € 1,021 million	-€ 116 million	€ 312 million to € 904 million
	Mainline locomotives	116,718 tonnes	N/A	€ 309 million to € 1,154 million	-€ 338 million	-€ 29 million to € 816 million
	Shunting locomotives	40,429 tonnes	N/A	€ 124 million to € 449 million	-€ 117 million	€ 7 million to € 332 million
	TOTAL	**196,074 tonnes**	**N/A**	**€ 861 million to € 2,623 million**	**-€ 572 million**	**€ 289 million to € 2,052 million**

Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

Table 7.2: Results for Stage IIIA (using HIGH CAFE DAMAGE COSTS)

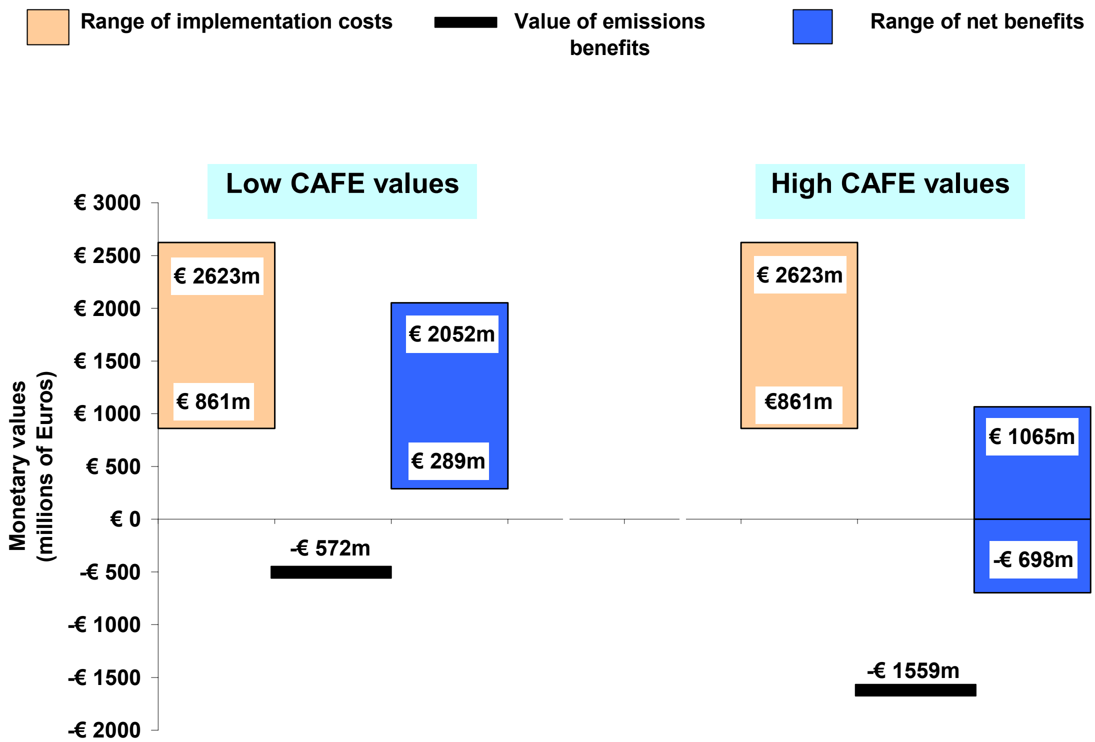
Options included in the strategy	Traction unit type	Reduction in NOx emissions (2005 to 2020)	Reduction in PM_{10} emissions (2005 to 2020) (tonnes)	NPV of total implementation costs (2005 to 2020)	NPV of combined NOx and PM_{10} benefits - HIGH CAFE DAMAGE COSTS	Net costs (positive) or net benefits (negative) (2005 to 2020)
A range of options could be used to meet the Stage IIIA limits including: (a) Improved diesel combustion performance, (b) Improved charging and injection technology, (c) Optimised air cooling, (d) possible use of Exhaust Gas Recirculation	Railcars	38,927 tonnes	N/A	€ 428 million to € 1,021 million	-€ 317 million	€ 111 million to € 703 million
	Mainline locomotives	116,718 tonnes	N/A	€ 309 million to € 1,154 million	-€ 922 million	-€ 613 million to € 232 million
	Shunting locomotives	40,429 tonnes	N/A	€ 124 million to € 449 million	-€ 319 million	-€ 195 million to € 129 million
	TOTAL	**196,074 tonnes**	**N/A**	**€ 861 million to € 2,623 million**	**-€ 1,559 million**	**-€ 698 million to € 1,065 million**

Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

The cost-benefit analysis results for the implementation of Stage IIIA indicate that under most scenarios the implementation costs will outweigh the emissions benefits. Using the low CAFE damage cost values, there are no net benefits; estimated net costs over the 2005 to 2020 time period were found to range from around €290 million to more than €2050 million. Using the high CAFE damage costs, it has been estimated that if the implementation costs are low, then there could be net benefits of approximately €700 million up to 2020. However, if the implementation costs are high, there could be net costs of up to €1065 million. The analysis results indicate that the implementation of Stage IIIA on new rail vehicles will lead to a total reduction in railway NOx emissions of more than 196,000 tonnes between now and 2020; there would be no reduction in PM_{10} emissions from new rail vehicles due to the Stage IIIA limits.

The graph below (Figure 7.1) provides a graphical summary of the results for Stage IIIA highlighting the range of costs and emissions benefits associated with ensuring that new traction units meet these emission limits between now and 2020.

Figure 7.1: Initial estimates of the ranges of costs and benefits associated with ensuring that future rail vehicles meet the Stage IIIA limits (2005-2020)



Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

7.3 Results for Stage IIIB

Table 7.3 and Table 7.4 below provide details of the estimated costs and benefits associated with meeting the Stage IIIB limits, using both the low and high CAFE damage cost values.

Table 7.3: Initial estimates of the costs and benefits of meeting the Stage IIIB limits (using LOW CAFE DAMAGE COSTS)

Options included in the strategy	Traction unit type	Reduction in NOx emissions (2012 to 2020)	Reduction in PM_{10} emissions (2012 to 2020) (tonnes)	NPV of total implementation costs (2012 to 2020)	NPV of combined NOx and PM_{10} benefits - LOW CAFE DAMAGE COSTS	Net costs (positive) or net benefits (negative) (2012 to 2020)
A range of options could be used to meet the Stage IIIB limits including: (a) Further development of the internal engine design measures for meeting the Stage IIIA limits will be required to meet the Stage IIIB NOx limits, (b) SCR exhaust after-treatment technology could be used to abate NOx emissions, (c) the use of a Diesel Particulate Filter to control PM_{10} emissions	Railcars	38,547 tonnes	723 tonnes	€ 909 million to € 1,052 million	-€ 113 million	€ 797 million to € 939 million
	Mainline locomotives	126,662 tonnes	1,976 tonnes	€ 624 million to € 1,112 million	-€ 374 million	€ 250 million to € 1,112 million
	Shunting locomotives	43,874 tonnes	684 tonnes	€ 257 million to € 449 million	-€ 129 million	€ 128 million to € 319 million
	TOTAL	**374,291 tonnes**	**6,081 tonnes**	**€ 1,790 million to € 2,613 million**	**-€ 616 million**	**€ 1,175 million to € 2,371 million**

Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

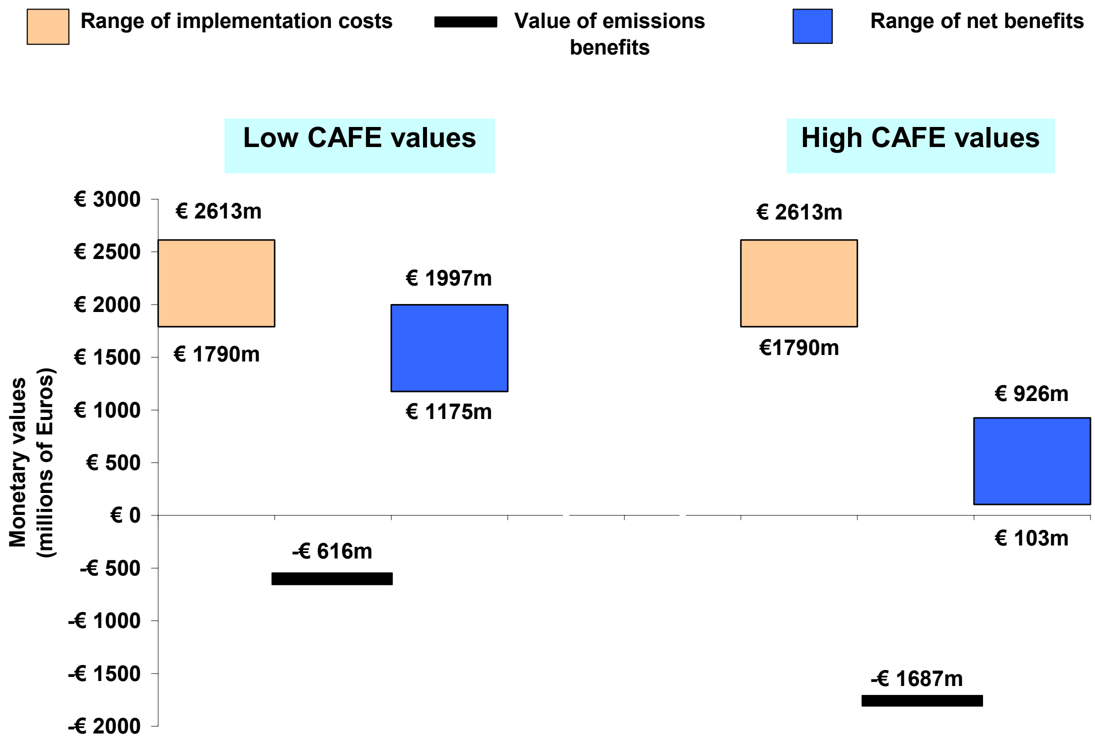
Table 7.4: Initial estimates of the costs and benefits of meeting the Stage IIIB limits (using HIGH CAFE DAMAGE COSTS)

Options included in the strategy	Traction unit type	Reduction in NOx emissions (2012 to 2020)	Reduction in PM_{10} emissions (2012 to 2020) (tonnes)	NPV of total implementation costs (2012 to 2020)	NPV of combined NOx and PM_{10} benefits - HIGH CAFE DAMAGE COSTS	Net costs (positive) or net benefits (negative) (2012 to 2020)
A range of options could be used to meet the Stage IIIB limits including: (a) Further development of the internal engine design measures for meeting the Stage IIIA limits will be required to meet the Stage IIIB NOx limits, (b) SCR exhaust after-treatment technology could be used to abate NOx emissions, (c) the use of a Diesel Particulate Filter to control PM_{10} emissions	Railcars	38,547 tonnes	723 tonnes	€ 909 million to € 1,052 million	-€ 309 million	€ 601 million to € 743 million
	Mainline locomotives	126,662 tonnes	1,976 tonnes	€ 624 million to € 1,112 million	-€ 1,024 million	-€ 400 million to € 88 million
	Shunting locomotives	43,874 tonnes	684 tonnes	€ 257 million to € 449 million	-€ 355 million	-€ 97 million to € 94 million
	TOTAL	**374,291 tonnes**	**6,081 tonnes**	**€ 1,790 million to € 2,613 million**	**-€ 1,687 million**	**€ 103 million to € 926 million**

Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

For Stage IIIB, the analysis results indicate that there would be no overall net benefits associated with meeting these emission limits. Using the low CAFE damage cost values, net costs between 2012 and 2020 were estimated to range from €1175 million to €2371 million; using the high CAFE values, net costs were estimated to range from €103 million to €926 million. Figure 7.2 below provides a graphical summary of the results for Stage IIIB, highlighting these first estimates for the possible range of costs and emissions benefits associated with ensuring that new traction units meet these emission limits between 2012 and 2020.

Figure 7.2: Initial estimates of the ranges of costs and benefits associated with ensuring that future rail vehicles meet the Stage IIIB limits (2012-2020)



Note: benefits are indicated by negative numbers. Values should only be treated as indicative values.

7.4 Other factors for consideration

The analysis results presented in this section of the report indicate that under most scenarios the costs associated with meeting the Stage IIIA and Stage IIIB limits exceed the monetary value of emissions benefits. It should be noted that these results do not include the costs associated with setting up the additional urea distribution and storage infrastructure that would be required if SCR technology was to be used as a measure for meeting these future emissions limits. Bearing this factor in mind, it is therefore likely that the costs of meeting the Stage IIIB limits will be even higher than reported in this study.

As reported for the existing fleet, there will also be a need to ensure that sulphur-free diesel (10 ppm maximum sulphur content) is used consistently across the whole of the European rail network in the near future. This fuel will be necessary if exhaust after-treatment options such as SCR technology are to be used in the future. An assessment of the costs associated with introducing sulphur-free diesel to those railways that do not currently use it was beyond the scope of this study.

As discussed at the beginning of this section, the results for Stage IIIA and Stage IIIB should only be viewed as initial indicative results, as there is still much uncertainty regarding the technical feasibility of certain options – in particular, options that could be used to meet the Stage IIIB limit values are at an early stage in the development process, and it is not possible to quantify the specific costs and benefits associated with different options with any great degree of accuracy at this point in time. Further work, building on this initial study, will be required to assess the costs, benefits, and technical feasibility of meeting the Stage IIIB limit values.

8 Results for strategies for tackling potential railway contributors to air quality hot spots

8.1 Shunting yards

8.1.1 Overview

This part of the study was focused on carrying out an initial examination of the costs and benefits associated with reducing emissions from shunting yards and from terminal passenger railway stations. For shunting yards, the analysis focused on assessing strategies based on some of the technical options identified during Work Package 2. The analysis carried out for shunting yards was of a very similar nature to the analysis carried out for the existing fleet. As described in Section 4.2, the strategies developed for shunting yards were based around the following options:

- Retrofit closed channel DPF
- Retrofit SCR+DPF
- Re-engining

The air quality modelling carried out for Work Package 3 indicated that only intensively used shunting yards would contribute in a significant manner to nitrogen dioxide (NO_2) concentrations at shunting yards. In Work Package 3 intensively used shunting yards were defined by referring to detailed actual emissions and activity data from working shunting yards. The air quality modelling results indicated that shunting yards with very high emissions per unit area could be the most significant contributors to NO_2 concentrations, and hence for the strategy analysis, operational data on the chosen shunting yard from WP3 with the highest NOx emissions per unit area was used to define a busy shunting yard.

Table 8.1: Activity data and emissions data for intensively used shunting yards

Total annual shunting hours	Shunting yard area (km^2)	Total annual NOx emissions (Tonnes)	Total annual PM_{10} emissions (Tonnes)	NOx emissions per unit area (Tonnes/km^2)	PM_{10} emissions per unit area (Tonnes/km^2)
17,546	0.1	12.303	0.545	123.03	5.45

For the purposes of this study, it was assumed that the data presented above was representative of busy shunting yards across Europe. In practice, there will be significant deviations in operating and emissions performance at different busy shunting yards across the EU, but it was necessary to make this simplifying assumption for the purposes of this study.

The data presented in Table 8.1 above provides a value for the annual total hours of shunting operation at a busy shunting yard. This figure was used in conjunction with data collated as part of Work Package 2 on the average annual operating hours of individual shunting locomotives. This work indicated that on average, shunting locomotives operate for a total of 3,500 hours per year. Based on this figure and the total annual shunting hours at the busiest shunting yards, it was estimated that a total of five shunting locomotives would operate at yards such as the one defined by the data in Table 8.1. This estimate was used as the basis for estimating the capital and operating costs associated with controlling emissions from the busiest shunting yards.

8.1.2 Results

The results of the cost-benefit analysis for controlling emissions from shunting yards are presented below with estimates for the following parameters for each strategy assessed:

- Reduction in NOx emissions (2005-2020)
- Reduction in PM_{10} emissions (2005-2020)
- Total implementation costs (2005-2020)
- Monetary value of emissions benefits (2005-2020)
- Net costs (positive) or net benefits (negative)

Table 8.2 below provides estimates of the costs and benefits based on using the low CAFE damage values, whilst Table 8.3 provides estimates using the high CAFE damage values. It should be noted that the costs and benefits presented below relate to just one shunting yard. At this point it is not clear how many busy shunting yards significantly contribute to NO_2 concentrations across Europe, and hence it has not been possible to factor these results up to the European level.

Table 8.2: Initial estimates of the costs and benefits associated with strategies for reducing emissions from a busy shunting yard (LOW CAFE DAMAGE COST VALUES)

Strategy description	Reduction in NOx emissions (2005 to 2020)	Reduction in PM_{10} emissions (2005 to 2020)	NPV of total implementation costs (2005 to 2020)	NPV of combined NOx and PM_{10} benefits - low CAFE damage costs	Net costs (positive) or net benefits (negative) (2005 to 2020)
Closed channel DPF	0 tonnes	5 tonnes	€ 0.7 million	-€ 0.1 million	**€ 0.6 million**
Combined SCR + DPF	81 tonnes	5 tonnes	€ 1.0 million	-€ 0.5 million	**€ 0.5 million**
Re-engining	47 tonnes	2 tonnes	€ 90,000	-€ 0.3 million	**-€ 0.2 million**

Note: benefits are indicated by negative values. Values should only be treated as indicative values.

Table 8.3: Initial estimates of the costs and benefits associated with strategies for reducing emissions from a busy shunting yard (HIGH CAFE DAMAGE COST VALUES)

Strategy description	Reduction in NOx emissions (2005 to 2020)	Reduction in PM_{10} emissions (2005 to 2020)	NPV of total implementation costs (2005 to 2020)	NPV of combined NOx and PM_{10} benefits - low CAFE damage costs	Net costs (positive) or net benefits (negative) (2005 to 2020)
Closed channel DPF	0 tonnes	5 tonnes	€ 0.7 million	-€ 0.4 million	**€ 0.3 million**
Combined SCR + DPF	81 tonnes	5 tonnes	€ 1.0 million	-€ 1.3 million	**-€ 0.3 million**
Re-engining	47 tonnes	2 tonnes	€ 90,000	-€ 0.7 million	**-€ 0.6 million**

Note: benefits are indicated by negative values. Values should only be treated as indicative values.

As can be seen from the tables if the low CAFE values are used, the analysis results indicate that only re-engining would have net benefits (€0.2 million up to 2020), whilst if the high CAFE values are used, both re-engining and combined SCR+DPF would give net benefits. However, it should be noted that the total implementation costs associated with re-engining (taking into account cost reductions due to reduced fuel consumption and maintenance costs) are much lower than for combined SCR+DPF technology.

8.2 Idling at terminal stations

8.2.1 Overview

The analysis of idling at stations was carried out in much less detail than for any of the other strategies assessed during this study, and for this reason, no quantitative data indicating the possible costs and benefits associated with different strategies to reduce idling emissions are presented in this section. It was felt that at this stage, the analysis was not carried out in sufficient detail to be able to quote a robust set of results. In particular, there was a lack of detailed data on the costs associated with options such as auxiliary engines and shore power supply, and there was a lack of information regarding the practicality of applying such options - for instance, the use of shore supply would mean that some changes to the way in which terminal stations operate would be needed, but no information was available on the what the cost implications of such changes could be. For these reasons, the initial analysis carried out in this area has been used to make qualitative assessments of each of the strategies, with initial indications given as to whether there could be net costs or net benefits associated with each strategy.

The strategies that were assessed for this part of the study were as follows:

- Shore power supply for terminal stations
- Fitting small auxiliary engines/power units to traction units that can be used to provide auxiliary power during station turnarounds
- Retrofit combined SCR+DPF
- Retrofit closed channel DPF
- Re-engining with improved engines

8.2.2 Results

The results for options to reduce idling are presented in Figure 8.1 below. As can be seen from the figure, an initial qualitative assessment of the possible costs and benefits associated with each strategy has been made, with indications of the likely direction and magnitude of costs and benefits.

Figure 8.1: Initial qualitative assessment of strategies for reducing idling emissions

	Implementation costs	Emissions benefits	Net costs or net benefits
Shore supply	Low to medium	High	NET BENEFITS - HIGH ✓✓✓
Auxiliary engines	Medium	Medium to high	NET BENEFITS - MEDIUM ✓✓
Re-engining	Low to medium	Medium	NET COSTS - MEDIUM ××
Combined SCR+DPF	High	High	NET COSTS - MEDIUM ××
Closed channel DPF	Medium	Low	NET COSTS - HIGH ×××

As can be seen from the figure, at this stage, the initial results indicate that shore supply and the use of auxiliary engines might lead to net benefits. It is thought likely that all of the other options would lead to net costs rather than net benefits, with closed channel DPFs likely to have the greatest net costs. Much more research is required in order to be able to accurately quantify the costs and benefits associated with each of these options, and at this stage, no firm recommendations can be made with regard to which options would be most appropriate in practice for reducing emissions at terminal stations.

9 Conclusions

9.1 Overview

This study has been carried out to assess the costs and benefits over the 2005 to 2020 time period of implementing strategies to reduce pollutant emissions from the existing and future European railway fleet. For the existing fleet, the strategy options assessed focused on technical measures that could be retrofitted to current vehicles, as well as examining re-engining. For the future fleet, the study has provided initial indications of the costs of ensuring that new traction units meet the NRMM Stage IIIA and Stage IIIB emission limits, as well as quantifying the emissions benefits associated with meeting these limit values. The analysis was carried out using the results from Work Packages 1, 2, and 3, and by using the EC's Impact Assessment Guidelines to quantify the costs and benefits of the various strategy options over the 2005 to 2020 time period. The emissions benefits associated with each strategy option were converted into monetary values using low and high NOx and particulate matter damage cost values from the EC's CAFE programme. The following sections provide a brief summary of the main results and conclusions.

9.2 Strategy options for the existing fleet

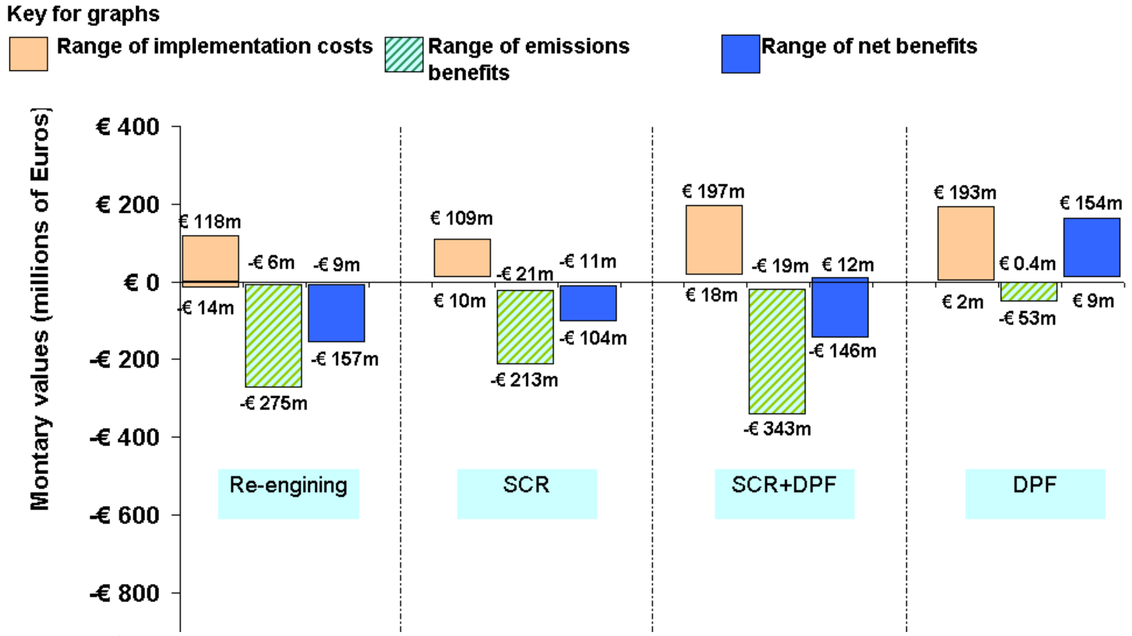
For the existing fleet, the cost-benefit analysis showed that strategies that include re-engining, SCR technology, and combined SCR+DPF technology could lead to net emissions benefits. The cost-benefit analysis results for the most promising strategy options for the existing fleet are presented in Figure 9.1 (low CAFE values) and Figure 9.2 (high CAFE values). The results indicated that for **re-engining**, net benefits over the 2005-2020 time period could range from **€9 million to €156 million** using the low CAFE damage values, and from **€20 million to €636 million** using the high CAFE values. In some scenarios, the analysis also showed that there may not be net implementation costs associated with re-engining, as for some types of traction units, the reductions in operating costs were anticipated to be greater than the capital costs associated with the new engines.

The analysis results indicated that the net benefits of individual strategies using **SCR technology** could range from **€11 million to €104 million** based on the low CAFE damage values; for the high CAFE values, the net benefits of SCR technology were found to range from **€47 million to €472 million**.

Combined **SCR+DPF technology** was found to have the largest implementation costs of all the different types of strategies (ranging from €18 million to €197 million over the 2005-2020 time period), but these strategies could also potentially lead to the greatest net benefits. Using the low CAFE values, **net benefits** of up to **€146 million** could be achieved over the 2005-2020 time period, although it should be noted that some strategies were found to give **net costs** of up to **€12 million** over the same time period; with the high CAFE values, the **net benefits** were found to range from **€34 million to €745 million**.

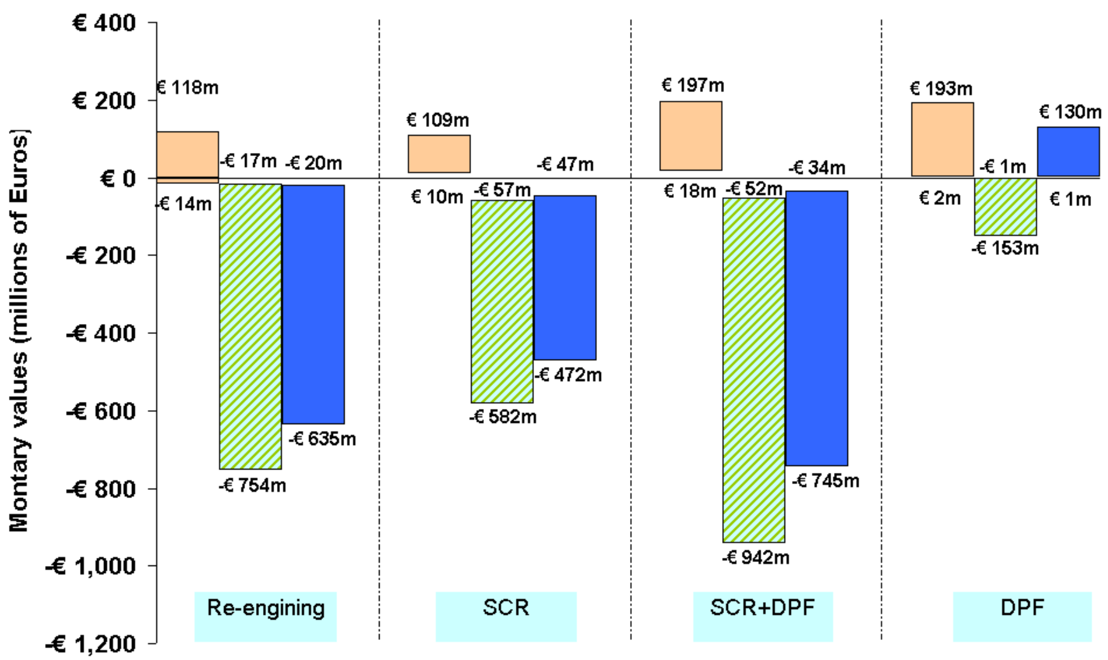
In all cases, **DPF technology** was found to lead to net costs rather than net benefits. Using the low CAFE values, the analysis results indicated that **net costs** could range from **€9 million to €154 million**, whilst with the high CAFE values, net costs could range from **€1 million to €130 million.**

Figure 9.1: Initial estimates of the range of costs and benefits for strategy options for the existing fleet that lead to net benefits (low CAFE damage costs)



Note: benefits are indicated by negative values. Values should only be treated as indicative values.

Figure 9.2: Initial estimates of the range of costs and benefits for strategy options for the existing fleet that lead to net benefits (high CAFE damage costs)

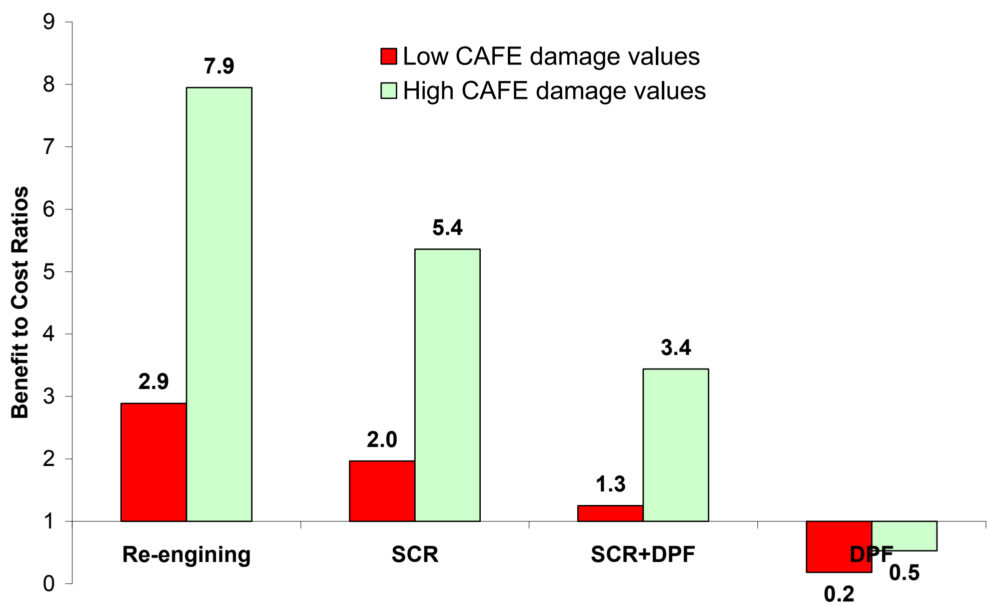


Note: benefits are indicated by negative values. Values should only be treated as indicative values.

Although the analysis results have indicated that fitting SCR or combined SCR+DPF equipment to existing rail vehicles could lead to large net benefits, it must be stressed that it is not clear at this stage how feasible it is in practice to equip specific existing railcars and locomotives with SCR equipment. The work carried out during Work Package 2, clearly illustrated that there are very significant space, weight, and technology limitations for applying such equipment to existing traction units; in most cases it would not be a straightforward task to integrate SCR equipment within the space envelopes available on current railcars and locomotives. In many cases, it may be impossible to fit such equipment. It is clear that much further work needs to be carried out by the railway industry to understand in much greater detail the possibilities and limitations for equipping existing traction units with exhaust after-treatment equipment. It should also be noted that if existing vehicles are to be retrofitted with emissions abatement equipment in the future, there will be a need to ensure that sulphur-free diesel (maximum sulphur content of 10 ppm) is used by all diesel rail vehicles across Europe.

Further analysis was also carried out to quantify the average benefit-to-cost ratios associated with each technology (see Figure 9.3 below). As can be seen from the figure, re-engining was found to have the largest benefit-to-cost ratio.

Figure 9.3: Average benefit-to-cost Ratios for strategy options for the existing fleet



Based on the results from this study, and the findings from Work Package 2, it would appear that re-engining is the most suitable option for reducing NOx and PM_{10} emissions from the existing fleet. The net benefits associated with re-engining strategies are relatively large (in the case of the low CAFE values they could be greater than the benefits of using combined SCR+DPF technology), this strategy has the highest average benefit-to-cost ratio, and there is the additional advantage that in some cases railway operators will reduce the overall costs of their operations by re-engining. Furthermore, there is extensive experience within the industry of re-engining existing traction units, although it should be stressed that re-engining will not be possible in all cases. In particular, it is not practical to re-engine some older traction units due to the need to significantly modify off-engine support systems. As with fitting exhaust after-treatment equipment to existing vehicles, the potential for re-engining specific designs of traction units needs to be checked on a vehicle by vehicle basis.

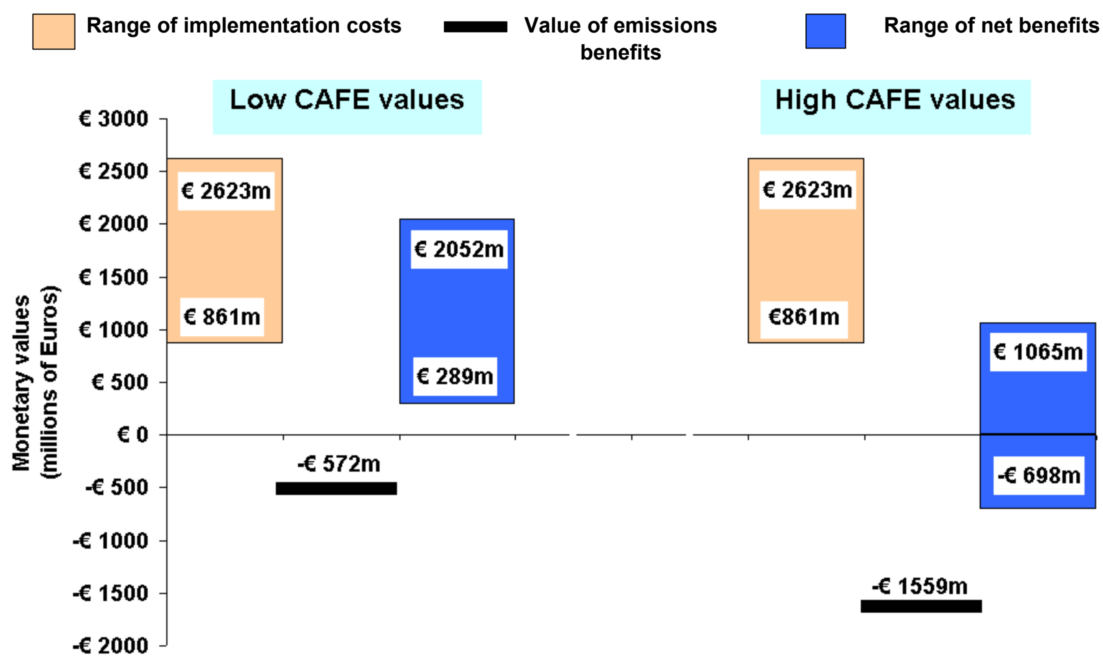
9.3 Strategy options for the future fleet

The analysis carried out for the future fleet was concerned with providing **initial** estimates of the costs and benefits associated with ensuring that future rail vehicles meet the Stage IIIA and Stage IIIB emissions limits. It is important to stress that the cost and benefit values reported for Stage IIIA and Stage IIIB should only be viewed as first estimates, and much further work will be required to refine these estimates following the completion of this study. This is particularly the case for the analysis carried out for Stage IIIB, as at this point in time there is no experience of using the necessary technologies on rail vehicles, and in some cases the technology is still under development.

9.3.1 Initial estimates of the costs and benefits associated with meeting the Stage IIIA limits

A summary of the results of the analysis carried out for meeting the Stage IIIA limits is presented below in Figure 9.4.

Figure 9.4: Initial estimates of the costs and benefits associated with meeting the Stage IIIA limits (2005-2020)



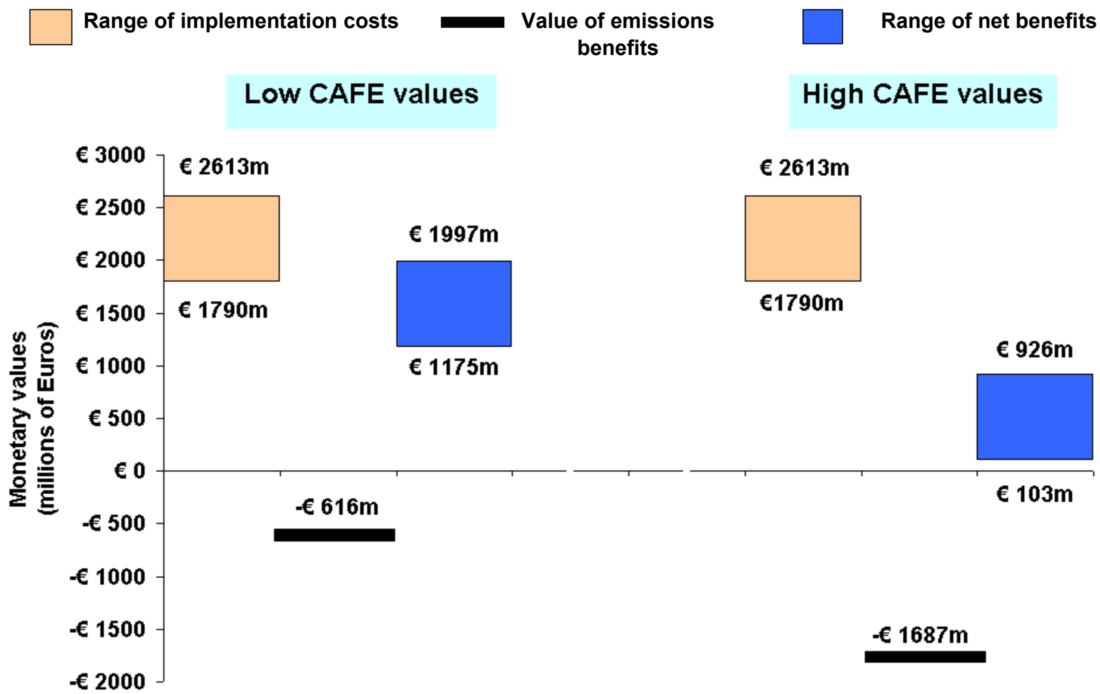
Note: benefits are indicated by negative values. Values should only be treated as indicative values.

As can be seen from the figure, the analysis results have indicated that for Stage IIIA, there would be implementation costs of between €861 million and €2623 million over the 2005 to 2020 time period. Using the low CAFE values, the monetary value of emissions benefits due to reduced environmental impacts was estimated to be €572 million over the same time period; if the high CAFE values are used, the value of emissions benefits was estimated to be €1787 million. Using the **low CAFE values**, the analysis results indicated that Stage IIIA would have **net costs** rather than net benefits over the 2005-2020 time period. The net costs over this time period were estimated to range from **€289 million to more than €2 billion**. Using the **high CAFE values**, the analysis results indicated that in the best case scenario (i.e. if the implementation costs are at the low end of the range), there could be **net benefits** of around **€700 million** over the 2005-2020 time period. If the implementation costs are high, the analysis results indicated that there could be **net costs** of more than **€1 billion** over the same time period

9.3.2 Initial estimates of the costs and benefits associated with meeting the Stage IIIB limits

A summary of the analysis results for developing initial estimates of the costs and benefits associated with Stage IIIB can be found below in Figure 9.5.

Figure 9.5: Initial estimates of the costs and benefits associated with meeting the Stage IIIB limits (2012-2020)



Note: negative values indicate benefits, whilst positive values indicate additional costs

For Stage IIIB, it can be seen from Figure 9.5 that the total implementation costs have been estimated to range from €1790 million to €2613 million, whilst estimates of the monetary value of emissions benefits range from €616 million (low CAFE values) to €1787 million (high CAFE values). Based on these initial estimates, the analysis results indicate that there would not be any net emissions benefits associated with future rail vehicles meeting the Stage IIIB limit values over the 2012-2020 time period. Using the **low CAFE damage values**, the results indicated that there would be **net costs** of **between €1.2 billion and €2 billion** over the 2012-2020 time period; using the **high CAFE values**, the results indicated that there could be **net costs** of **between €100 million and over €900 million** over the same time period.

As with the existing fleet, there will be a need to ensure that sulphur-free diesel is used by all railway operators across Europe in the near future, as this will be a necessary pre-requisite for the exhaust after-treatment that will be required for meeting the Stage IIIB limits.

9.4 Strategy options for potential railway contributors to air quality hot spots

Strategy options were assessed for controlling emissions from very busy shunting yards and from idling trains at busy terminal stations. For both of these situations, it was not possible to carry out detailed analysis at the European level, and hence the work focused on investigating the costs and benefits for one busy shunting yard and one busy train station.

For the shunting yard, the analysis results using the **low CAFE damage values** indicated that **re-engining** could lead to **net benefits** of up to **€0.2 million per shunting yard** over the 2005-2020 time period. Both combined SCR+DPF and closed channel DPF technology would lead to net costs under this scenario. Using the **high CAFE damage values**, **re-engining** was found to give **net benefits** of **€0.6 million** and **combined SCR+DPF** technology would give **net benefits** of **€0.3 million** over the 2005-2020 time period. However, it should be noted that the total implementation costs associated with re-engining would be much lower than for combined SCR+DPF technology due to the reductions in operating costs associated with this option.

It was not possible to carry out a detailed quantitative analysis of the costs and benefits associated with controlling emissions from idling trains at terminal stations due to a lack of robust quantitative data. For this reason, a qualitative assessment of the costs and benefits associated with different strategies was carried out. A summary of the results of this assessment is presented below in Figure 9.6.

Figure 9.6: Initial qualitative assessment of strategies for reducing idling emissions

	Implementation costs	Emissions benefits	Net costs or net benefits
Shore supply	Low to medium	High	NET BENEFITS - HIGH ✓✓✓
Auxiliary engines	Medium	Medium to high	NET BENEFITS - MEDIUM ✓✓
Re-engining	Low to medium	Medium	NET COSTS - MEDIUM ××
Combined SCR+DPF	High	High	NET COSTS - MEDIUM ××
Closed channel DPF	Medium	Low	NET COSTS - HIGH ×××

The results of this initial assessment indicated that the use of station shore supply to provide auxiliary power might lead to the greatest net benefits. However, it must be stressed that no firm recommendations can be made at this point, as many of the practical implications of applying shore supply to terminal stations could not be assessed during this study.

10 Recommendations for future work

There are a number of issues which were not examined during this study, and it is recognised that further work is required to assess the wider implications of introducing strategies for reducing emissions from rail vehicles in the future. This section provides an overview of some of the issues that should be examined as part of future work.

10.1 Technical feasibility of applying emissions abatement equipment to railway traction units

The work carried out during this study should be considered as an initial investigation into the costs and benefits associated with controlling NOx and PM_{10} emissions from the existing fleet. However, it must always be borne in mind that the work carried out during this study is based on theoretical analysis, and in practice, the railway sector does not have experience of using many of the measures discussed during this study. In particular, there is currently no experience of using technologies such as SCR and EGR, and experience of DPF technology is very limited. There is more experience in the sector of re-engining existing traction units, but even in this field, much more knowledge and experience of what is and is not possible is needed. It is strongly recommended that further work should be carried out, using the results and information from this study as the starting point for a more detailed, practical investigation of the costs, benefits, feasibility, and limitations associated with reducing emissions from the diesel railway fleet. Additionally, as many of the technical options discussed and assessed during this study have not been full developed, there is the very strong likelihood that the capital and operating costs associated with some of these technologies will change in the near future. Furthermore, a full technical review of the Stage IIIB limits is due to take place by the end of 2007, and it is clear that further work will be required to contribute to the review process.

10.2 More detailed assessment of strategies for controlling emissions at shunting yards and from trains idling at terminal stations

During this study it was only possible to carry out an initial assessment of strategies for controlling emissions from shunting yards and terminal stations. In particular, there was a lack of robust cost data on measures for tackling idling and it is recommended that both of these areas are investigated in much more detail in future.

10.3 Assessment of the impacts of options and strategies on CO_2 emissions

The scope of the study was concerned with strategy options that could be used to reduce emissions of NOx and PM_{10}. However, it must also be recognised that CO_2 emissions are an important and growing problem for the whole of the transport sector. It was beyond the scope of this study to quantify in detail the impacts of each technology on CO_2 emissions, and to quantify the monetary value of any CO_2 impacts, but it should be noted that some technical measures would lead to increases in CO_2 emissions whilst others will lead to reductions. In particular, certain types of diesel particulate filters are known to increase fuel consumption, and hence emissions of CO_2 by up to 4%. Exhaust Gas Recirculation equipment can also increase CO_2 emissions by a similar amount. On the other hand, re-engining can lead to a reduction in fuel consumption, with a corresponding reduction in CO_2 emissions. It is recommended that further, more detailed analysis should be carried out to quantify the impacts of each technology option on CO_2 emissions, as well as to quantify the monetary value of any changes in CO_2 emissions.

10.4 Issues associated with re-engining existing traction units

The amended NRMM Directive requires that if rail vehicles are to be re-engined, they must be fitted with new engines that meet the relevant NRMM emission limit values (Stage IIIA or Stage IIIB) that are in force at the time the re-engining is carried out. This requirement has important implications for railway operators and the owners of traction units; as of January 2006 any operator that wishes to re-engine a railcar must fit an engine that complies with the Stage IIIA limits. However, at this point in time there are only a very restricted number of engines on the market that meet the Stage IIIA limits. Existing locomotives will also soon be affected by this requirement. Hence, if an operator/owner wants to replace an old inefficient engine in a DMU railcar that has poor emissions performance and is unable to fit one of the limited number of engines that currently meets the Stage IIIA limits, the operator/owner is incentivised to keep the old engine in place. There may be engines available that do not quite meet the NRMM Stage IIIA limits, but that would significantly improve the overall emissions performance of the vehicle, whilst reducing fuel consumption and maintenance costs. At this point in time the NRMM Directive prohibits operators and/or owners from fitting such engines. This is an important point as the manner in which the NRMM Directive is worded may in practice be hindering the process of improving the emissions performance of the existing fleet. There may therefore be an argument for allowing greater flexibility in the types of engines that can be fitted to existing rail vehicles when they are re-engined. It is recommended that this issue should be examined in greater depth.

10.5 Wider impacts associated with reducing emissions from railway traction units

The analysis has also uncovered some other factors that should be taken into consideration when deciding how to reduce NOx and PM_{10} emissions from the European railway fleet. One of the main factors that needs to be taken into account is the fact that although the analysis has focused on the net costs *to society* and the net benefits *to society* of measures to reduce emissions from the railways, in practice, the costs of measures will, in the first instance, be borne by the railway industry, whilst the benefits will be received by society as a whole. If the railway industry were to apply emissions reduction measures to a proportion of the fleet across Europe, then one option would be to recoup the costs associated with such actions by increasing the prices of tickets for passenger services, or increasing the costs of rail freight, and hence spreading the cost of actions to society as a whole. Whilst such a situation may mean that emissions from the rail sector decrease, there is also the possibility that increasing the costs of rail travel to recoup the implementation costs may lead to unintended consequences. In particular, it is possible that increases in ticket prices may mean that fewer people choose to travel by train, choosing instead to travel by car, and hence leading to increases in emissions from road vehicles that could outweigh the reductions in railway emissions. A similar outcome might also be possible for freight operations; if rail freight costs were to increase significantly, businesses may be more likely to choose road freight services to transport their goods. It was beyond the scope of this study to investigate and quantify these types of impacts, but it is recommended that this aspect should be take into account in any future work carried out on the costs and benefits of controlling pollutant emissions from the railways.

Annex 1: Cost benefit analysis methodology

A1.1 Overview

This section of the report provides an explanation of the cost benefit analysis (CBA) methodology that will be used to assess each of the strategy options, and provides details of all the assumptions that will be used in this analysis. The CBA methodology used in this study is consistent with European guidance on how cost benefit analysis should be carried out. The strategy options that have been developed in the foregoing sections are each quite detailed and complex, and this has necessitated the development of a technology uptake and emissions model that will be used to calculate the costs and emissions benefits associated with each option. The reductions in emissions calculated using this model can then be used in combination with pollutant damage cost values, as published in the European Commission's Clean Air For Europe (CAFE) programme in order to be able to quantify the monetary value of the emissions benefits of each strategy, and set these against the costs of each strategy.

To be able to develop the models that will allow this assessment of the costs and benefits to be carried out, it has been necessary to make a number of assumptions with regard to cost, emissions abatement performance, train activity data, etc. In support of carrying out the CBA, this section of the report provides full details of the following items

- Description of the CBA methodology and the use of a discount rate
- Monetary value of the damage costs associated with pollutant emissions (CAFÉ pollutant externality values)
- Representative vehicles included in the analysis
- Baseline emission factors used for the representative vehicles
- Activity data for calculating total baseline emissions from diesel rail traction
- Emissions abatement performance of technical measures
- Costs and technical lifetimes of emissions abatement options
- Discount rate used in the cost benefits analysis

A1.2 Cost benefit analysis (CBA) methodology and discount rate used

The cost benefit analysis (CBA) methodology used in this study is consistent with the methodologies set out in the European Commission's Impact Assessment Guidelines (European Commission 2005a)[1] and the cost reporting guidance for assessing environmental protection measures published by the European Environment Agency (EEA, 1999)[2]. To carry out CBA, detailed information is required on all the costs and benefits associated with a strategy or policy option, along with details of the points in time when the costs and benefits occur. There is also the need to use a discount rate to allow costs that occur at different points in time to be compared. The box below sets out the EC's guidance on cost-benefit analysis and the use of discount rates, directly taken from the Impact Assessment Guidelines document:

Box 1: EC guidance on the use of CBA and discount rates (as published in the EC's Impact Assessment Guidelines)

Cost-benefit analysis and discounting

Most policy options result in costs and benefits that arise at different times. Building a railway line has an immediate cost, but provides benefits over a long period. When beneficiaries receive a constant amount of money over a set period of time, their benefit will be worth more in the first year than in the last year of the programme. Conversely, costs to be paid in the future are less onerous.

The discount rate is a correction factor reflecting these facts. All in all, discounting allows the direct comparison of costs and benefits occurring in different points in time, valuing immediate costs and benefits more highly than those that occur later. When discounting is used, it should be applied both to costs and benefits.

You should use a **discount rate of 4%**. This discount rate is expressed in real terms, taking account of inflation. You should therefore apply it to costs and benefits expressed in constant prices. The total of the discounted costs and benefits of a policy option is called its **net present value**.

An example

Suppose a project incurs €1,000,000 this year, and yields benefits of €200,000 each year for the following six years, after adjusting for inflation.

Then, using the discount rate of 4% recommended by these guidelines, the net present value of the project is:

$$\frac{200{,}000}{1.04} + \frac{200{,}000}{1.04^2} + \frac{200{,}000}{1.04^3} + \frac{200{,}000}{1.04^4} + \frac{200{,}000}{1.04^5} + \frac{200{,}000}{1.04^6} - 1{,}000{,}000$$

This equals 1,048,427 – 1,000,000 so that the net present value of the project is €48,427.

Thus, the project generates net benefits to society, and as long as the distribution of costs and benefits among different social groups is judged acceptable, the project should go ahead.

Annualised costs and benefits

You need to be careful when comparing policies with different time horizons, because the net present value criterion is no longer valid. To make valid comparisons in such circumstances, it is often useful to calculate the *annualised value* of alternative policies. This is defined as the fixed annual stream of income that would be paid by a fixed-interest annuity with the same net present value as the policy. It is determined by the formula:

$$\text{Annualised value} = \frac{\text{Present value x discount rate}}{1 - (1 + \text{discount rate})^{-\text{time horizon}}}$$

-where the time horizon is defined in years and the discount rate is divided by 100 (that is, 4% is 0.04).

So to compare a project with a present value of €1500 and a lifetime of 5 years with a project with a present value of €1750 and a lifetime of 7 years, we calculate their annualised values. For the first project:

$\frac{1500 \times 0.04}{1-(1+0.04)^{-5}}$ which equals $\frac{60}{1-0.822}$, so that its annualised value is €336.94

For the second project:

$\frac{1750 \times 0.04}{1-(1+0.04)^{-7}}$, or $\frac{70}{1-0.76}$, giving an annualised value of €291.57

Thus, although the second project yields higher net benefits, because these are spread out more thinly over time the first project in fact represents better value.

With regard to the CBA being carried out to assess the Rail Diesel Study strategy options, it was necessary to annualise the costs of each option as described in the guidance above, as the lifetime of a re-engining option, for example, is much greater than the lifetime of exhaust after-treatment options such as SCR and diesel particulate filters.

The Impacts assessment Guidelines refer to the use of the **Net Present Value** (NPV) of costs and benefits. The NPV concept refers to the fact that a fixed sum of money received in the future is worth less than the same amount of money received now. For example, €1 received in 2010 would be worth less than €1 received now. As the costs and benefits associated with each strategy would be incurred over an extended period of time covering many years, it has been necessary to use the NPV concept to present all of the costs and benefits in a readily comparable manner.

The type of CBA described in the above box is known as social CBA. In social CBA, the costs are either completely accounted for at the time they are incurred, or they are annualised using the discount rate, as described in Box 1. In a private CBA, which would be carried out by private companies that want to assess the costs and benefits of a certain action, the capital costs are depreciated over the lifetime of the capital for accounting purposes so that the depreciation profile is used in the analysis. In most cases, private CBA would provide different results to those obtained from a social CBA.

Annex 2: CAFE methodology for valuing the damage costs associated with emissions of air pollutants

A2.1 Monetary value of the damage caused by pollutant emissions (CAFE values)
The European Commission's Clean Air For Europe (CAFE) programme included the development of new values for the external damage costs associated with air pollution. These damage costs take into account the costs associated with pollution-related damage to human health, damage to agricultural and horticultural production, and damage to materials, and detailed values have been published for each Member State in the EU25, along with EU25 average values. The following sections provide more details on the impacts that have been included in the CAFE damage cost valuation methodology.

Human health impacts
Damage to human health from air pollution is primarily related to impacts from particulate matter and impacts from ozone (NOx emissions are a precursor of atmospheric ozone). The health impacts that are included in the CAFE valuation methodology include:

- Chronic mortality from particulate matter
- Acute mortality from ozone
- Infant mortality from particulate matter
- Morbidity impacts from PM and ozone

A detailed discussion of all of these issues can be found in the CAFE methodology reports (European Commission, 2005b)[3].

Impacts on agriculture and horticulture
Air pollution is recognised as having a significant impact on agricultural and horticultural production. These impacts include the following:

- Visible injury to crops
- Reductions in crop yield
- Interaction of ozone with climate leading to subsequent reductions in crop yield
- Reductions in livestock production

Ozone is currently the most serious air pollutant with regard to its detrimental effects on agriculture and horticulture, and it is possible to make reasonable quantitative estimates of the impacts of ozone on these sectors, and these estimates have been included in the CAFE CBA damage cost values for air pollution. For other impacts (e.g. visible injury to crops, reductions in livestock production, etc), it is not currently possible to explicitly quantify these impacts, but the CAFE methodology takes them into account as part of the "extended-CBA" methodology used (European Commission, 2005b)[3].

Damage to materials
Air pollution is associated with a number of impacts on materials. These include:

- Acid corrosion of stone
- Acid impacts on materials of cultural merit
- Ozone damage to polymeric materials, particularly natural rubbers
- Soiling of buildings and materials used in other applications

Monetary valuation for all of these impacts is included in the CAFÉ CBA methodology.

Damage to ecosystems

Since the 1970s, it has been understood that air pollution can have significant impacts on ecological systems. Studies carried out in the 1970s linked declines in fish stocks and forests to long-range trans-boundary sulphur dioxide emissions. Currently, ecological sensitivity to air pollution is thought to be greatest for semi-natural vegetation, followed by forests, and then crops.

A2.2 CAFÉ damage cost values

The monetary value of the air pollution-related health impacts, agricultural impacts, materials impacts and ecosystem impacts described above have been used to develop the CAFÉ air pollution damage cost values in terms of Euros per tonne of pollutant emitted. For the Rail Diesel Study, the average EU25 damage cost values have been used, with sensitivity values based on different methods of valuing health impacts (Value of Life Years Lost (VOLY) and Value of Statistical Life (VSL)). These average values are presented below in Table A2.1

Table A2.1: CAFÉ pollutant damage cost values for NOx and $PM_{2.5}$ used in the analysis

PM mortality	VOLY median	VSL mean
O_3 mortality	VOLY median	VOLY mean
Health core?	Included	Included
Health sensitivity?	Not included	Included
Crops	Included	Included
EU25 (excluding Cyprus) averages		
NOx	**€4,400 per tonne**	**€12,000 per tonne**
$PM_{2.5}$	**€26,000 per tonne**	**€75,000 per tonne**

It should be noted that the CAFÉ damage costs for particulate matter are for $PM_{2.5}$ rather than for PM_{10}. However, research carried out by the Air Particles Expert Group in the UK (APEG, 1999)[4] has indicated that by mass, 94% of particulate matter emitted by diesel powered off-road machinery (including trains) consists of $PM_{2.5}$, with the remaining 6% falling in the size gap between 2.5 µm and 10µm aerodynamic diameter. The CAFÉ damage costs report (European Commission, 2005c)[5] provides details of the conversion factor that should be used to calculate damage costs for PM_{10}, and this has been used to provide a weighted average damage cost for PM emissions from diesel traction, taking into account the split between PM_{10} and $PM_{2.5}$. Using this conversion factor, the damage cost values for diesel rail PM emissions are as shown in Table A2.2.

Table A2.2: CAFÉ pollutant damage cost values for PM emissions from diesel rail vehicles

PM mortality	VOLY median	VSL mean
O_3 mortality	VOLY median	VOLY mean
Health core?	Included	Included
Health sensitivity?	Not included	Included
Crops	Included	Included
EU25 (excluding Cyprus) averages		
PM emissions (94% $PM_{2.5}$, 6% PM_{10})	**€25,453 per tonne**	**€73,422 per tonne**

Annex 3: Detailed costs and technical life-times of emissions abatement options for the existing fleet

Cost and technical life-time data for each strategy option for the existing fleet are presented in the following tables (Tables A3.1 to A3.7). It must be stressed that the costs provided in these tables are **indicative costs only;** installation and system integration costs, in particular, will vary depending on the number of traction units that are fitted with the particular type of emissions abatement technology, or that are re-engined. In addition to cost data, the tables also provide details of the technical life times of each type of emissions abatement equipment. These data have also been taken directly from the analysis carried out during Work Package 2.

Table A3.1: Cost assumptions for pre-1990 railcars (based on WP2 life-cycle cost estimates for VT810 railcar)

Parameters	Retrofit open channel DPF	Re-engining
Assumed technical life-time of equipment (years)	8	16
Annual average operating performance of vehicle (km)	120000	120000
Average diesel consumption (per engine) (Litres per 100 km)	35	35
Assumed cost of diesel (€ per litre)	0.75	0.75
Equipment capital cost (€ per engine)	€ 7,000	€ 50,000
Development of system (€ per engine)	€ 2,000	€ 12,500
Integration of system (€ per engine)	€ 500	€ 12,500
System installation (€ per engine)	€ 1,500	€ 12,500
Change in diesel consumption (litres per 100 km)	1	-3.5
Change in diesel costs (€)	€ 900	-€ 3,150
Consumption of additional operating supplies/materials (per engine) (litres per 100 km)	0	€ 0
Unit cost of additional operating supplies **(urea)** (€ per litre)	N/A	N/A
Total cost of additional operating supplies **(urea)** (€ per year)	N/A	N/A
Change in maintenance costs (€ per year)	N/A	-€ 10,000
TOTAL CAPITAL/FIXED COSTS	**€ 11,000**	**€ 87,500**
TOTAL ADDITIONAL OPERATING AND MAINTENANCE COSTS	**€ 900**	**-€ 13,150**

Table A3.2: Cost assumptions for post-1990 railcars (based on WP2 life-cycle cost estimates for VT612 railcar)

Parameters	Open channel DPF	Retrofit SCR system	Retrofit SCR + DPF system
Assumed technical life-time of equipment (years)	8	8	8
Annual average operating performance of vehicle (km)	200000	200000	200000
Average diesel consumption (per engine) (Litres per 100 km)	65.0	65.0	65.0
Assumed cost of diesel (€ per litre)	0.75	0.75	0.75
Equipment capital cost (€ per engine)	€ 28,000	€ 25,000	€ 42,500
Development of system (€ per engine)	€ 1,250	€ 1,250	€ 1,500
Integration of system (€ per engine)	€ 500	€ 1,000	€ 1,500
System installation (€ per engine)	€ 1,250	€ 2,000	€ 2,500
Change in diesel consumption (litres per 100 km)	+1.25	0.00	1.25
Change in diesel costs (€)	€ 1,875	€ 0	€ 1,875
Consumption of additional operating supplies/materials (per engine) (litres per 100 km)	0	+2.00	+2.00
Unit cost of additional operating supplies **(urea)** (€ per litre)	N/A	€ 0.40	€ 0.40
Total cost of additional operating supplies **(urea)** (€ per year)	N/A	€ 1,600	€ 1,600
Change in maintenance costs (€ per year)	€ 1,500	€ 1,250	€ 2,000
TOTAL CAPITAL/FIXED COSTS (per engine)	**€ 31,000**	**€ 29,250**	**€ 48,000**
TOTAL ADDITIONAL OPERATING AND MAINTENANCE COSTS (per engine per year)	**€ 3,375**	**€ 2,850**	**€ 5,475**

Table A3.3: Cost assumptions for post-1990 railcars (based on WP2 life-cycle cost estimates for VT642 railcar)

Parameters	Retrofit open channel DPF	Retrofit SCR + DPF systems
Assumed technical life-time of equipment (years)	8	8
Annual average operating performance of vehicle (km)	120000	120000
Average diesel consumption (per engine) (Litres per 100 km)	43.5	43.5
Assumed cost of diesel (€ per litre)	€ 0.75	0.75
Equipment capital cost (€ per engine)	€ 10,250	€ 22,500
Development of system (€ per engine)	€ 500	€ 1,250
Integration of system (€ per engine)	€ 750	€ 1,250
System installation (€ per engine)	€ 500	€ 3,000
Change in diesel consumption (litres per 100 km)	1.00	1.50
Change in diesel costs (€)	€ 900	€ 1,350
Consumption of additional operating supplies/materials (per engine) (litres per 100 km)	0	+1.10
Unit cost of additional operating supplies **(urea)** (€ per litre)	N/A	€ 0.40
Total cost of additional operating supplies **(urea)** (€ per year)	N/A	€ 528
Change in maintenance costs (€ per year)	€ 500	€ 1,500
TOTAL CAPITAL/FIXED COSTS (per engine)	**€ 12,000**	**€ 28,000**
TOTAL ADDITIONAL OPERATING AND MAINTENANCE COSTS (per engine per year)	**€ 1,400**	**€ 3,378**

Table A3.4: Cost assumptions for 1975-1989 mainline locomotives (based on WP2 life-cycle cost estimates for Class 232 locomotive)

Parameters	**Retrofit open channel DPF**	**Re-engining**
Assumed technical life-time of equipment (years)	8	16
Annual average operating performance of vehicle (km)	100000	100000
Average diesel consumption (per engine) (Litres per 100 km)	300	300
Assumed cost of diesel (€ per litre)	0.75	0.75
Equipment capital cost (€ per engine)	€ 80,000	€ 250,000
Development of system (€ per engine)	€ 5,000	€ 62,500
Integration of system (€ per engine)	€ 5,000	€ 62,500
System installation (€ per engine)	€ 7,500	€ 62,500
Change in diesel consumption (litres per 100 km)	+7.00	-35.00
Change in diesel costs (€)	€ 5,250	-€ 26,250
Consumption of additional operating supplies/materials (per engine) (litres per 100 km)	0	0
Unit cost of additional operating supplies **(urea)** (€ per litre)	N/A	N/A
Total cost of additional operating supplies **(urea)** (€ per year)	N/A	N/A
Change in maintenance costs (€ per year)	€ 5,000	-€ 17,500
TOTAL CAPITAL/FIXED COSTS (per engine)	**€ 97,500**	**€ 437,500**
TOTAL ADDITIONAL OPERATING AND MAINTENANCE COSTS (per engine per year)	**€ 10,250**	**-€ 43,750**

Table A3.5: Cost assumptions for 1990-2004 mainline locomotives (based on WP2 life-cycle cost estimates for Class 218 locomotive)

Parameters	**Retrofit closed channel DPF**	**Retrofit SCR + DPF**
Assumed technical life-time of equipment (years)	8	8
Annual average operating performance of vehicle (km)	100000	100000
Average diesel consumption (per engine) (Litres per 100 km)	300	300
Assumed cost of diesel (€ per litre)	€ 0.75	€ 0.75
Equipment capital cost (€ per engine)	€ 110,000	€ 150,000
Development of system (€ per engine)	€ 3,500	€ 5,000
Integration of system (€ per engine)	€ 5,000	€ 5,000
System installation (€ per engine)	€ 10,000	€ 15,000
Change in diesel consumption (litres per 100 km)	+10.00	+7.50
Change in diesel costs (€)	€ 7,500	€ 5,625
Consumption of additional operating supplies/materials (per engine) (litres per 100 km)	0	+10.00
Unit cost of additional operating supplies **(urea)** (€ per litre)	N/A	€ 0.40
Total cost of additional operating supplies **(urea)** (€ per year)	N/A	€ 4,000
Change in maintenance costs (€ per year)	€ 5,000	€ 7,500
TOTAL CAPITAL/FIXED COSTS (per engine)	**€ 128,500**	**€ 175,000**
TOTAL ADDITIONAL OPERATING AND MAINTENANCE COSTS (per engine per year)	**€ 12,500**	**€ 17,125**

Table A3.6: Cost assumptions for 1975-1989 shunting locomotives (based on WP2 life-cycle cost estimates for Class 742 locomotive)

Parameters	Retrofit closed channel DPF	Retrofit SCR + DPF	Re-engining
Assumed technical life-time of equipment (years)	8	8	16
Annual average operating performance of vehicle (hours)	3500	3500	3500
Average diesel consumption (per engine) (Litres per hour)	35	35	35
Assumed cost of diesel (€ per litre)	0.75	0.75	0.75
Equipment capital cost (€ per engine)	€ 45,000	€ 70,000	€ 120,000
Development of system (€ per engine)	€ 3,000	€ 4,000	€ 30,000
Integration of system (€ per engine)	€ 3,000	€ 4,000	€ 30,000
System installation (€ per engine)	€ 2,500	€ 6,000	€ 30,000
Change in diesel consumption (litres per hour)	+1.50	+1.50	-3.50
Change in diesel costs (€)	€ 3,938	€ 3,938	-€ 9,188
Consumption of additional operating supplies/materials (per engine) (litres per 100 km)	0	+1.00	+0.00
Unit cost of additional operating supplies **(urea)** (€ per litre)	N/A	€ 0.40	N/A
Total cost of additional operating supplies **(urea)** (€ per year)	N/A	€ 1,400	N/A
Change in maintenance costs (€ per year)	€ 3,000	€ 3,000	-€ 12,500
TOTAL CAPITAL/FIXED COSTS (per engine)	**€ 53,500**	**€ 84,000**	**€ 210,000**
TOTAL ADDITIONAL OPERATING AND MAINTENANCE COSTS (per engine per year)	**€ 6,938**	**€ 8,338**	**-€ 21,688**

Table A3.7: Cost assumptions for 1990-2004 shunting locomotives (based on WP2 life-cycle cost estimates for Class 290 locomotive)

Parameters	Retrofit closed channel DPF	Retrofit SCR	Retrofit SCR + DPF
Assumed technical life-time of equipment (years)	8	8	8
Annual average operating performance of vehicle (hours)	3500	3500	3500
Average diesel consumption (per engine) (Litres per hour)	45	45	45
Assumed cost of diesel (€ per litre)	€ 0.75	€ 0.75	€ 0.75
Equipment capital cost (€ per engine)	€ 55,000	€ 50,000	€ 85,000
Development of system (€ per engine)	€ 3,000	€ 3,000	€ 5,000
Integration of system (€ per engine)	€ 3,000	€ 3,000	€ 5,000
System installation (€ per engine)	€ 3,000	€ 3,500	€ 7,000
Change in diesel consumption (litres per hour)	+2.00	0.00	+2.00
Change in diesel costs (€)	€ 5,250	€ 0	€ 5,250
Consumption of additional operating supplies/materials **(urea)** (per engine) (litres per 100 km)	0	+1.50	+1.50
Unit cost of additional operating supplies **(urea)** (€ per litre)	N/A	€ 0.40	€ 0.40
Total cost of additional operating supplies **(urea)** (€ per year)	N/A	€ 2,100	€ 2,100
Change in maintenance costs (€ per year)	€ 3,000	€ 3,000	€ 3,000
TOTAL CAPITAL/FIXED COSTS (per engine)	**€ 64,000**	**€ 59,500**	**€ 102,000**
TOTAL ADDITIONAL OPERATING AND MAINTENANCE COSTS (per engine per year)	**€ 8,250**	**€ 5,100**	**€ 10,350**

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