Technical support for the review obligations under Regulation (EU) 2016/1628 (NRMM)

Draft Final Report

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List of abbreviations, acronyms and terms

AAQ	Ambient Air Quality
AECC	Association for Emission Control by Catalyst
AEI	Average Exposure Indicator
AQD	Air Quality Directive
AQP	Air Quality Plans
ASC	Ammonia slip catalyst
BAFU	Bundesamt für Umwelt (CH)
BC	Black Carbon
CBA	Cost-benefit Analysis
CCNR	Central Commission for the Navigation of the Rhine
CECE	Committee for European Construction Equipment
CESNI	Comité Européen pour l'Élaboration de Standards dans le Domaine de Navigation Intérieure
CHF	Swiss Franc
CI	Compression-ignition
CLEPA	European Association of Automotive Suppliers
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CO_2	Carbon Dioxide
DOC	Diesel oxidation catalyst
DPF	Diesel Particulate Filter
EC	European Commission
ECA	European Court of Auditors
EEA	European Environment Agency
EMEP	European Monitoring and Evaluation Programme
ENI	European Vessel Identification Number
EPA	Environmental Protection Agency
ERCs	Emission Reduction Commitments

EU	European Union
FOEN	Federal Office for the Environment (CH)
IFEU	Institute for Energy and Environmental Research
IPCC	Intergovernmental Panel on Climate Change
IWW	Inland Waterways
JRC	Joint Research Center
kg	kilogram
kt	kilotonnes
kW	kilowatt
LEZ	Low Emissions Zone
MS	Member State
M€	Million Euro
NAPCP	National Air Pollution Control Programmes
NECD	National Emissions Ceilings Directive
NGO	Non-governmental Organization
NoBo	Notified Body
NO_x	Nitrogen Oxides
NRE	Non-Road Engines
NRMM	Non-Road Mobile Machinery
O_3	Ozone
OAPC	Ordinance on Air Pollution Control
OBD	On-Board Diagnostics
OEM	Original Equipment Manufacturer
PM	Particulate Matter
PN	Particulate Number
REC	Retrofit Emission Control
SCR	Selective catalytic reduction

TSIs	Technical Specifications for Interoperability
TSP	Total Suspended Particles
UF	Ultrafine Particles
UINC	Union Inland Navigation Certificate
UK	United Kingdom
UN	United Nations
UNECE	United Nations Economic Commission for Europe
VAT	Value-added Tax
VDMA	Mechanical Engineering Industry Association (DE)
VERT	Verminderung der Emissionen von Real-Dieselmotoren im Tunnelbau
VOC	Volatile Organic Compound
WHO	World Health Organization
µm	micrometers

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Executive summary

There are serious environmental problems in the EU, such as climate change, human health, ecosystems, including breaches of adopted air quality standards and critical loads to which emissions of particulate matter (PM) and oxides of nitrogen (NO_x) from non-road mobile machinery (NRMM) contribute.

Regulation (EU) 2016/1628 applies to new NRMM engines; existing engines are not addressed. Therefore, recital 23 of Regulation (EU) 2016/1628 mentions "*Given the long lifetime of non-road mobile machinery, it is appropriate to consider the retrofitting of engines already in service. Such retrofitting should, in particular, target densely populated urban areas as a means of helping Member States to comply with Union air quality legislation. To ensure a comparable and ambitious level of retrofitting, Member States should take into account the principles of UNECE Regulation No. 132*". More specifically Article 60 requires that by 31 December 2018, the Commission shall submit a report to the European Parliament and to the Council regarding the assessment of the possibility of laying down harmonised measures for the installation of retrofit emission control devices in engines in non-road mobile machinery that has already been placed on the Union market.

This report compiles information and presents the results of assessments and analyses which aim at making a contribution to the discussion on retrofitting measures for non-road mobile machinery. The key findings are:

1. With regard to **environmental problems**:

- The contributions of the sub-category NRMM to emissions of NO_x and PM at national, regional and local level vary from negligible to significant, depending on country, region and city. There is no pattern indicating that PM and NO_x emissions from NRMM are of the same importance throughout the EU. At the level of EU-28, according to EMEP, the contribution to total NO_x emissions is about 10 % and to total $PM_{2.5}$ emissions about 3 to 4 %.
- For the sub-sector agriculture/construction, Stage I to IIIA machinery is responsible for 56 % of the total NO_x emissions and 67 % of the total PM emissions emitted in EU28 in 2019 from this sub-sector.
- For the sub-sector inland waterways, unregulated engines are responsible for about 90 % of total inland waterways emissions for both pollutants in 2019 for EU28. In the railway sector, unregulated and Stage IIIA engines contribute the highest to total railway emissions with a share of 87 % for NO_x emissions and 92 % for PM emissions.
- PM emissions contain also black carbon (BC) which contributes to climate change, in particular in the Artic region. According to EMEP the contribution to total emissions is about 16 %. Therefore, a reduction of black carbon emissions is desirable and does not depend on geographical parameters. However, there are still large uncertainties associated with the emissions and effects of black carbon and in consequence BC is not an official target of the EU climate change policy yet.
- Violations of the air quality limit values laid down for NO_2 and PM occur mainly in cities and highly populated regions, often close to busy roads. In tendency breaches of the NO_2 limit value are of greater relevance since these are still relatively high in number while the number of violations of the PM limit values is declining.
- Due to the atmospheric processes it is difficult to quantify the actual contribution of NRMM emissions to violations of the air pollution problems; again, there are large variations between countries, regions and cities.
- The Commission cannot tailor NRMM retrofitting measures which could make an optimal contribution to national, regional or local abatement plans; even in cities in which retrofitting measures have been taken it is difficult for local authorities to quantify the effect.

- Recent studies, carried out on behalf of the Commission, show that measures designed for compliance with the National Emissions Ceilings Directive (NECD) will bring the NO_2 air pollution below WHO guidelines and for $PM_{2.5}$ within reach of WHO guidelines for most areas of the EU. With regard to critical loads, the study shows that some countries will have to take additional measures to meet their emission ceilings for NO_x and $PM_{2.5}$.
- With regard to NRMM emissions the Regulation (EU) 2016/1628 will make a significant contribution to emission reductions mentioned above in the coming years.

2. With regard to **measures taken by Member States**:

- Many EU Member States are still not complying with the limits laid down in the Ambient Air Quality Directives (AQD) and the NEC Directive and several infringement cases pending against Member States.
- Nevertheless, only very few EU Member States take NRMM retrofitting measures. At European level such measures are taken in Switzerland, Austria, Germany and the United Kingdom. In the EU the measures taken concern polluted areas and are of regional or local character. The measures taken foresee retrofitting as an option to be taken in cases in which the operator does not prefer to use NRMM with engines complying with the more recent stages of EU legislation, e.g. stages IIIA or IIIB or better. In consequence the measures taken within the EU do not force retrofitting.
- Switzerland requires diesel particle filter (DPF) for diesel-powered construction equipment > 18 kW which entailed in the past a significant retrofitting programme.
- All measures taken concern retrofitting with particle filters; retrofitting with selective catalytic reduction (SCR) devices is not required.
- Based on the experiences gained with retrofitting programmes, the practical implementation of retrofitting programmes requires a number of prerequisites. Apart from the certification procedure, see below, guidance needs to be given to the owner of NRMM and an inspection/surveillance system needs to be established in order to ensure enforcement. For new engines surveillance/inspection covers just the placing on the market. Therefore, to require the establishment of an inspection/surveillance system for retrofitted engine which are already on the market is in conflict with the fact that such a system is not required for new engines.

3. With regard to the **use of retrofitting technologies and their certification**:

- Retrofitting technologies are available for both, PM and NO_x reduction. Technologies are proven and there is, as a rule, no major technical problem which cannot be solved. In practice focus is given on PM reduction while NO_x retrofitting measures are by far less often taken and concentrate on on-road vehicles.
- When retrofitting, the technologies used in new engines must be taken into account. From a technical point of view, it is much easier to retrofit NRE engines of stages I to IIIA than those of stages IIIB or IV, since almost all of the latter are already equipped with after-treatment systems. Therefore, retrofitting Stage IIIB and IV engines usually requires active cooperation with the OEMs and often leads to the need to apply for a new type approval. This makes retrofitting stage IIIB and IV engine unattractive.
- Retrofitting inland waterway vessels and railway vehicles is more complex but possible in many cases. In contrast to the other NRMM sub-categories retrofitting measures as well as more general "greening of the fleet" Programmes are being discussed at EU Level since a couple of years and some Action has been taken.
- Investment and running costs are a function of engine size: the larger the engine, the higher the costs; cost figures have been identified from literature and used in the cost/benefit calculations; the key figures taken for the cost/benefit calculations are as follows:

Table ES 1 DPF cost ranges used for the cost/benefit calculations

Power range In kW	DPF investment costs in €2018*	Mean DPF investment costs in €2018	DPF operating costs p.a. in €2018	Mean DPF operating costs p.a. in €2018
> 18	2500 – 4250	3500	130	130
18-37	3000 – 5250	4500	250	250
37-75	4000 – 7500	5500	450 – 500	475
75-130	4500 – 8000	6500	750 – 1000	875
130-300	5100 – 12500	7500	1300 – 1900	1600
300-560	6200 – 22500	12500	1700 – 2100	1900

Table ES 2 SCR cost ranges used for the cost/benefit calculations

Power range In kW	SCR investment costs in €2018		SCR operating costs p.a. in €2018
	System costs in €	Assembly costs in €	
19-130	6000	3000	180
130-300	10000	4000	220
300-560	15000	5000	300

- Costs for combined DPF/SCR systems are about 20 % to 30 % lower than the sum of the individual single measure DPF and SCR costs.
- Certification procedures ensure that the retrofitting device as such and the retrofitted engine in total meet pre-defined requirements. Several certification procedures for retrofitting devices are available but differ in detail and are not internationally harmonised. Moreover, they all focus on DPF retrofitting. Most widely used in Europe have been the VERT or the Swiss certification procedures. A significant number of systems have been certified in the past and are available to the market.
- Since 2015 the certification procedure under Regulation UNECE R 132 is in place; it binds legally all those UN Contracting Parties which signed the same Regulation. It covers NRE engines and DPF and SCR retrofitting in the power range 19 to 560 kW and is most appropriate for internationally harmonised measures since it has been established at international level, involving experts from all UNECE members. This opens the option of recognition and free access of retrofitted NRMM in all EU Member States. Moreover, it can be considered as the most up-dated of all certification procedures and further up-dates are possible within an internationally coordinated procedure.
- In tendency UNECE R 132 requires the certification of well-defined after-treatment/engine combinations; this might entail additional costs compared to other certification procedures.
- However, since UNECE R 132 is a new regulation, only few countries are actually using this procedure in practice, although in reply to a questionnaire many Member States expressed their intention to apply this regulation in future which opens the option to achieve an EU wide harmonisation in near future;
- Since there is currently no pressure to retrofit there seem to be no systems certified under UNECE R 132; it would take some time before a significant number of systems are certified. In

the light of the costs associated with certification there will be hardly any UNECE certified system without additional political initiatives.

- In the light of the notification requirements laid down in UNECE R 132 it would be of advantage to establish within the EU a communication tool to be used by all Member States. It should be considered whether the IMI tool established under Regulation (EU) 2016/1628 is an appropriate option.

4. With regard to **costs and benefits of retrofitting measures**:

- In the cost/benefit calculations the ownership costs are compared to the social benefits, expressed as external costs.
- With regard to PM and NO_2 external costs considered in this study are limited to health costs and taken from studies which focussed on road transport. The estimates distinguish between general external costs and external costs for urban areas which are higher due the higher population density. External costs of BC pollution are taken from literature as well. Only order of magnitude values of averaged estimates can be given within the scope of this study; the following key figures are used in the cost/benefit calculations:

Table ES 3 Estimated external costs used in this study

All figures in €/kg	General	Urban area
PM_{10}	10	50
$PM_{2.5}$	75	250
NO_2	10	20
CO_2	0.15	
BC	200	

- Cost/benefit calculations are subject of uncertainties. Therefore, error margins have been given to the technology costs and the external costs. However, the lifetime of equipment, its operational hours the fleet turn-over and other parameter are also subject to errors. This makes the whole cost/benefit calculations somewhat uncertain.
- Moreover, the costs/benefit calculation cover for EU 28, not individual Member States or for specific region or cities. Therefore, they provide only a broad indication for smaller territorial entities.
- The results obtained for the sub-sector agriculture/construction show negative benefits (losses) for the small to medium range power classes up to 130 kW and for all emission Stages and all retrofitting technologies examined in this study (DPF, SCR, and the combined system). Some very few exceptions exist for Stage I and unregulated machinery for the urban scenario only and for low retrofitting costs and high reduction efficiency and external costs. Retrofitting is cost beneficial for the 130-560 kW class for Stage I and unregulated machinery and for urban conditions only, although the benefits are rather small. Clear benefits are only observed for the most powerful machinery (> 560 kW) for non-urban conditions. As this class was largely unregulated (before the introduction of Stage V) with high emission levels because of the high power, big emission savings have been calculated for all retrofitting options examined.
- For inland waterways clear benefits are observed for all Stages, which are greater for unregulated vessels and for the combined system (DPF+SCR). For railcars, retrofitting is cost-beneficial for DPF and DPF+SCR for almost all Stages. SCR retrofitting is beneficial for locomotives only in few cases for Stage IIIA and unregulated engines, whereas DPF and the combined system shows clears benefits for all Stages but Stage IIIB. DPF and the combined

system is cost-beneficial for almost all Stages for shunting locomotives, with few exceptions for Stage IIIB engines, whereas SCR shows benefits for unregulated and Stage IIIA engines, but not for Stage IIIB engines.

- The emissions reductions achieved by these measures, as a share of the total emissions of each sub-sector are summarised in the following table.

Table ES 4 Emissions reductions achieved (within each subsector) for high and low reduction efficiency values

	Retrofitting System	Emissions reductions for high reduction efficiency	Emissions reductions for low reduction efficiency
Agriculture - Construction	SCR	11 % of NO_x emissions	8 % of NO_x emissions
	DPF	24 % of PM emissions	22 % of PM emissions
	DPF+SCR	12 % of NO_x and PM emissions	10 % of NO_x and PM emissions
Inland waterways	SCR	58 % of NO_x emissions	38 % of NO_x emissions
	DPF	65 % of PM emissions	59 % of PM emissions
	DPF+SCR	56 % of NO_x and PM emissions	53 % of NO_x and PM emissions
Railways	SCR	38 % of total NO_x emissions	25 % of NO_x emissions
	DPF	52 % of PM emissions	46 % of PM emissions
	DPF+SCR	38 % of NO_x and PM emissions	36 % of NO_x and PM emissions

5. With regard to **other aspects associated with retrofitting NRMM and the assessment carried out:**

- Retrofitting of NRMM is one possible measure in a long list of potential measures capable to reduce PM and NO_x emissions; it is important to note that the study does not consider alternative emission reduction options covering all possible sources.
- An important aspect to consider is the principle of subsidiarity. To reduce emissions as part of the NEC Directive or to design measures for the improvement of local air quality lies to a large extent in the responsibility of Member States. To intervene into local Air Quality Plans would clearly be in conflict with the subsidiarity principle.
- In policy terms, the measure "retrofitting of NRMM" has also to be assessed against measures taken by the Commission for the on-road sector since these two sectors corresponds to each other to a certain extent. In the past, measures on NRMM followed with some delay those taken for the on-road sector. Taking measures like NRMM retrofitting or providing economic incentives which have not been taken at EU level for road transport would raise the question why now for NRMM and not in the past for road vehicles.
- Retrofitting measures lose sense with time since the turn-over of the NRMM fleets will lead to the usage of clean technologies in the coming years. There is a time window between 2020 to

about 2030 within which action could make sense. After 2030 the normal turnover of the NRMM fleets already dominates the emissions of this sector.

- However, the scope of large-scale, short-term retrofitting is limited by the existing industrial capacities. Moreover, short-term retrofitting is only possible if the usage of after-treatment equipment not certified under UNECE R 132 is allowed, at least for a transition period.

6. With regard to **policy options and financial incentives**:

- The following three policy options have been assessed:
- Mandatory retrofitting of all NRMM of the subcategory NRE with a Stage V PN limit value
- Non-binding retrofitting of all NRMM of the subcategory NRE with a Stage V PN limit value used in polluted zones
- Do nothing
- To limit the assessment on the sub-category NRE is justified by the fact that the sectors IWW and rail are of special character and would need to be studied in greater detail.
- The option "Mandatory Retrofitting" of all NRE cannot be recommended since it is in conflict with a number of aspects, e.g. the subsidiary principle and non-existence of similar measures in Member States, lack of sufficient retrofitting capacity and certified systems, conflict with the replacement engine rules laid down in the NRMM Regulation, non-existence of similar measures for the on-road sector, unclear repercussions on the NRMM second-hand market and high absolute costs.
- More appropriate seems to be the second option, a non-binding Recommendation to be applied in polluted zones. A Commission Recommendation gives guidance to Member States which consider taking such measures as well as to the few countries, regions or cities which actually have already taken measures; from the Commission's perspective it would be mainly a contribution to harmonisation, meeting at the same time the requirements mentioned in the recital of the Regulation.
- Aspects to be covered by a Commission Recommendation have been identified and an example has been drafted. Most appropriate seems to be to cover construction machinery falling into the category NRE within the power range 19-560 kW, to require certification under UNECE R 132 and to ensure guidance and surveillance.
- With regard to the timing, the implementation scheme of the Regulation (EU) 2016/1628 should be taken into account.
- It is proposed that the Recommendation should be applied 2 years after its publication at the latest. This timing allows to identify and announce new zones but also to adapt zones for which retrofitting requirements have already been laid down to the proposed Recommendations;
- It is recommended that in polluted zones either Stage IIIB or IV engines must be used or engines must be retrofitted in accordance with UNECE R 132; in practical terms the option to allow stages IIIB/IV will make retrofitting for variable speed engines in the power class 37-560 kW superfluous in most of the cases since there are enough NRMM available or in use which meet these emission stages; these engines have just to be used in places where the fact of their low emissions is most beneficial; if necessary leasing is another option.
- NRMM equipped with constant speed engines or with variable speed engines in the power class 19 to 37 kW should get one extra year for retrofitting since there are no stage IIIB/IV engines on the market.
- In cases where retrofitting proves to be technically impossible, temporary exemptions should be granted. A period of 2 years should be sufficient to solve the identified and proven cases. The number of exemptions should be kept as small as possible. Applications for exemptions should be forwarded within the one-year period between the announcement of the zone and the application of the Recommendation.

- Moreover, it should be recommended to ensure a minimum of 1 year between the announcing of zones and the application of these Recommendations. This allows the construction industry to prepare the required change of machinery, e.g. by exchanging older machines with those complying with the requirements or to retrofit, if necessary. However, in the period between the publication of the Recommendation and its application it should be recommended that Member States, States or local authorities encourage end-users which plan to retrofit construction machinery should apply exclusively the provisions of UNECE R 132 for the certification process.
- NRMM already retrofitted in the past can continue to be used in these zones.
- The proposed timing looks as follows:

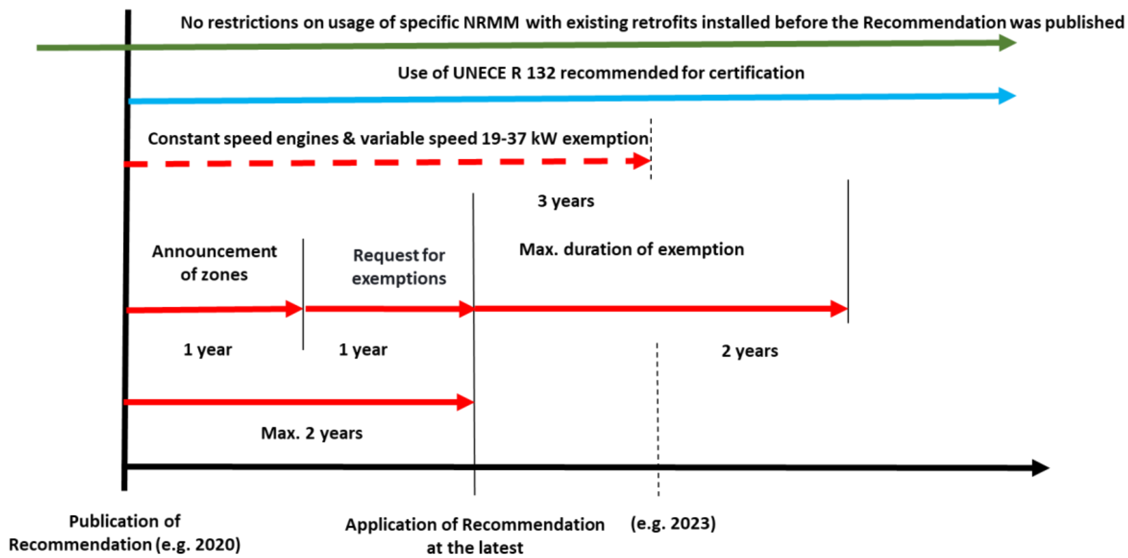

Figure ES 1 Timing of action according to proposed Recommendation

- Since NRE Stage V engines are placed on the market, including transition scheme, in the period 1.1.2019 to 1.1.2022 the purchase of stage V NRMM is another option for the end-user.
- The currently proposed minimum requirements of stage IIIB/IV could be tightened by requiring mandatory stage V retrofitting to stage V in accordance with UNECE R 132 in a couple of years;
- “Do nothing” is a valid option since only very few Member States seem to be interested in retrofitting. Thus, little or no retrofitting takes place and one could question the need of action at EU level. Moreover, the harmonisation of certification will happen after adoption of UNECE R 132 in the coming years more or less automatically.
- Apart from financial support in the IWW sector no financial support is currently given in EU Member States for retrofitting activities.
- Financial incentives, if desired, have to respect a number of aspects laid down in EU legislation, among other requests measures should be performance based and non-discriminatory in regard to both technologies used to achieve the performance level and equal access/opportunity for economic operators in any member state;
- Financial incentives for retrofitting only might have a positive impact on retrofitting but a negative impact on the introduction of stage V.
- Financial incentive programmes for IWW, locomotives and railcars make more sense than programmes for the NRE subcategory. They also require significantly fewer financial resources.

The Commission should therefore continue the discussions in the relevant bodies in a targeted manner.

- Other policies might have an impact on the retrofitting issue and change the picture, e.g.
    - In January 2019 the particle limit values for occupational health have been tightened which could result in additional retrofitting requirements,
    - In 2019/2020 the Commission will publish the results of the fitness check of the air quality limit values which might request to comply with lower limits,
    - Commission work on public procurement.
- In the coming years the Commission will have additional review options. These could be used to tighten the emission limited values further and make an additional contribution to reduce air pollution, if necessary.

1 Introduction

Off-road engines are used for many different machines, from the lawnmower to the power generator, going through the railcar and river barges propelled by liquid or gaseous fuels. Agricultural tractors, construction machines, generator sets, rail and inland water engines are the main categories of engines included in non-road mobile machinery (NRMM).

Non-road mobile machinery is mainly powered by off-road engines, which are divided into several engine categories[1]. Since September 16, 2016, the emissions from new off-road engines are regulated by a new EU Regulation that applies as of 1 January 2017 (NRMM Regulation) and replaces older Directives (European Commission, 2016c).

The NRMM Regulation lays down emission limits for NRMM engines for different power ranges and applications. It also defines the procedures engine manufacturers have to follow in order to obtain type-approval for off-road engines – which is a prerequisite for placing their engines on the EU market. In addition, Implementing Regulations and Delegated Regulations have been published[2].

Agricultural tractors fall under a separate Regulation (EU) No 167/2013 (European Commission, 2013d) and associated Delegated and Implementing Acts (European Commission, 2015; European Commission, 2018c) but must meet the emissions limits from the NRMM Directive.

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[1] (1) 'category NRE':
(a) engines for non-road mobile machinery intended and suited to move, or to be moved, by road or otherwise, that are not excluded under Article 2(2) and are not included in any other category set out in points (2) to (10) of this paragraph;
(b) engines having a reference power of less than 560 kW used in the place of Stage V engines of categories IWP, IWA, RLL or RLR;
(2) 'category NRG': engines having a reference power that is greater than 560 kW, exclusively for use in generating sets; engines for generating sets other than those having those characteristics are included in the categories NRE or NRS, according to their characteristics;
(3) 'category NRSh': hand-held SI engines having a reference power that is less than 19 kW, exclusively for use in hand-held machinery;
(4) 'category NRS': SI engines having a reference power that is less than 56 kW and not included in category NRSh;
(5) 'category IWP':
(a) engines exclusively for use in inland waterway vessels, for their direct or indirect propulsion, or intended for their direct or indirect propulsion, having a reference power that is greater than or equal to 19 kW;
(b) engines used in place of engines of category IWA provided that they comply with Article 24(8);
(6) 'category IWA': auxiliary engines exclusively for use in inland waterway vessels and having a reference power that is greater than or equal to 19 kW;
(7) 'category RLL': engines exclusively for use in locomotives, for their propulsion or intended for their propulsion;
(8) 'category RLR':
(a) engines exclusively for use in railcars, for their propulsion or intended for their propulsion;
(b) engines used in the place of Stage V engines of category RLL;
(9) 'category SMB': SI engines exclusively for use in snowmobiles; engines for snowmobiles other than SI engines are included in the category NRE;
(10) 'category ATS': SI engines exclusively for use in ATVs and SbS; engines for ATVs and SbS other than SI engines are included in the category NRE.

[2] Commission Delegated Regulation (EU) 2018/989 amends and corrects Delegated Regulation (EU) 2017/654 on technical requirements for Stage V NRMM. Commission Delegated Regulation (EU) 2018/987 amends and corrects Delegated Regulation (EU) 2017/655 on in-service monitoring of gaseous emissions of NRMM Stage V equipment. Commission Implementing Regulation (EU) 2018/988 amends and corrects the NRMM Stage V Implementing Regulation (EU) 2017/656. Commission Delegated Regulation (EU) 2018/985 supplements Regulation (EU) No 167/2013 with Stage V environmental and propulsion unit performance requirements (REPPR) for agricultural and forestry vehicles and their engines. It repeals Commission Delegated Regulation (EU) 2015/96. Commission Implementing Regulation (EU) 2018/986 amends Implementing Regulation (EU) 2015/504 to adapt the administrative provisions for the approval and market surveillance of agricultural and forestry tractors to Stage V emissions limits.

The requirements for the source category most relevant for this study, engines of category NRE[3] with variable or constant speed[4], are shown in Table 1-1f (VDMA, 2017).

Table 1-1 Emission limit values for NRE engines used in NRMM

Power [kW]	CO [g/kWh]	HC [g/kWh]	NO_x [g/kWh]	Particulate [g/kWh]	Particulate [#/kWh]	Date[A]
		NMHC + NO_x				
Stage I						
$37 \le P_n < 75$	6.5	1.3	9.2	0.85	–	Apr. 99
$75 \le P_n < 130$	5.0	1.3	9.2	0.70	–	1999
$130 \le P_n \le 560$	5.0	1.3	9.2	0.54	–	1999
Stage II						
$18 \le P_n < 37$	5.5	1.5	8.0	0.8	–	2001
$37 \le P_n < 75$	5.0	1.3	7.0	0.4	–	2004
$75 \le P_n < 130$	5.0	1.0	6.0	0.3	–	2003
$130 \le P_n \le 560$	3.5	1.0	6.0	0.2	–	2002
Stage III A						
$19 \le P_n < 37$	5.5	7.5		0.6	–	2007
$37 \le P_n < 75$	5.0	4.7		0.4	–	2008
$75 \le P_n < 130$	5.0	4.0		0.3	–	2007
$130 \le P_n \le 560$	3.5	4.0		0.2	–	2006
Stage III B						
$37 \le P_n < 56$	5.0	4.7		0.025	–	2013
$56 \le P_n < 75$	5.0	0.19	3.3	0.025	–	2012
$75 \le P_n < 130$	5.0	0.19	3.3	0.025	–	2012
$130 \le P_n \le 560$	3.5	0.19	2.0	0.025	–	2011
Stage IV						
$56 \le P_n < 130$	5.0	0.19	0.4	0.025	–	Oct. 2014
$130 \le P_n \le 560$	3.5	0.19	0.4	0.025	–	2014
Stage V						
$0 \le P_n < 8$	8.00	7.50[C]		0.40[B]	–	2019
$8 \le P_n < 19$	6.60	7.50[C]		0.40	–	2019
$19 \le P_n < 37$	5.00	4.70[C]		0.015	$1*10^{12}$	2019
$37 \le P_n < 56$	5.00	4.70[C]		0.015	$1*10^{12}$	2019
$56 \le P_n < 130$	5.00	0.19[C]	0.40	0.015	$1*10^{12}$	2020
$130 \le P_n \le 560$	3.50	0.19[C]	0.40	0.015	$1*10^{12}$	2019
$P_n > 560$	3.50	0.19[D]	3.50[E]	0.045[F]	–	2019

A Date for placing the engine on the market, type approval one year earlier.
B 0.60 for hand-startable, air-cooled direct injection engines.
C A = 1.10 for gas engines.
D A = 6.00 for gas engines.
E 0.67 for gensets.
F 0.35 for gensets.

3 'category NRE':
(a) engines for non-road mobile machinery intended and suited to move, or to be moved, by road or otherwise, that are not excluded under Article 2(2) and are not included in any other category set out in points (2) to (10) of this paragraph;
(b) engines having a reference power of less than 560 kW used in the place of Stage V engines of categories IWP, IWA, RLL or RLR;
4 From Stage V, variable speed and constant speed engines are treated equally.

Moreover, based on Regulation 2016/1628, railcars and inland waterway vessels (IWW) > 300 kW have to comply with more stringent limit values, see Table 1-2 and Table 1-3.

Table 1-2 Emission limit values for inland waterways vessel

Power [kW]	CO [g/kWh]	HC[A] [g/kWh]	NO_x [g/kWh]	Particulate [g/kWh]	Particulate [#/kWh]	Date[B]
		NMHC + NO_x				
Stufe V						
$19 \leq P_n < 75$	5.00	4.70		0.30	–	2019
$75 \leq P_n < 130$	5.00	5.40		0.14	–	2019
$130 \leq P_n \leq 300$	3.50	1.00	2.10	0.10	–	2019
$P_n > 300$	3.50	0.19	1.80	0.015	$1*10^{12}$	2020

A HC limit for fully and partially gaseous-fueled engines: Where an A-factor is defined, the HC limit is calculated by the formula HC = 0.19 + (1.5 x A x GER), the maximum allowed is HC = 0.19 + A. For a combined HC and NOx limit, the combined limit value for HC and NO_x shall be reduced by 0.19 g/kWh and apply for NO_x only. GER is the average gas energy ratio over the appropriate test cycle.

B Date for placing the engine on the market, type approval one year earlier.

Table 1-3 Emission limit values for railcars

Stage	Power	NO_x [g/kWh]	HC [g/kWh]	CO [g/kWh]	PM [g/kWh]	PN [#/kWh]	Date[A]
		HC + NO_x [g/kWh]					
III A	$P_n > 130$ kW	4.0		3.5	0.20	–	2006
III B	$P_n > 130$ kW	2.0	0.19	3.5	0.025	–	2012
V	$P_n > 0$ kW	2.00	0.19[A]	3.50	0.015	$1*10^{12}$	2021

A Date for placing on the market of engines, type approval one year earlier.

B A = 6.00 for gas engines.

The new Regulation (EU) 2016/1628 sets the world's toughest emission standards for NRMM and will result in significant emission reductions in the coming years, in particular with regard to particulate matter (PM) (European Commission, 2014a). The new Stage V PM emission standards aim at requiring the wide-range introduction of highly-efficient diesel particulate filters (DPF) for the category NRE > 19 kW, IWW vessels > 300 kW and railcars by laying down particle number (PN) limits for off-road engines. The type approval for Stage V new off-road engines will be phased in for different engine types from 1 January 2018 to 1 January 2020. The market placement for the engines will be, as a rule, one year after the scheduled type approval. According to this timeline, most of the new non-road engines entering the EU market will be Stage V-certified in the period 1^{th} of January 2019 to 1^{th} of January 2021[5].

[5] Special rules are laid down in the regulation for the 'transition period'. These are the first 24 months following the dates set out in Annex III of the EU Regulation for the placing on the market of Stage V engines. Within this period a transition engine, e.g. an engine that has an engine production date that is prior to the date set out for the placing on the market of Stage V engines and that complies with the latest applicable emission limits defined in the relevant legislation applicable on 5 October 2016 or falls within a power range, or is used or intended for use in an application, that was not subject to pollutant emission limits and type-approval at Union level on 5 October 2016, or the non-road mobile machinery in which those transition engines are installed, may continue to be placed on the market provided that the machinery in which the transition engine is installed has a production date not later than 18 months following the start of the transition period. Moreover, for engines of category NRE, Member States shall authorise the extension of the

Member States and in particular cities in Member States still face severe problems with total national emissions and elevated ambient air concentrations of nitrogen dioxide (NO_2) and PM[6]. Mobile machinery contributes to these problems.

The Regulation (EU) 2016/1628 applies to new engines; existing engines are not addressed. Therefore, recital 23 of Regulation (EU) 2016/1628 mentions *"Given the long lifetime of non-road mobile machinery, it is appropriate to consider the retrofitting of engines already in service. Such retrofitting should, in particular, target densely populated urban areas as a means of helping Member States to comply with Union air quality legislation. To ensure a comparable and ambitious level of retrofitting, Member States should take into account the principles of UNECE Regulation No. 132"* and lays down in Article 60 concrete requirements: "*By 31 December 2018, the Commission shall submit a report to the European Parliament and to the Council regarding the assessment of the possibility of laying down harmonised measures for the installation of retrofit emission control devices in engines in non-road mobile machinery that has already been placed on the Union market. That report shall also address technical measures and financial incentive schemes as a means of helping Member States to comply with Union air quality legislation, by assessing possible action against air pollution in densely populated areas, and with due respect for the Union rules on state aid.*"

This report compiles information and presents the results of assessments and analyses which aim at making a contribution to the discussion on retrofitting measures for non-road mobile machinery. More specifically, the following issues are addressed:

- technological and technical solutions, including their technical feasibility, for retrofit systems for NRMM engines;
- the contribution retrofitting of existing non-road mobile machinery could make with regard to total emissions and air quality;
- the costs and benefits in economic terms, as far as possible, associated with retrofitting measures;
- policy options for the EU Commission to tackle the issue, in particular:
    - possible ways forward for laying down harmonised measures at EU level for retrofit systems, including regulatory and non-regulatory approaches,
    - financial incentive schemes which EU Member States could introduce to promote the installation of retrofit systems.

The analysis focuses on retrofit systems for NRMM engines reducing particulate matter (PM), oxides of nitrogen (NO_x), or both PM and NO_x, since these are the most relevant pollutants.

In the first part (chapters "Air pollution problems and the potential contribution of emissions from non-road mobile machinery" and "Measures taken at Member States, State and local level") of this analysis the air pollution problems are described as well as the measures taken by the EU and Member States. The purpose of this part is to explain and analyse the framework within which retrofitting measures have to fit.

In the second part (chapters "Technologies of new NRMM engines complying with the different limit value Stages", "Retrofitting technologies and costs", "Approval and testing of after-treatment devices", "Potential problems associated with retrofitting due to existing legislation", "Implementing retrofitting

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transition period and of the 18-month period by an additional 12 months for OEMs with a total yearly production of less than 100 units of non-road mobile machinery equipped with internal combustion engines. Moreover, for engines of category NRE used in mobile cranes, the transition period and the 18-month period shall be extended by 12 months. For engines of category NRS with an engine power of less than 19 kW used in snow throwers, the transition period of 18-months shall be extended by 24 months.

[6] Occupational aspects are not covered by the study; neither are they part of Regulation (EU) 2016/1628.

measures" and "The EU after-treatment market") the technologies used for new non-road machinery engines and the available retrofitting technologies, including their costs and retrofitting procedures are described. The objective of this part is to explain and analyse the framework of retrofitting measures.

In the third part (chapters "Emission estimates" and "External costs") relevant information for scenario design is given. This includes own emission estimates and external costs considerations, as well as the description of the cost model used.

In the fourth part (chapter "Cost benefit analysis") the results of the cost/benefit analysis are presented.

Finally, in the fifth part (chapters "Positions of industrial associations and NGOs with regard to retrofitting", "Policy options" and "Financial incentives") the pros and cons of policy options are discussed in the light of the results obtained in parts 1 to 4.

Most of this work is based on a review of literature. However, the results on emissions and costs/benefits are based on calculations newly carried out within the framework of this study.

2 Air pollution problems and the potential contribution of emissions from non-road mobile machinery

2.1 Introduction

Emissions of NRMM contribute to a number of environmental problems[7]. With regard to the NRMM emissions considered in this report the most problematic pollutants are particulate matter (PM), nitrogen dioxide (NO_2) and - linked to NO_x emissions - ground-level ozone (O_3) (European Environment Agency, 2017a).

Particulate matter (PM) is one of the most serious air pollution health risks in the EU. PM is divided into fractions:

TSP: total suspended particles which in practical terms covers all PM suspended in air and collected by so-called high-volume samplers, applying standard measurement procedures;

PM_{10}: inhalable particles, with diameters that are generally 10 micrometers (µm) and smaller;

$PM_{2.5}$: fine inhalable particles, with diameters that are generally 2.5 µm and smaller, and

UF: Ultrafine particles, i.e. particles smaller than 0.1 µm in diameter; these are usually measured as a number concentration.

The following figure shows the number, surface and volume (corresponding to mass) distribution of PM in ambient air (particle diameter expressed in 1 nm = 10^{-3} µm).

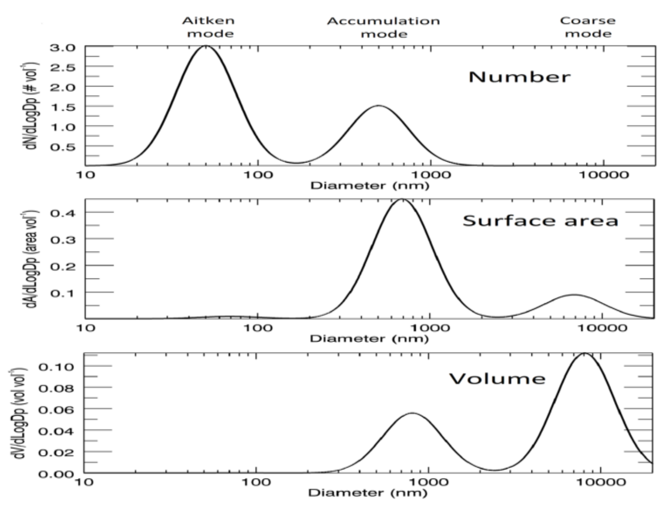

Figure 2-1 Particle size distribution of PM in ambient air

UF, belonging to the Aitken mode (term used in aerosol physics), are high in number but very low in mass. $PM_{2.5}$. belongs to the Aitken and the accumulation mode and covers most of the surface offered by PM. PM_{10} finally covers most of the inhalable mass of PM.

[7] The analysis presented in the following relies on simplifying assumptions. The quality of the results depends on the quality of the input data. Unfortunately, the complexity of the issue as well as the fact that input data on ambient air quality and emission data are characterised by uncertainties which vary between Member States, regions and cities, allows only providing an incomplete and simplified picture of the problems.

Another relevant sub-fraction of PM is black carbon (BC)[8]. BC is a constituent of $PM_{2.5}$ formed from incomplete fuel combustion. BC is mainly present in the so-called Aitken fraction of particulate matter ($PM_{0.1}$).

Since not all TSP is inhalable, concern on human health concentrates on PM_{10} and $PM_{2.5}$. The World Health Organisation acknowledges there is no evidence to suggest any threshold value exists below which the adverse health effects associated with $PM_{2.5}$ exposure can be avoided.

While there is considerable toxicological evidence of potential detrimental effects of PM_{10} and $PM_{2.5}$ on human health, the existing body of epidemiological evidence for UF is considered to be insufficient to reach a conclusion on the exposure–response relationship. Therefore, no WHO recommendations are provided at this point in time.

Nitrogen dioxide (NO_2) is a risk to human health[9]. Moreover, NO_2 is also a major cause of eutrophication (over-fertilisation that may negatively affect biodiversity and cause excessive plant and algal growth in marine ecosystems) and acidification. Eutrophication is still a widespread problem; a large percentage of the EU's ecosystem areas are exposed to nitrogen deposition that exceeds eutrophication limits. NO_2 also contributes to the formation of PM[10] and ozone.

Ozone (O_3) is a risk to human health. Moreover, when absorbed by plants, O_3 damages plant cells, impairing their ability to grow and reproduce, and leading to reduced agricultural crop yields, decreased forest growth and reduced biodiversity. Ozone is a secondary pollutant, formed from precursor pollutants, primarily NO_x[11], VOCs, methane and carbon monoxide. Exposure in cities is still very high and a high percentage of EU urban inhabitants are exposed to ozone concentrations above the EU target value.

PM, NO_x and O_3 also causes damage to buildings and materials.

Ozone is not considered further in this report since within the scope of this study it is not possible to identify the contribution of NRMM emissions to O_3 pollution.

2.2 National total emissions

Primary PM and NO_x originates from both natural and anthropogenic sources.

Natural PM sources include sea salt, naturally suspended dust, pollen and volcanic ash, while anthropogenic sources include fuel combustion for power generation, domestic heating and transport, industry and waste incineration, and agriculture, as well as brakes, tyres and road wear. PM can also be

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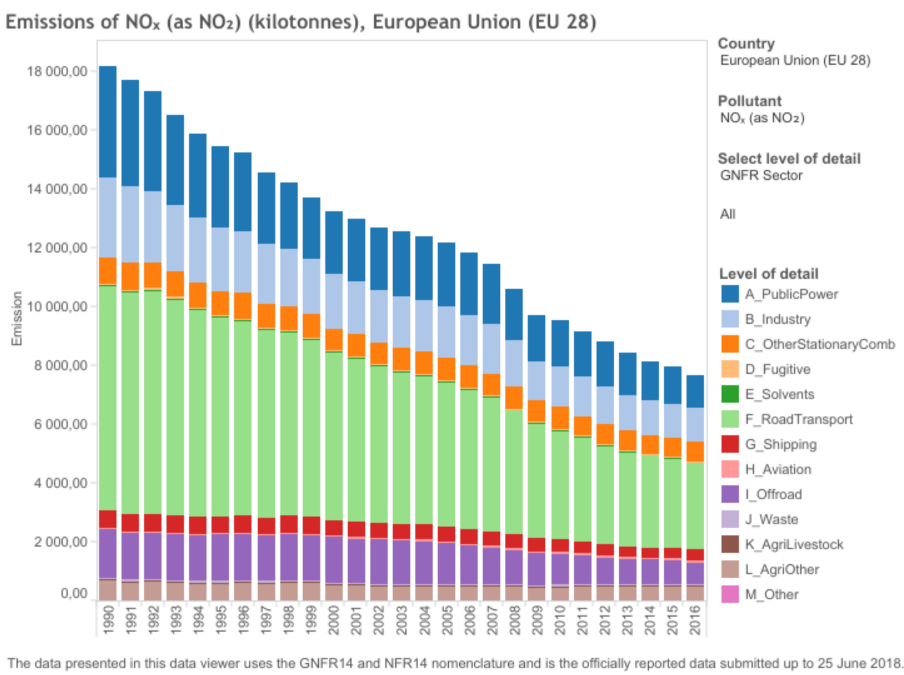
[8] General definition: A solid form of mostly pure carbon that absorbs solar radiation (light) at all wavelengths.
[9] With regard to effects of NO_2 it should be mentioned that, according to WHO 2005 (WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulphur dioxide Global update 2005), numerous epidemiological studies have used NO_2 as a marker for the cocktail of combustion-related pollutants, in particular, those emitted by road traffic or indoor combustion sources. In these studies, any observed health effects could also have been associated with other combustion products, such as ultrafine particles, nitrous oxide (NO), particulate matter or benzene. Although several studies – both outdoors and indoors – have attempted to focus on the health risks of NO_2, the contributing effects of these other, highly correlated co-pollutants were often difficult to rule out. Thus, health effects, often attributed to NO_2, are in reality effects caused by a mixture of air pollutants associated with traffic emissions. This view has been confirmed in the 2015 paper "WHO Expert Consultation: Available evidence for the future update of the WHO Global Air Quality Guidelines" which concluded "*Few existing studies have considered two or more pollutant models, but experts emphasized that, particularly in the context of long-term exposure, the fact that NO_2 may represent other constituents in the mixture of traffic-related air pollutants needs to be addressed when reviewing the evidence*."
[10] Reductions in precursor emissions cannot be directly transferred to decreases in PM concentrations. However, models show that European anthropogenic emission changes also dominate the evolution of secondary PM, contributing to a decrease in the concentrations of those compounds.
[11] NO_x is a generic term for the nitrogen oxides that are most relevant for air pollution, namely nitric oxide (NO) and nitrogen dioxide (NO_2).

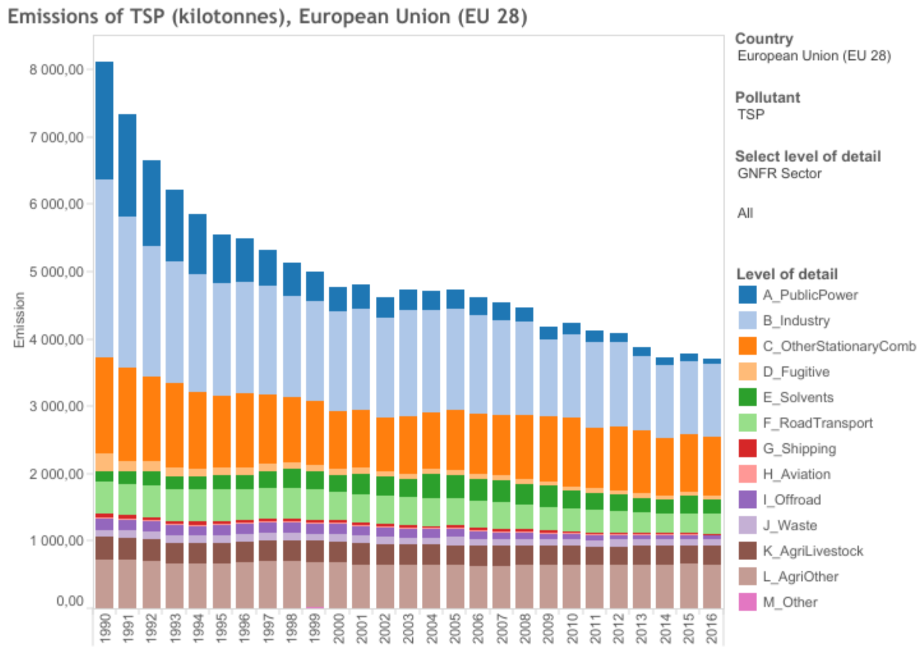
formed in the atmosphere from various precursor pollutants including nitrogen oxides (NO_x). Depending on the situation natural sources can contribute significantly to total PM emissions.

Natural NO_x emissions due to biological decay processes and lightning contribute little to airborne NO_x. However, the overwhelming majority of NO_x emissions come from combustion-related emissions sources of human origin, primarily fossil fuel combustion in electric utilities, high-temperature operations at other industrial sources, and operation of combustion engines, e.g. in motor vehicles and mobile machinery. NO accounts for the majority of NO_x emissions: NO is subsequently oxidised to form NO_2, although some NO_2 is also emitted directly. Depending on the design of the after-treatment system the proportion of NO_2 (i.e. the NO_2/NO_x ratio) in the exhaust of combustion engines can be considerably higher in diesel engines than in petrol engines, because some exhaust after-treatment systems increase oxidation of NO generating higher direct NO_2 emissions[12].

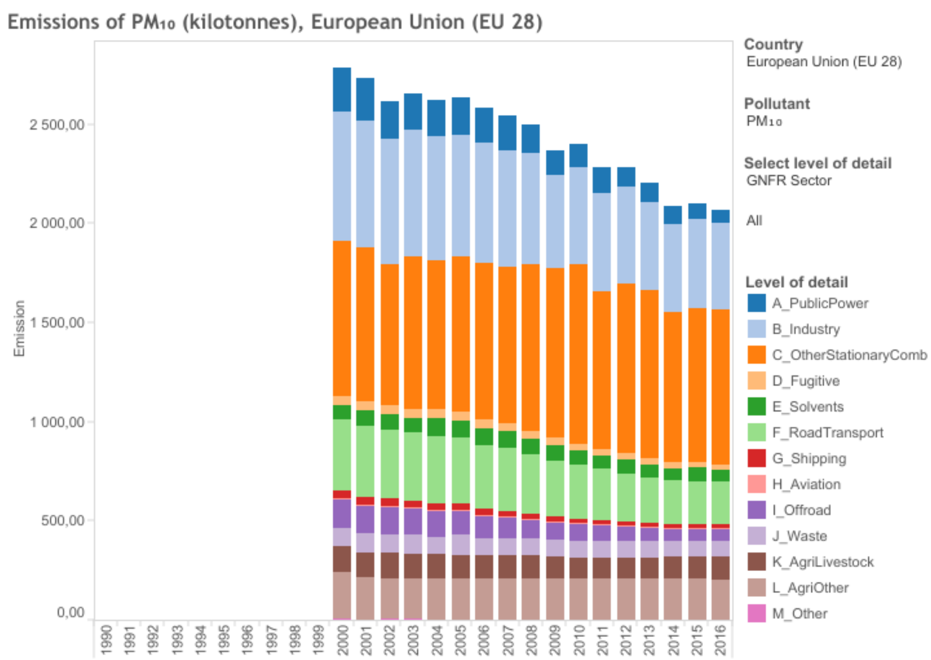
PM and NO_x are emitted directly from anthropogenic emission sources in large quantities. The following Figure 2-2 shows the national emissions of NO_x and several fractions of PM in EU 28, as reported to EMEP under the UNECE Convention on long range trans-boundary air pollution (EMEP, 2018).



[12] This depends strongly on the formulation of the after-treatment system, especially presence of catalytic coatings to promote oxidation. Such coatings are mostly present with self-regenerating DPFs and may be absent from those with separate regeneration systems such as burners, post combustion injection, etc. In fact, retrofit of a non-after-treated engine with a generic self-regenerating DPF that has not been tailored to the operating profile of the machine can increase absolute emission of direct NO_2 unless combined with an SCR. The negative impact of a retrofit DPF on direct NO_2 depends strongly on retrofit design. If the entire population of existing machines were suddenly retrofitted with self-regenerating DPFs then local NO_2 would increase as consequence.



The data presented in this data viewer uses the GNFR14 and NFR14 nomenclature and is the officially reported data submitted up to 25 June 2018.



The data presented in this data viewer uses the GNFR14 and NFR14 nomenclature and is the officially reported data submitted up to 25 June 2018.

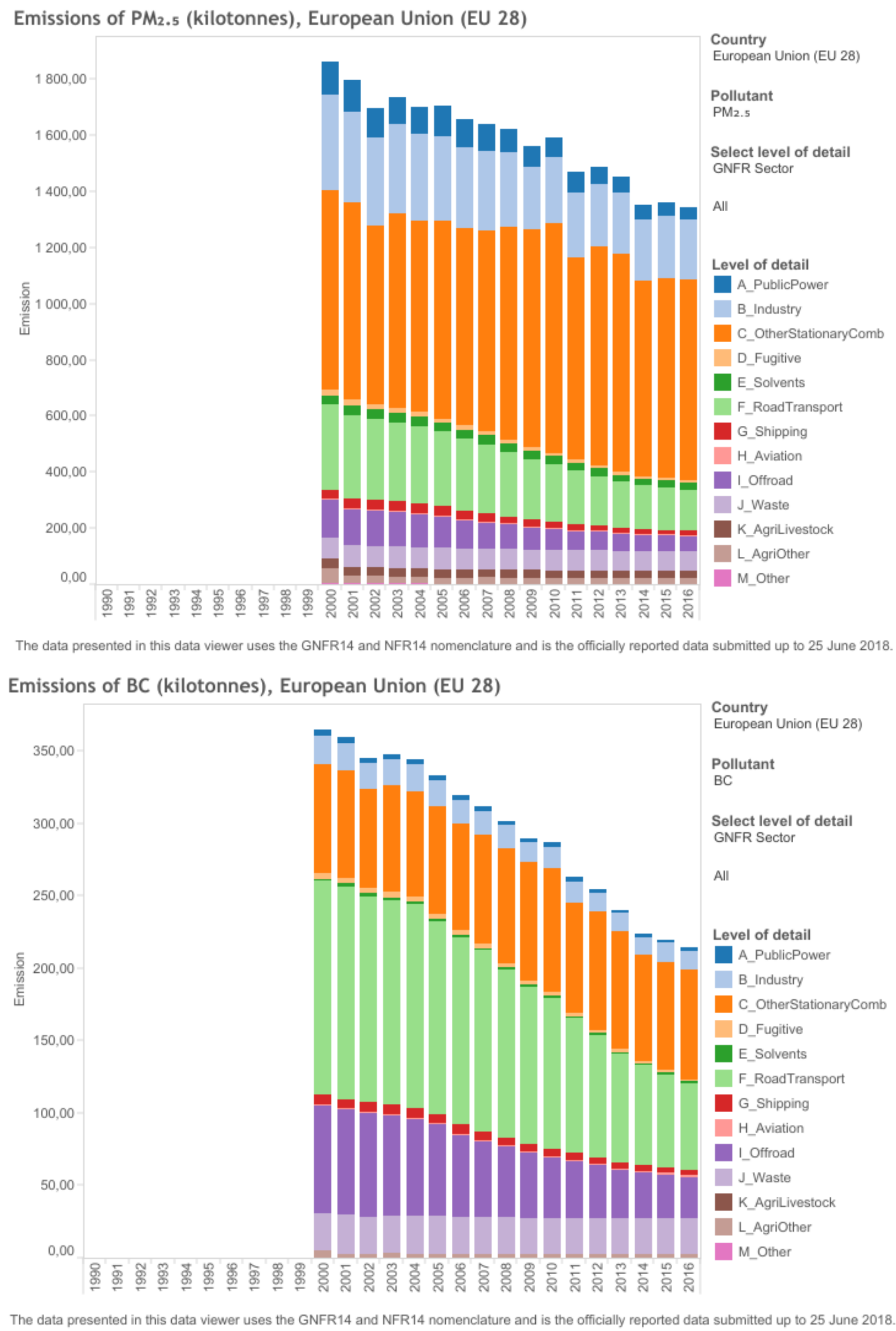


Figure 2-2 Emission data from EMEP

In general emissions have decreased in recent decades, e.g. NO_x emissions for the EU are more than 30 % below 2005 and emissions of $PM_{2.5}$ have reduced by almost 20 % in the EU compared with their 2005 levels. Nevertheless, emissions are still too high to ensure the protection of public health or the environment throughout the EU.

Figure 2-2 allows drawing some general conclusions on the contribution of the sector off-road which corresponds largely to non-road mobile machinery[13]:

- NRMM sources are relevant contributors to total NO_x emissions; in 2016 the sector accounts for about 10 % of total emissions.
- NRMM sources are negligible for TSP emissions and of minor importance for PM_{10} (about 2,5 % of total in 2016).
- NRMM sources contribute somewhat to total $PM_{2.5}$ (about 3,5 % in 2016)
- NRMM contribute significantly to BC emissions (about 16 % in 2016).

The contribution of emissions from non-road mobile machinery to total PM and NO_x emissions differs considerably from one Member State to the other Moreover, detailed EMEP data show that the relevance of NRMM emissions differs also at national level. For example, the NO_x shares of NRMM emissions of totals are 6,5 % for Germany, 13 % for France, 6,9 % for Italy, 9,8 % for Poland and 9,7 % for Spain. For $PM_{2.5}$ the respective shares are 6,7 % for Germany, 4,9 % for France, 2,8 % for Italy, 7,3 % for Poland and 2,7 % for Spain.

This corresponds in tendency with other findings. For example, Amann et al. - based on PRIMES energy balances - estimated for NO_x that the NRMM contribution varies between 3 and 39 % (Amann et al., 2011). Although these data might not be fully comparable with each other and might not correlate exactly with the definition of non-road mobile machinery as laid down in Regulation (EU) 2016/1628, these figures can be taken as an indicator on the

variability of emissions and order of magnitude of their contribution to the totals[14].

Austrian and German (Helms and Heidt, 2014; Lichtbau et al., 2009) studies suggest that the majority of PM emissions from NRMM are caused by the agriculture sub-sector, followed by the construction machinery sub-sector.

2.3 Spatial resolution

Total emissions of a pollutant occur at different locations and different source categories contribute to total ambient air pollution in different areas with different relevance.

Figure 2-3 illustrates - as an example - in a schematic manner the contribution of different areas and different source categories to PM pollution. It shows that the larger urban area or the city level alone accounts for only a fraction of the PM mass. In this example the non-road ("off-road" in Figure 2-3) sector contributes to PM emissions at all spatial levels (European-, country-, greater urban- and city-level). The actual contribution, however, differs significantly, as shown in the following.

[13] The NRMM emission data of EMEP does not be in all details correspond to the definition of NRMM as laid down in the EU NRMM Regulation. It contains, according to EMEP NFR codes: Mobile combustion in manufacturing industries and construction, railways, pipeline transport, commercial and institutional mobile, mobile household and gardening, agriculture, forestry and fishing, other mobile, including military, land based and recreational boats. However, possible deviations are not considered as relevant for the conclusion presented.

[14] Pease note that uncertainties are associated with all emission estimates. For example, Jörß et al. studied uncertainties of the carefully designed German PAREST inventory and concluded that these are for NO_x at about 10 to 12%, PM_{10} at about 14 to 15 and $PM_{2.5}$ at about 15 to 16 %, see Jörß, W. und V. Handke (2010**):** Unsicherheiten der PAREST-Referenz-Emissionsdatenbasis. Forschungs-Teilbericht an das Umweltbundesamt, im Rahmen des PAREST-Vorhabens: FKZ 206 43 200/01 „Strategien zur Verminderung der Feinstaubbelastung", Berlin: IZT.

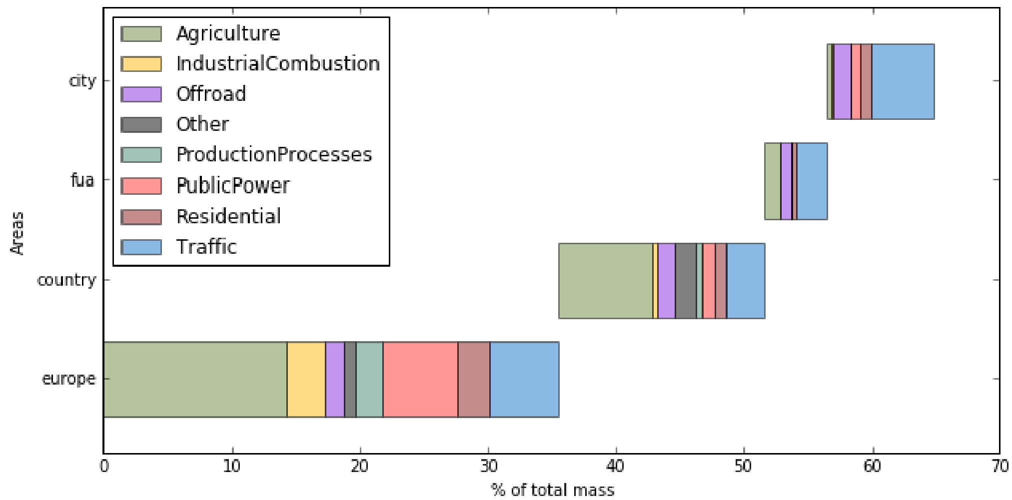


Figure 2-3 Contribution of different areas to total PM mass

Diegmann et al. (2015) studied the source contribution of 242 polluted areas Germany up to the end of 2012. Key findings are:

- For NO_2 the spatial contributions were 10 % for the regional background (range 10 to 48 %), 30 % for the urban background (range 0 to 58 %) and 47 % for additional sources (range 18 to 82 %). With regard to the sources the following contribution are identified: Long-range transport mean 23 % (range 10 % to 48 %), road transport mean 61 % (range 31 % to 86 %), industry mean 4 % (range 0 to 14 %), domestic sources mean 8 % (range about 2 % to 32 %) and other transport, including rail and inland waterways, no mean due to too little data, but range from about 0 % to 12 %. Too little data are available for the NRMM contribution, but the range of data at hand is 1 % to 25 %. Local road traffic is named as the biggest polluter in 68 % of the cases with 46 % having at least 50 % from this source group.
- For PM_{10} the spatial contributions show that the mean values were 52 % for the regional background (range 30 to 72 %)[15], 22 % for the urban background (range 3 to 45 % and 26 % for additional sources (range 8 to 45 %). Moreover, with regard to the sources the following contribution was identified: Long-range transport mean 51 % (range 30 % to 72 %), road transport mean 34 % (range 3 % to 53 %), industry mean 6 % (range 3 to 30 %), domestic sources mean 9 % (range about 0 % to 29 %) and other sources, including NRMM, mean 1 % (range about 0 % to 1 %).

Although the source category definition differs compared to those by Diegmann et al. (2015) this general picture of a significant variability was also found by Thunis et al. (2017)[16] for $PM_{2.5}$.

The findings correspond also to the results of European Environment Agency (2013b), where, regarding PM_{10}, there were differences in the ranking of sources by the cities that reported on the contribution of sources to exceedances. All of the cities identify traffic as the main source of PM_{10}. Commercial and

[15] the regional background was identified as the biggest contributor in 81 % of the cases with 52 % having at least 50 % from this source group.

[16] In the Thunis study NRMM fall under "Other sources" which include, apart from non-road mobile machinery, emissions from outside the EU and international shipping. Therefore, the source category "Other sources" cannot be compared with the source category definition used in the Table 2-1 and it therefore left aside. This, however, does not change the conclusion that there is a high variability among cities in the EU with regard to the contribution of different sources to total $PM_{2.5}$.

residential sources are placed either in second (Berlin, Milan, Vilnius) or third (Paris, Prague) place, with the exception of Ploiesti, where it is not considered a main source. Regarding industry, Paris and Ploiesti identify it as a main contributor to PM_{10} levels, while for Prague it is the least important contributor. Milan is the only city to consider agriculture as a main source of PM_{10}. And finally, Milan also considers natural sources to be a contributor to PM_{10}, albeit the smallest contributor.

The city core's own contribution to annual $PM_{2.5}$ concentrations (at its location with the highest concentration) is on average (over the 84 considered cities) around 26 %. The largest contributions are found in Milan (57 %) the lowest contributions in Burgas (6 %). In general, local emissions are a significant contributor to annual PM concentrations in the largest EU cities, stressing the importance of local air quality planning.

At the greater city scale (city core plus commuting zone), its contribution to annual $PM_{2.5}$ concentrations at the worst spot in the city is on average (over all 150 cities) around 31 %. The largest contributions are found in Paris (66 %) the lowest in Nicosia (6 %).

The contribution from the entire country (including city core and commuting zone) to annual $PM_{2.5}$ concentrations at the worst spot in the city is on average (over all 150 cities) around 56 %. The largest contributions are found in Milan (89 %) the lowest in Valletta (12 %).

Variations in the contributions of the sector NRMM to totals are also observed by individual city-related studies for the respective city level. The following Table 2-1 shows a few examples from a number of studies:

Table 2-1 Contribution of NRMM to total emissions

Contribution of NRMM to PM and NOx in European cities				
City	NO_x	PM_{10}	$PM_{2.5}$	Source
	% NRMM	% NRMM	% NRMM	
Berlin	14		16	AVISO 2016: Emissionskataster Berlin
London	6-10	9-11	14	GLA 2010, London Atmospheric Emissions Inventory
Stuttgart	14	6		Luftreinhalteplan/ Teilplan Stuttgart
Barcelona	12	2		APICE
Marseille	2	3	3	APICE
Thessaloniki	33	12	12	APICE
Venice	10	11	13	APICE
Madrid	13	3	4	Madrid Air Quality Plan 2011

All these studies show that individual air pollution abatement plans have to be developed. The impact of a given abatement measure on air quality differs from city to city, even for cities that are located in the same country. Actions taken at different scales or in different activity sectors therefore lead to impacts on air quality that is city-specific. Consequently, it is important to take into account these city-specific circumstances when designing air quality plans. Actions that are efficient in one city might not be efficient in others. This variability makes it difficult, if not impossible, to justify a general retrofitting measure for a – in many cases – relatively small a source category.

2.4 EU Clean Air Policy

2.4.1 Background

For decades the EU has been working to improve air quality. The overall objective is to reduce air pollution to levels which minimise harmful effects on human health and the environment over the whole EU territory.

The general policy approach is that EU legislation sets limits and targets on one hand but leaves on the other hand the choice of means to comply with goals agreed at EU level to the Member States. In addition, mandatory emission limits for new major source categories are set at EU level which support the national air pollution policies and contribute to the harmonisation of the common market.

For key sources of pollution, EU-level standards are applied to ensure efficient internal market functioning. More specifically, EU policy, as laid down in the 2013 Clean Air Programme for Europe (European Commission, 2013a), is based on:

- Ambient air quality standards set out in the Ambient Air Quality Directives (European Commission, 2004a; European Commission, 2008) for ground level PM, NO_2 and O_3 and a number of other pollutants[17]. These air quality standards were to be attained by all Member States across their territories from – depending on the pollutant – 2005 or 2010 onwards. If the set limit values are exceeded, Member States are required to adopt air quality plans detailing measures and to keep the exceedance period as short as possible. Air quality limit values are not set in stone and are time-by-time adapted to progress in science and research. For example, a fitness check is currently looking at the performance of the two complementary EU Ambient Air Quality (AAQ) Directives (Directives 2008/50/EC and 2004/107/EC). The findings of the fitness check will be presented in 2019/20 and will be used to assess whether the AAQ Directives are fit for purpose.
- National emission reduction targets established in the National Emissions Ceiling Directive (NECD) for the most important trans-boundary air pollutants among which one finds NO_x and PM (European Commission, 2016b). The national emission reduction targets were recently revised to include new limits that need to be met in 2020 and 2030, and an additional pollutant – fine particulate matter ($PM_{2.5}$). Member States have to develop National Air Pollution Control Programmes by 2019 with a view to complying with their emission reduction commitments.

2.4.2 Human Health and Air Quality Directives (AQD)

Humans can be adversely affected by exposure to air pollutants in ambient air. In response, the European Union has developed an extensive body of legislation which establishes health-based standards and

[17] There is no ambient air limit value for black carbon. WHO concluded in 2015 (WHO Expert Consultation: Available evidence for the future update of the WHO Global Air Quality Guidelines) that the available body of scientific evidence needs to be reviewed. Whether a guideline should be produced, or some other form of recommendation that would stimulate more research and monitoring of BC, is something that should be discussed as an outcome of the revision at a later Stage.

objectives for a number of pollutants present in the air (AQD). As far as NO_2 and PM are concerned these standards and objectives are summarised in the Table 2-2 below (European Commission, 2008)[18,19].

Table 2-2 Air quality limit and target values for PM and NO_2

Pollutant	Concentration	Averaging period	Legal nature	Permitted exceedances each year
$PM_{2.5}$	25 µg/m³***	1 year	Target value entered into force 1.1.2010 Limit value entered into force 1.1.2015	n/a
NO_2	200 µg/m³	1 hour	Limit value entered into force 1.1.2010	18
	40 µg/m³	1 year	Limit value entered into force 1.1.2010*	n/a
PM_{10}	50 µg/m³	24 hours	Limit value entered into force 1.1.2005**	35
	40 µg/m³	1 year	Limit value entered into force 1.1.2005**	n/a

*Under Directive 2008/50/EU, the Member State can apply for an extension of up to five years (i.e. maximum up to 2015) in a specific zone. The request is subject to an assessment by the Commission. In such cases within the time extension period the limit value applies at the level of the limit value + maximum margin of tolerance (48 µg/m³ for annual NO_2 limit value).
**Under Directive 2008/50/EU, the Member State was able to apply for an extension until three years after the date of entry into force of the new Directive (i.e. May 2011) in a specific zone. The request was subject to assessment by the Commission. In such cases within the time extension period the limit value applies at the level of the limit value + maximum margin of tolerance (35 days at 75µg/m³ for daily PM_{10} limit value, 48 µg/m³ for annual PM_{10} limit value).
***Standard introduced by Directive.

Directive 2008/50/EC introduced additional $PM_{2.5}$ objectives targeting the exposure of the population to fine particles. These objectives are set at national level and are based on the average exposure indicator (AEI), see Table 2-3 below. This is determined as a 3-year running annual mean $PM_{2.5}$ concentration averaged over the selected monitoring stations in agglomerations and larger urban areas, set in urban background locations to best assess the $PM_{2.5}$ exposure of the general population.

[18] In practical terms the pollutant regulated is defined by the measurement method applied. The reference method for the measurement of nitrogen dioxide and oxides of nitrogen is that described in EN14211:2005 'Ambient air quality — Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence'. *Reference method for the sampling and measurement of PM_{10}.* The reference method for the sampling and measurement of PM_{10} is that described in EN 12341:1999 'Air Quality — Determination of the PM_{10} fraction of suspended particulate matter — Reference method and field test procedure to demonstrate reference equivalence of measurement methods'. *Reference method for the sampling and measurement of $PM_{2,5}$* The reference method for the sampling and measurement of $PM_{2,5}$ is that described in EN 14907:2005 'Standard gravimetric measurement method for the determination of the $PM_{2,5}$ mass fraction of suspended particulate matter'.
[19] Note that in the near future aspects of occupational health could also become more relevant for retrofitting. On 16 January 2019, the Directive (EU) 2019/130 on the protection of workers from the risks related to exposure to carcinogens or mutagens at work was published. The Directive sets an exposure limit value to diesel engine exhaust fumes of 0.05 mg/m³ measured as elemental carbon. This limit value will enter into force 2 years after the end of the transposition period, and 5 years after the end of the transposition period for the sectors of underground mining and tunnel construction. Retrofitting existing machinery could be an option to comply with the Directive.

Table 2-3 Exposure concentration obligation and exposure reduction target for $PM_{2.5}$

Title	Metric	Averaging period	Legal nature	Permitted exceedances each year
$PM_{2.5}$ Exposure concentration obligation	20 µg/m³ (AEI)	Based on 3-year average	Legally binding in 2015 (years 2013,2014,2015)	n/a
$PM_{2.5}$ Exposure reduction target	Percentage reduction + all measures to reach 18 µg/m3 (AEI)	Based on 3-year average	Reduction to be attained where possible in 2020, determined on the basis of the value of exposure indicator in 2010	n/a

Under EU law a limit value is legally binding from the date it enters into force subject to any exceedances permitted by the legislation. In case of violations of the target value Member States have to take all necessary measures not entailing disproportionate costs in order to ensure that the target value is attained, and so it is less strict than a limit value.

The air quality survey in the European Union shows, that air quality has generally improved over the last decades. Nevertheless, the air quality is still of major concern (Diegmann et al., 2015; European Environment Agency, 2017a; European Environment Agency, 2018a):

- With regard to NO_2 22 of the EU 28 Member States recorded concentrations above the annual limit value (in more than 130 cities); 89 % of all values above the annual limit value, were observed at traffic stations.
- PM_{10} concentrations continued to be above the EU limit value in 18 Member States. There were 19 % of stations with concentrations above this daily limit value for PM_{10} in 20 Member States; 95 % of those stations were either urban (78 %) or suburban (17 %).
- $PM_{2.5}$ concentrations were higher than the limit value in eight Member States. These values above the limit value occurred primarily (93 % of cases) in urban or suburban areas.

Consequently, concentrations of and NO_2 and PM_{10} continued to exceed the EU limit values in large parts of Europe in recent years.

More specifically, as far as NO_2 is concerned, the limit values were violated in:

- Germany – in 26 air quality zones annual concentrations reported in 2016 were as high as 82 µg/m³ against a limit value of 40 µg/m³ (in Stuttgart);
- France – in 12 air quality zones annual concentrations reported in 2016 were as high as 96 µg/m³ (in Paris);
- the United Kingdom – in 16 air quality zones annual concentrations reported in 2016 were as high as 102 µg/m³ (in London).

More specifically, as far as PM_{10} is concerned, violations of the limit values occurred in:

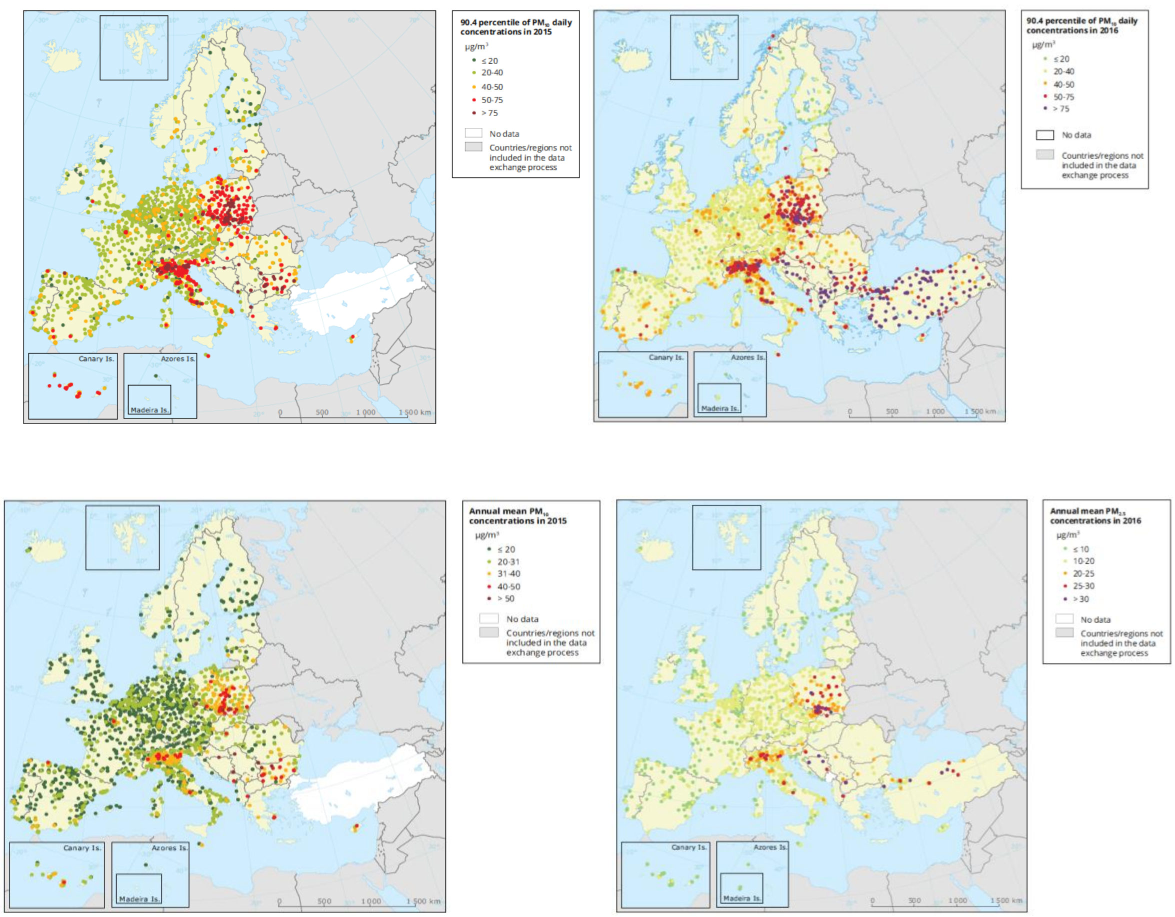
- Italy – in 28 air quality zones the daily limit values have been persistently exceeded, in 2016 on up to 89 days;

- Hungary – in 3 air quality zones the daily limit values have been persistently exceeded, in 2016 on up to 76 days;
- Romania – in the agglomeration of Bucharest, the daily limit values have been persistently exceeded, ever since the EU law became applicable to Romania, and in 2016 on 38 days.

In total, there are 13 infringement cases pending against Member States on persistent exceedances of NO_2 levels (Austria, Belgium, the Czech Republic, Germany, Denmark, France, Spain, Hungary, Italy, Luxembourg, Poland, Portugal, and the United Kingdom).

The European Commission has been pursuing infringement procedures for persistent excessive particulate matter (PM_{10}) levels against 16 Member States (Belgium, Bulgaria, the Czech Republic, Germany, Greece, Spain, France, Hungary, Italy, Latvia, Portugal, Poland, Romania, Sweden, Slovakia and Slovenia).

The following charts, taken from the EEA (European Environment Agency, 2017a; European Environment Agency, 2018a), show the air quality situation in the EU in 2015 and 2016, see Figure 2-4. It indicates that violations are still wide-spread but that PM and NO_2 violations concentrate to a certain extend on different parts of the EU, although there are cities which suffer under both: high PM and high NO_2 concentrations. However, the pictures show as well that air quality improved somewhat between 2015 and 2016, a trend observed since many years.



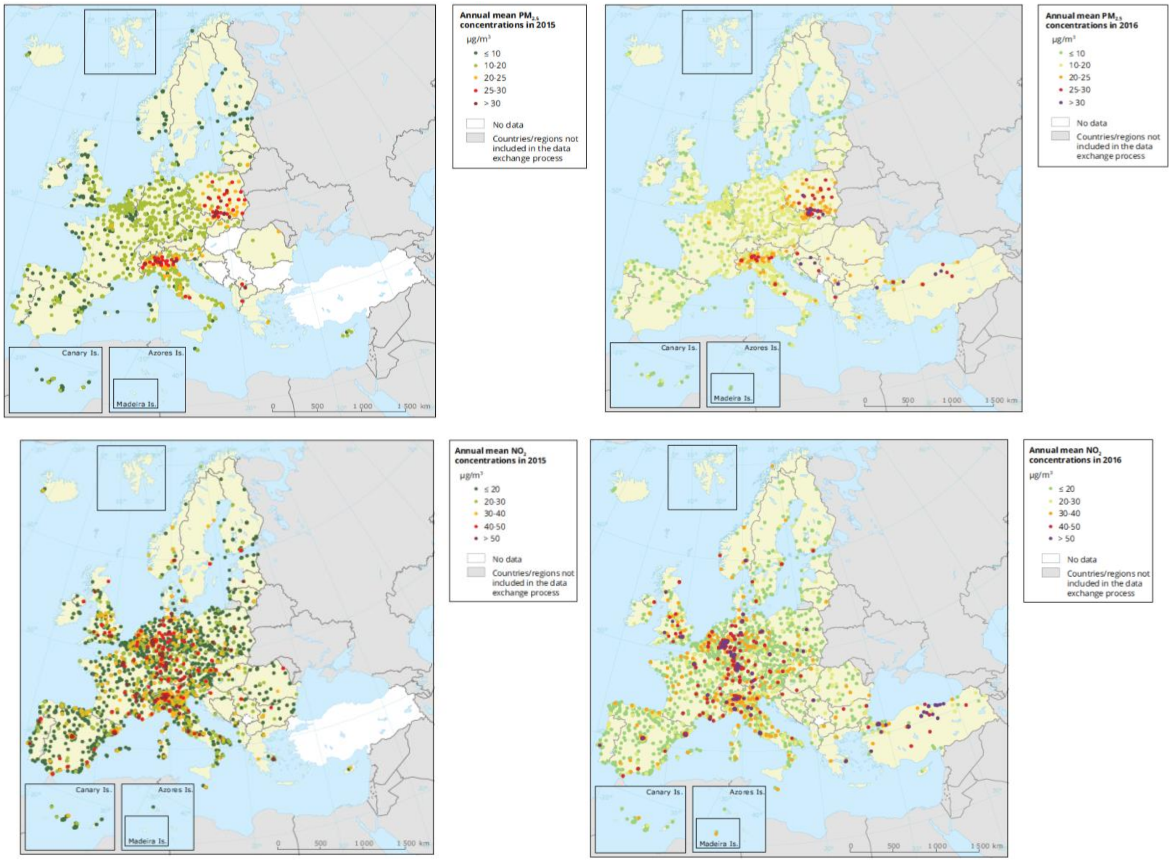


Figure 2-4 Air quality situation of the pollutants PM and NO_2 in 2015 and 2016 in the EU

Violations of the air quality limits occur since many years[20]. In May 2018 the EU Commission has been referring France, Germany, Hungary, Italy, Romania and the United Kingdom to the Court of Justice of the EU for failing to respect agreed air quality limit values and for failing to take appropriate measures to keep exceedance periods as short as possible:

- France, Germany, and the United Kingdom are referred to the Court of Justice of the EU for failure to respect limit values for NO_2;
- Hungary, Italy, and Romania are referred to the Court of Justice over persistently high levels of PM_{10}.

In 2017 and 2018, respectively, the Court of Justice of the EU has already handed down judgments on two of the most severe particulate matter exceedances in Europe, namely in Bulgaria and Poland.

More recently, on 24 January 2019, the Commission urged Greece to comply with the EU ambient air Directive and called on France and Sweden to bring their national air quality legislation in line with the rules of Directive 2008/50/EC.

In all cases of exceedance of limit values set by EU law on ambient air quality Member States have to adopt Air Quality Plans and ensure that such plans set appropriate measures so that the exceedance period can be kept as short as possible. Guided by the principle of subsidiarity, EU legislation gives Member States the choice of which means to use to comply with the limit values.

[20] The limits set out under EU legislation on ambient air quality had to be met in 2010 and 2005, respectively.

Since the legal proceedings are lengthy, some of the cases delivered by the Commission to the Court of Justice might turn out of no substance anymore. Germany, for example, improved PM_{10} air quality significantly and is now nearly in full compliance, see Figure 2-5. This might also be the case in some other Member States against which cases have been opened.

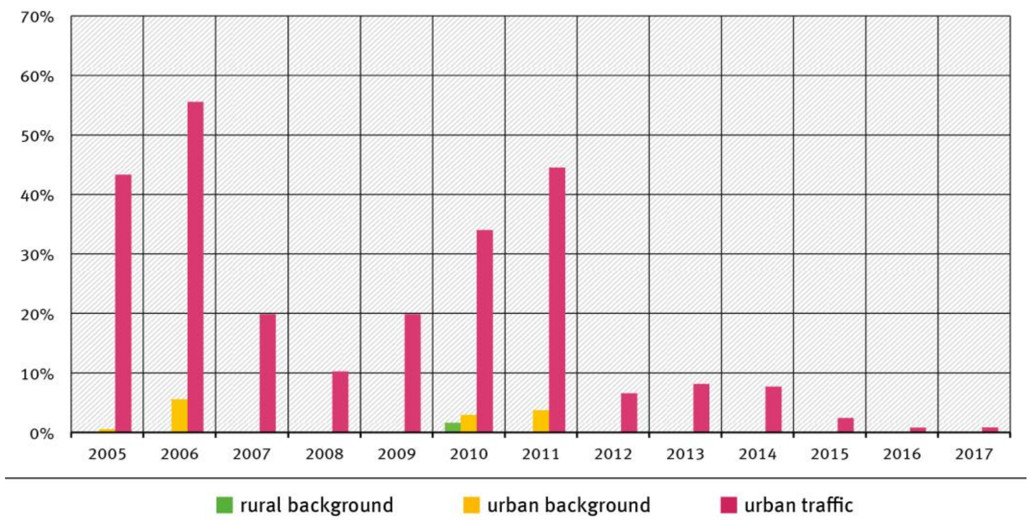


Figure 2-5 Percentage share of PM_{10} stations in Germany exceeding the EU limit values in recent years

Nevertheless, in a recent publication the European Court of Auditors (2018) concluded that EU action to protect human health from air pollution had not delivered the expected impact. The ECA underlined that the significant human and economic costs have not yet been reflected in adequate action across the EU and that Air Quality Plans often did not deliver the expected results. Despite the Commission taking legal action against many Member States with a favourable outcome, Member States continue to frequently breach air quality limits. Many EU policies have an impact on air quality, but, given the significant human and economic costs, the ECA considers that some EU policies do not yet sufficiently reflect the importance of improving air quality. The ECA report makes recommendations to the European Commission aimed at improving air quality.

Recommendations cover more effective actions which should be taken by the Commission; the update of the Ambient Air Quality Directive; the prioritisation and mainstreaming of air quality policy into other EU policies; and the improvement of public awareness and information.

2.4.3 The National Emissions Ceilings Directive

The NECD (European Commission, 2001)[21] and the Gothenburg Protocol (UNECE, 1979) set emission ceilings for 2010 for European countries for a number of pollutants, including NO_x. The 2012 amended Gothenburg Protocol (UNECE, 2012) and the new NECD (European Commission, 2016b)[22] set 2020

[21] The NEC directive is the key legislation for the achievement of towards the achievement of the long-term objectives of not exceeding the so-called critical loads, and of effective protection of human health against risks from air pollution, as laid down in the EU's Fifth and Sixth Environmental Action Programmes, as well as for attaining the EU air quality standards for a number of pollutants, including NO_2, particles (PM_{10} and $PM_{2.5}$) and ground-level ozone.

[22] The new NECD replaces the existing one from 2001 by keeping the current 2010 emission caps in place up to 2020, after which they will be replaced by percentage emission reduction commitments (ERCs) for 2020, in line with those already adopted in 2012 under the LRTAP Convention’s Gothenburg Protocol.

emission reduction commitments for a number of pollutants, including NO_x and primary $PM_{2.5}$ emissions. Moreover, it sets more ambitious reduction commitments for 2030 and the years beyond.

The driving force for the NECD is the reduction of critical loads which is, inter alia, partly caused by NO_x emissions. In fact, three-quarters of EU ecosystems are currently exposed to more nitrogen deposition than they can cope with and nearly one-tenth is still receiving too much acid fallout (Hettenlingh et al., 2017).

In 2015 six Member States (Austria, Belgium, France, Germany, Ireland and Luxembourg) exceeded their NO_x ceilings, with Austria and Luxembourg exceeding the most, by 26 and 29 per cent, respectively (European Environment Agency, 2017b).

On top of reporting past emissions, Member States must also report projected emissions for future target years, in order to assess whether or not they are on track towards meeting their reduction commitments for 2020 and 2030. According to the projections reported some countries seem not on track to meet their reduction commitments set for 2020 for one or more of the five pollutants. Moreover, about 22 Member States seem not on track for one or more of their 2030 commitments.

Following the new NEC Directive, Member States have to produce and report by April 2019 national air pollution control programmes (NAPCP) that set out the additional emission abatement measures needed to achieve their future emission reduction commitments.

In the NECD fixed kiloton emission ceilings were set based on a proposal from the Commission and the agreed reduction targets in the 1999 Gothenburg Protocol. Improved emission inventory methodologies, updated and improved emission factors and the inclusion of new sources have in some cases led to increased reported emissions. The changed methodology contributes to the non-compliance of several of the Member States in this study. The NECD provides no mechanism to compensate for this, which may constitute a disincentive for improving inventories, and could inhibit ambitions for setting future reduction commitments.

It should be mentioned that some non-road mobile machinery sources were omitted by some Member States at the time the ceilings were set. Germany also notes that the EU level emission standards for non-road mobile machinery were delayed and inadequate, which delayed and weakened potential NO_X reductions in this sector (Clark et al., 2013).

2.4.4 Climate Change

A number of air pollutants are also climate forcers, which have a potential impact on climate and global warming in the short term (i.e. from less than a year to a few decades). Linked to PM and NO_x emissions, O_3 and BC are examples of air pollutants that are short-lived climate forcers that contribute directly to global warming[23].

The IPCC's fifth assessment report (IPCC, 2014) sums up estimates for some such forcers, in mean watts per m^2 for the years 1750–2011 (+ means warming, - cooling)[24],see Figure 2-6.

In addition, the new NECD establishes more far-reaching legally binding ERCs to be achieved by 2030, as well as intermediate reduction targets for 2025. The latter are defined by a linear trajectory between the emission levels in 2020 and 2030. While the 2001 NECD covered, inter alia, NO_x the new one was to be extended to also cover fine particulate matter ($PM_{2.5}$). The ambition level of the Commission's proposal for a new NECD was to cut EU-wide emissions of NO_x by 69 per cent and $PM_{2.5}$ by 51 per cent by 2030, compared to the emission levels in the base year 2005.

[23] Ozone is not considered further in any detail since the actual contribution of NRMM emission to O_3 formation is difficult to determine.

[24] Please note that the uncertainties are considerable.

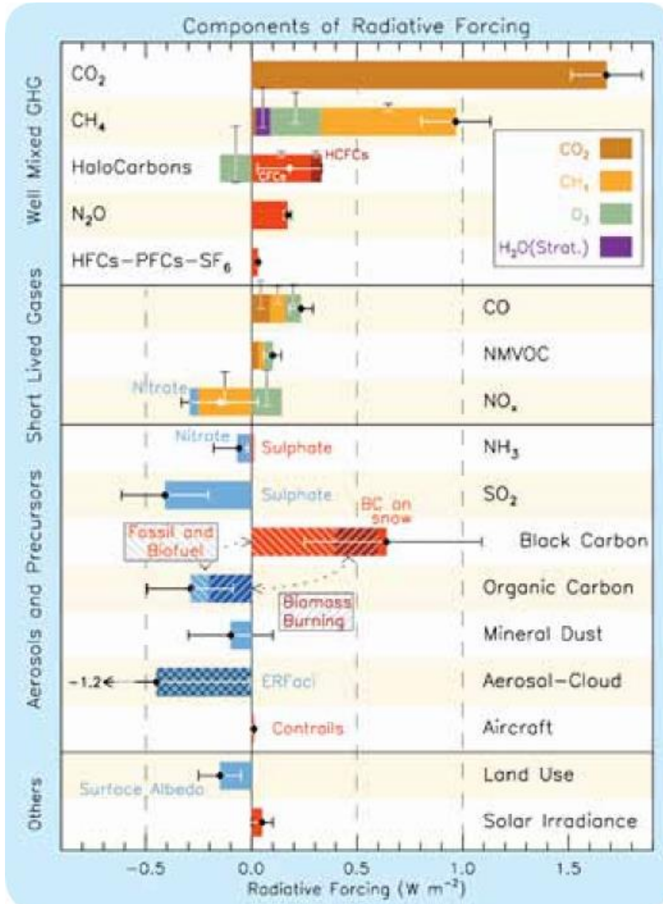


Figure 2-6 Components of radiative forcings[25]

NO_x has both warming and cooling effects. Overall, the cooling effect appears to be dominant.

PM in general, including components, such as organic carbon, ammonium (NH_{4+}), sulphate ($SO4_{2-}$) and nitrate (NO_{3-}), are strong light-scatterers and produce a cooling effect, so that the overall effect of PM is cooling rather than warming.

Black carbon, however, includes strongly light-absorbing material and is thought to yield large positive radiative forcing. BC causes warming through absorption of sunlight and by reducing surface albedo when deposited on snow. BC also affects clouds, with a consequent impact on their distribution and radiative properties (Stohl et al., 2015). Black Carbon Is important to factor in since the arctic climate and glaciers are especially vulnerable to BC deposition because of its impact on the albedo, accelerating melting and increasing sensitivity to warming[26,27]. BC has received particular attention in recent years since emission reduction might have an immediate climate benefit. This has been underlined by the recently published special report of IPPC which modelled pathways that limit global warming to 1,5 °C (IPCC, 2018). These pathways include significant black carbon reductions of 35 % until 2015.

[25] IPPC 2013: AR5 WG 1
[26] Despite its importance, little is known about past natural or anthropogenic emissions of BC and its deposition.
[27] The response, however, is somewhat more complex since Arctic BC located at low altitudes causes a strong local surface warming, but BC located at higher altitudes causes a surface cooling.

The radiative forcing of BC is a function of the period considered: Figure 2-7 shows the GWP and the GTP[28] of several pollutants for different time intervals. Due to its limited lifetime in the atmosphere, BC makes a very important contribution when looking at the 10 years interval but a much lower when looking at longer time periods.

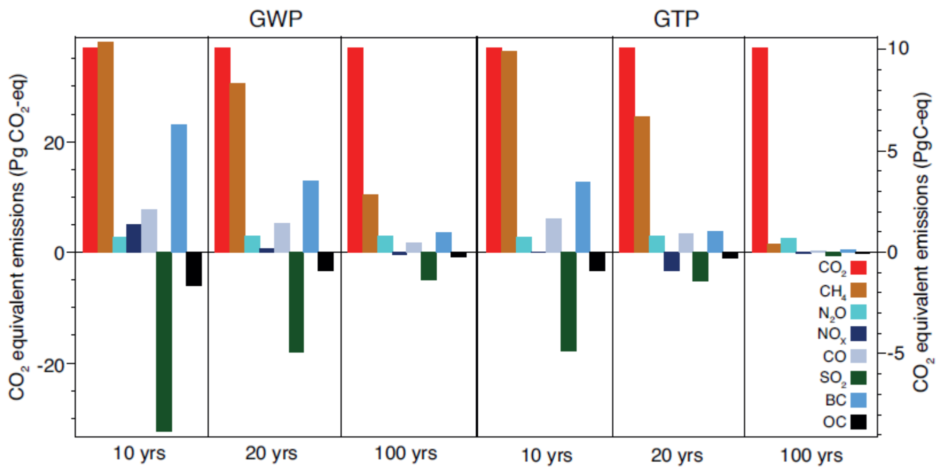


Figure 2-7 Global anthropogenic emissions weighted by GWP and GTP for different time horizons (aerosol-cloud interaction not included)

The Figure 2-8 shows BC emissions as a function of latitude as well as the major sources (Bond et al., 2013).

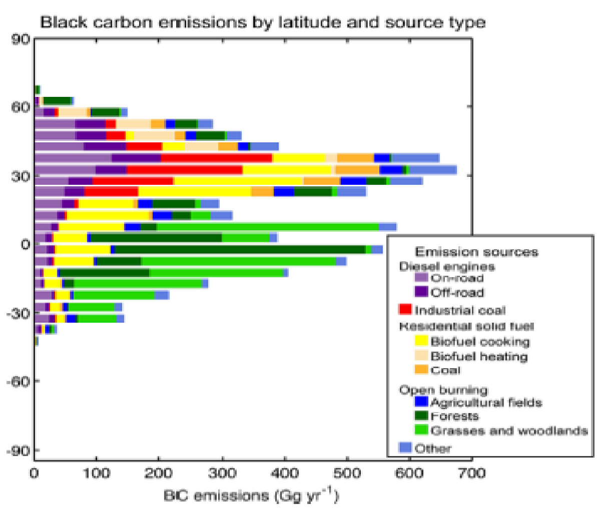


Figure 2-8 BC emissions by latitude and source type[29]

It indicates that emissions north of 40° latitude, i.e. including large parts of the EU, are of concern. According to this inventory off-road emissions contribute significantly to total BC emissions in the region

[28] GWP =Global Warming Potential equal to the integration of radiative forces for a chosen time horizon; GTP = Global Temperature Change Potential equal to the ratio of change in global surface temperature at a chosen point in time, relative to CO_2

[29] All these estimates however are subject to considerable uncertainty (Bond et al. 2013).

north of 40° latitude. The issue is addressed by the Arctic Council[30] which studies measures to reduce BC pollution (Kholod and Evans, 2016).

The non-road sectors appear also as of some relevance when looking at the net global mean temperature change by source sector, as shown in Figure 2-9.

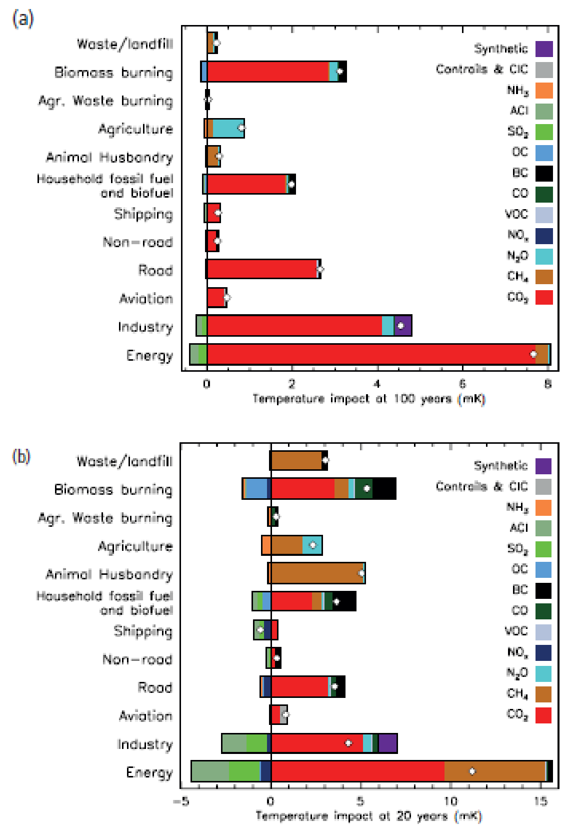


Figure 2-9 Net global mean temperature change by source sector for different time horizons (IPCC, 2013)

To calculate the data shown in Figure 2-9 one-year pulse emissions were taken and the temperature consequences after 20 and 100 years were determined.

Stohl et al. (2015) looking at the global BC emission did not identify NRMM as a major source of BC emissions, see Figure 2-10 below. For Stohl et al. (2015) reducing BC emissions from gas flaring is the most important measure to take, next to emission reductions from transport and from the residential/commercial sector.

[30] The Arctic Council is a high-level intergovernmental forum to provide a means for promoting cooperation, coordination and interaction among the Arctic states. Denmark, Finland and Sweden are members; many other EU Member States are observers.

Measures targeting BC reduction
Oil and gas industry: improving efficiency and reducing gas flaring
Transport: eliminating high-emitting vehicles (super-emitters)
Residential–commercial: clean biomass cooking stoves
Residential–commercial: replacement of kerosene wick lamps with LED lamps
Transport: widespread Euro VI emission standards (incl. particle filters) on diesel vehicles
Industrial processes: modernised (mechanised) coke ovens
Agriculture: effective ban of open-field burning of agricultural residues

Figure 2-10 Top ranking measures for BC reduction according to Stohl et al. (2015)

Other sources take a wider view and hint towards the high BC emissions of international shipping, e.g. Hansson et al. (2011). However, there are large uncertainties in BC emission estimates depending on the source and these uncertainties lead to a range of possible emissions. The uncertainty in the national emission inventory depends on the uncertainty in activity data and in emission factors. The share of exhaust BC emissions as part of $PM_{2.5}$ emissions varies and depends, inter alia, on the after-treatment systems applied. Estimates vary between 20 % - 60 % of $PM_{2.5}$ without exhaust after-treatment and 50 % - 70 % with after-treatment.

Finally, it should be mentioned that BC emission data are not officially collected under UNFCCC and the EU Greenhouse Gas Monitoring Mechanism (EU Member States) and are not included in the agreed reduction targets[31]. This can be taken as an indication that it is too early to call for a climate change related NRMM retrofitting policy.

2.4.5 Overview of Member States' air pollution problems

Taking into account the violations of the AQD and the NECD together as well as the contribution to BC emission into the Arctic region the following Table 2-4 shows MS' problems:

[31] Data compiled and held by EEA concern annual emissions of CO_2, CH_4, N_2O, HFCs, PFCs, unspecified mix of HFCs and PFCs, SF_6 and NF_3 from individual EU countries.

Table 2-4 List of Member States with regard to problems with NO_2/NO_x and PM/BC pollution

Member State	AQD	NECD	BC*
Austria	X	X	X
Belgium	X	X	X
Bulgaria			X
Cyprus			
Czech Rep	X		X
Denmark	X		X
Estonia			X
Finland			X
France	X	X	X
Germany	X	X	X
Greece			(X)
Hungary	X		X
Ireland		X	X
Italy	X		(X)
Latvia			X
Lithuania			X
Luxembourg	X	X	X
Malta			
Netherlands			X
Poland	X		X
Portugal	X		(X)
Romania	X		X
Slovakia			X
Slovenia			X
Spain	X		(X)
Sweden			X
UK	X		X

* () if only parts of Member States are within 40°N

In summary, nearly all EU Member States have problems with NO_2/NO_x and PM/BC pollution; only Cyprus and Malta seem to be free of any problems.

In the Impact Assessment accompanying the proposal for a new NRMM Regulation the Commission indicated that NRMM emissions will decrease in the coming years even without any additional measure taken, see Figure 2-11 and Figure 2-12 (European Commission, 2014a).

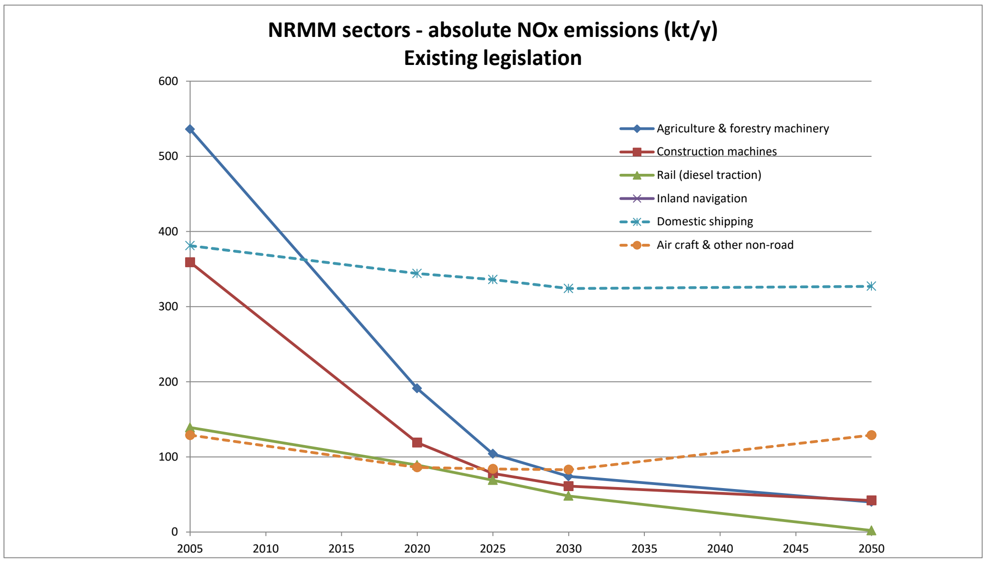


Figure 2-11 Predicted evolution of NO_x emission from the NRMM sector on the basis of pre-2016 legislation

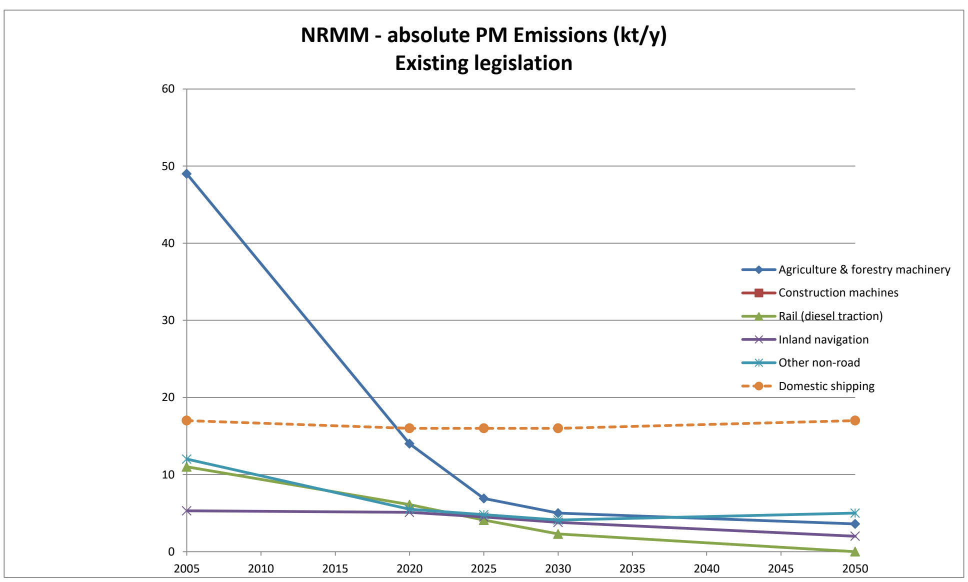


Figure 2-12 Predicted evolution of PM emission from the NRMM sector on the basis of pre-2016 legislation

This paper already predicted further reductions of PM emissions of the NRMM sector of more than 50 % from 2035 onwards due to the proposed more stringent emission limit values.

Very recently, Amann et al. (2018) presented an updated outlook for emissions and air quality in the European Union and explores the prospects of achieving the WHO guideline values to protect human health and the Union's long-term environmental policy objectives on the protection of ecosystems. Considering the interplay of all latest measures taken, including the new legislation on non-road mobile machinery, Amann et al. found that, for the EU 28 as a whole, by 2030 NO_x emissions will decline by 65 % and $PM_{2.5}$ by 51 %. However, the situation for individual countries differs. Additional measures are necessary in sub-sets of Member States, while for others implementation of latest legislation will lead to compliance. More specifically, the significant reductions in precursor emissions will reduce ambient $PM_{2.5}$ levels in the overwhelming majority of countries below the WHO guideline value of 10 µg/m^3. However, two areas in Europe will still face robust exceedances of the WHO guideline value, i.e. Northern Italy and Southern Poland. Also, for NO_2, substantial reductions in the number of stations registering annual average concentrations above 40 µg/m^3 are expected. While currently about 20 % of the nearly 2000 AIRBASE monitoring stations considered in the analysis are robust or possibly above this level, the implementation of the NEC Directive will reduce this percentage to almost zero.

In terms of mass NRMM emission will decrease as well and stay more or less stable in percentage terms, related to total emissions, for NO_x and will be cut by about 50 % for $PM_{2.5}$, see Table 2-5 and Table 2-6.

Table 2-5 Expected future emissions of NO_x

	2005	2030	2030	2030	2005	2030	2030	2030
	Kilotons	pre 2014 leg.	post 2014 leg.	post 2014 plus Climate	%	pre 2014 leg.	post 2014 leg.	post 2014 plus Climate
Power generation	2640	948	922	791	23	23	23	22
Domestic sector	704	528	528	437	6	13	13	12
Industrial combustion	1291	823	815	813	11	20	20	22
Industrial processes	233	169	169	168	2	4	4	5
Fuel extraction	3	1	1	1	0	0	0	0
Road transport	4846	1006	1006	906	42	25	25	25
Non-road mobile	1686	621	556	541	15	15	14	15
Waste treatment	6	2	2	2	0	0	0	0
Agriculture	7	7	7	7	0	0	0	0
Total	11416	4105	4006	3666	100	100	100	100

Table 2-6 Expected future emissions of $PM_{2.5}$

	2005	2030	2030	2030	2005	2030	2030	2030
	Kilotons	pre 2014 leg.	post 2014 leg.	post 2014 plus Climate	%	pre 2014 leg.	post 2014 leg.	post 2014 plus Climate
Power generation	127	46	44	41	7	4	5	5
Domestic sector	806	578	355	319	45	52	40	38
Industrial combustion	78	54	52	52	4	5	6	6
Industrial processes	182	147	147	148	10	13	17	18
Fuel extraction	6	3	3	3	0	0	0	0
Road transport	265	76	76	71	15	7	9	9
Non-road mobile	132	30	27	26	7	3	3	3
Waste treatment	70	68	68	68	4	6	8	8
Agriculture	110	106	106	106	6	10	12	13
Total	1776	1108	878	834	100	100	100	100

In summary, Amann et al. found that, broadly speaking, by 2030 the recent legislation will bring the NO_2 air pollution below WHO guidelines and for $PM_{2.5}$ within reach of WHO guidelines for most areas, while further efforts, especially for agricultural ammonia emissions and PM emissions from residential combustion of solid fuels will be required at hot spots. With regard to critical loads, the study shows that some countries will have to take additional measures to meet their emission ceilings for NO_x and $PM_{2.5}$.

2.4.6 Linking emissions and ambient concentrations or loads

Emissions and ambient air concentrations or loads are linked in a quite complex manner. However, it is not possible to address these relationships within the framework of this study. Some examples from the wide range of investigations are given to illustrate source-receptor relationships in order to facilitate political decision-making.

Kiesewetter et al. (2013). studied the effects of emission control measures on compliance with limit values at the local level (Kiesewetter et al., 2013). The study produced, inter alia, source-receptor relationships which show the concentration increase per kt NO_x or $PM_{2.5}$ emitted in a 7 km grid cell. The modelling results indicate that the relationships vary significantly. A particular emission reduction taken in one grid might result in very small improvements in air quality in one grid but in significant improvements in another grid. The Figure 2-13 below shows the results for NO_x and $PM_{2.5}$.

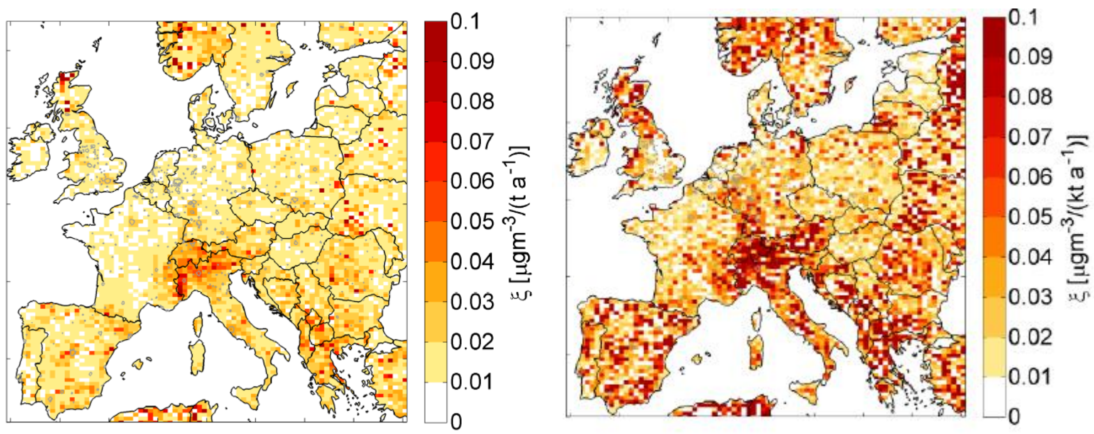


Figure 2-13 Change of ambient air concentrations of NO_x (left) and $PM_{2.5}$ (right) due to respective emissions reductions

However, within the grids the list of measures which can be taken depend not only on local measures. To give an example for Germany and NO_2, see Figure 2-14 below, measures on NRMM would mainly fall under the air mass category "urban background" and within this category it can deliver only a share. The air mass categories "regional" and "additional concentration" are the dominating parts (additional emissions are mainly road emissions) and without measures addressing these categories the air pollution problem cannot be solved. For PM, however, measures with regard to “regional background” and “urban background” could make a major contribution and solve some local air pollution problems.

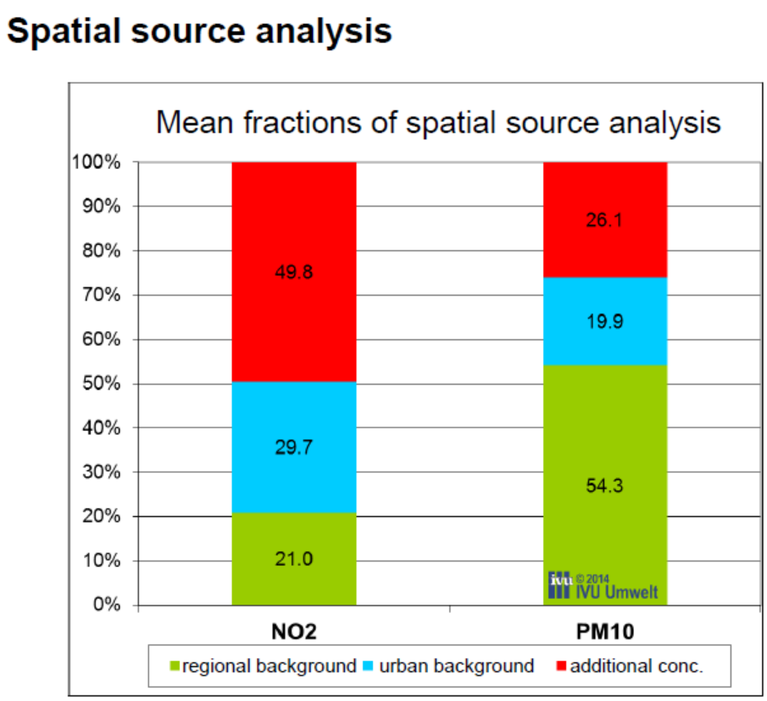
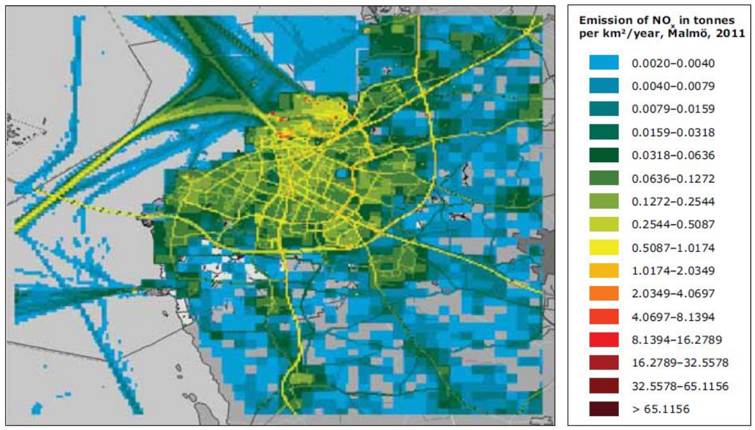


Figure 2-14 Contribution of different air masses to NO_2 and PM_{10} concentrations (IVU, 2014)

However, these are averages. Emission inventories for cities are much more complex, as shown for example for Malmö in Figure 2-15 (European Environment Agency, 2013a). NO_2, as well as PM exceedances often occur along streets. Consequently, a reduction of emissions in a 7 km*7 km grid does not automatically result in compliance with air quality limit values.



Source: Miljöförvaltningen, City of Malmö.

Figure 2-15 Emissions of NO_x in 2011, expressed in t/km^2 and year

Another example which underlines the fact that there is no general conclusion about the effectiveness of NRMM emission reduction measures is shown in Helms and Heidt (2014). They studied the effect of PM and NO_x emissions from NRMM at micro-level from a "standard" construction site. They found in case studies for Karlsruhe and Stuttgart that NRMM emissions contribute significantly to the calculated total PM_{10} concentrations (the sum of the background concentrations, the local exhaust gases through the construction site and motor vehicle traffic as well as particles from abrasion processes) and that in the immediate vicinity concentrations of about 70 $\mu g/m^3$ occur. Due to the influence of the construction site it is possible to exceed the daily average (50 $\mu g/m^3$), e.g. if the construction site is operated the full year. With regard to NO_2 in the immediate vicinity of the construction site the ambient NO_2 concentrations are similarly high or even higher than NO_2 concentrations in street canyons[32,33].

However, the influence of the additional emissions of the standard construction site vanishes rapidly with greater distance. Such a situation can happen in theory at many sites in the EU, even in grids, as identified by Kiesewetter et al. (2013), which are not very sensitive to NO_x or PM emission reductions. This might also the reason why the city of Zürich in its air quality reports does not mention the actual contribution the comprehensive Swiss retrofit policy made to local air quality[34]. While there is no doubt that the measure contributed to the improvement of air quality it is very difficult to identify the actual contribution to the avoidance of exceedances of hot spots.

[32]The German Federal Environment Agency stated in this respect that construction machines in the environment of construction sites have a significant share of the air pollution. Measures in this area would allow significant local reductions, especially in heavily polluted areas. Moreover, such measures also lead to a reduction in total emissions and background pollution. In the construction machinery sector, particulate emissions currently have a high environmental impact - partly due to the relatively high age of the machines, but also because of the fact that the emissions legislation at European level is lagging behind that for mobile machinery, which includes construction machinery. Therefore, it would make sense, on the one hand, to renew the machine fleets and, on the other hand, as far as possible, to retrofit all existing NRMM with DPF. Moreover, it is also worth considering retrofitting construction machinery with NO_x reduction technology.

[33] It should be noted that based on the date of the Helms study most of the equipment is likely to be Stage IIIA or earlier, i.e. without after-treatment. There have been significant (positive) changes in equipment fleets since that date.

[34] https://www.stadt-zuerich.ch/gud/de/index/umwelt_energie/luftqualitaet.html, see air quality reports.

The contribution of IWW vessels to air pollution differs significantly and is somewhat difficult to assess. Total emissions of NO_x and PM from inland waterway vessels are relatively small. Nevertheless, special situations might occur in cities located at heavily frequented rivers like the river Rhine[35]. However, the assessment of the situation gives different signals. Local air quality plans and studies (Bezirksregierung Köln, 2012; Korsten, 2018) suggest that the emissions of inland waterway vessels might contribute significantly to ambient air concentrations of $PM_{2.5}$[36]. A recent local air quality study (Korsten, 2018) suggests that the emissions of inland waterway vessels might contribute significantly to ambient air concentrations of $PM_{2.5}$. However, another study identified only a very small contribution of less than 1 µg/m³ to local air pollution problems in the area Cologne and Berlin (Lohmeyer, 2013) (similar findings are available for other parts of the river Rhine). This finding is in conflict to the views of some local air pollution authorities in Nordrhein-Westfalen and Berlin which – being in the position that all possible measures have to be taken in order to meet the air quality limit values - consider emissions from inland water vessels as a relevant source. NO_x emissions from inland waterway transport in cities such as Bonn or Düsseldorf can contribute up to 30 percent of total local NO_x emissions. However, the recently published AQP for Düsseldorf does not mention inland waterway vessels as a major source; measures in this sector concentrate on shore power supply for anchoring vessels [37]. This is more in line with, as in the case of PM, studies of the German Federal Institute of Hydrology which show that the average additional NO_2 load which is caused by the NO_x emissions vanishes quickly with distance from the fairway. At a distance of 200 meters from the shore, it is already below 5 µg/m³, resulting in a contribution of inland vessels to the NO_2 pollution below 10 percent at typical inner-city traffic-related measuring stations of cities like Cologne or Düsseldorf.

The relevance of emissions from railcars (and locomotives) to air pollution is not very clear either and differs among EU Member States, but also among cities. On average, about 20 % of Europe's current rail traffic is hauled by diesel locomotives. Some EU countries – such as the UK, Greece, Estonia, Latvia and Lithuania – are highly dependent on diesel traction[38]. Although only about 50 % of the tracks are electrified in the EU[39] the contribution to total emissions of NO_x and PM from this sub-sector is relatively small. Local air quality investigations in the EU which look at the specific contribution of railcars and locomotives are quite rare. EUROMOT (2006) concluded in a 2006 study that shunting yards may be important contributors to NO_2 concentrations and terminal stations may be significant contributors to NO_2 and PM_{10} concentrations. In 2005, as part of the diesel rail study, Hobson (2005) studied the contribution of rail diesel exhaust emissions to local air quality and concluded, based on pollutant dispersion modelling, even at very busy line sections the increase of NO_2 and PM concentrations is insignificant. More relevant are emissions from very busy shunting yards and at large terminal stations with a high amount of diesel activity. In 2014 Fuller et al. studied the impact of railway emissions to the air pollution in London (Fuller et al., 2014). Fuller et al. (2014) concluded on the basis of real-world measurements that no a clear pollution signal from the diesel trains could be detected (in fact, only small increments were found in the concentrations of NO_X, PM_{10} and BC) and that diesel trains do not make a large contribution to local air pollution concentrations. Nevertheless, there is no reason to believe that emissions from railcars or locomotives never contribute in a significant form to hot spots, e.g. in the vicinity of railway stations and along lines heavily frequented by diesel powered railcars or locomotives. Moreover, it should be mentioned

[35] It should also be noted that around 9 out of 10 inland waterway vessels in the EU are registered in Belgium, the Netherlands, Germany and France, where the environmental impacts are more intense, due to a higher concentration of the population along waterways.
[36] See: https://www.lanuv.nrw.de/umwelt/luft/luftreinhalteplanung-in-nrw/
[37] Bezirksregierung Düsseldorf: Luftreinhalteplan Düsseldorf 2018; see https://www.duesseldorf.de/umweltamt/umweltthemen-von-a-z/luft/luftreinhalteplan.html
[38] See EU-funded CleanER-D project
[39] The quota differs from country to country, e.g. it is currently at 51 % in France, at 60 % in Germany, in Austria is at 70 %, in Sweden and the Netherlands at 76 % etc.

that railway transport is a source of other emissions, even if fully electrified, as well, e.g. wear particles from brake systems, wheels, rails, overhead wires and pantographs (Gustafsson et al., 2007). The fact that PM pollution due to wear is also a matter of rail transport was recently demonstrated in the subterranean S-Bahn network of the city of Stuttgart. In part, the measured particulate matter concentrations were much higher than at a busy crossroads[40].

Another important aspect to consider are the meteorological conditions which can play an important role in the short-term or year-to year changes of ambient concentrations and loads. This can be episodes or general unfavourable conditions. As a rule, there are no easy measures at hand to reduce air pollution within episodes within short delays.

Moreover, cities located in valleys or in regions with hampered exchange of air masses suffer under the accumulation of pollutants.

Finally, some harbours face special problems, in particular with emissions from sea-going ships. For example, while inland waterway vessels contribute to 6 % of total emissions of ships in Hamburg (the second largest inland waterway harbour in Germany), sea-going ships contribute to about 78 %, most of it emitted while anchoring[41]. In total NO_x emissions of sea-going ships is higher than those of road transport and corresponds to about 40 % (for comparison NRMM contributes to about 2 %, but this part of the inventory is under review). Sea-going ships NO_x contribution is higher than the contribution of sea-going ships to total PM emissions which is about 16 % in the City of Hamburg, to be compared with about 1,5 % coming from NRMM. In summary, it can be assumed that due to the high emissions of sea-going ships the contribution of NRMM is minor in harbours.

2.5 Conclusions

The findings of this chapter allow drawing a number of conclusions relevant for the subject under investigation:

- NO_x and PM emissions still cause major environmental problems, including breaches of air quality limit and target values and critical loads; BC emissions are also of concern, in particular for the Arctic region.
- The general policy approach is that EU legislation sets limits and targets on one hand but leaves on the other hand the choice of means to comply with goals agreed at EU level to the Member States. In addition, mandatory emission limits for new major source categories are set at EU level which support the national air pollution policies and contribute to the harmonisation of the common market. EU measures on existing sources are rare.
- Violations of the air quality limit values laid down for NO_2 and PM occur in cities and highly populated regions. PM and NO_2 violations concentrate to a certain extend on different parts of the EU, although there are cities which suffer under both: high PM and high NO_2 concentrations;
- In tendency breaches of the NO_2 limit value are of greater relevance since these are still relatively high in number while the number of violations of the PM limit values seems to be declining.
- Emissions of NO_x and PM in total as well as the contribution of the sub-source NRMM vary at national, regional and local level. In some cases, NRMM emissions are a significant source of NO_x, often as well of PM and BC.
- There is no doubt that additional emission reductions are needed. However, for PM and NO_2 the actual contribution emissions reductions of the NRMM sector could make depends on local and regional conditions. This variability in terms of sectoral impact, even within a single country, calls

[40] Focus Monday 04.06.2018, 15:19
[41] Luftreinhalteplan für Hamburg (2. Fortschreibung)

for targeting NRMM retrofitting measures, if desired, at improving air quality at regional or city level.

- Emission reductions of BC would be in general beneficial for the environment due to its impact on climate change. Although BC emissions are a significant part of total PM emissions of NRMM they play a less important role in the current discussions. This might be partly caused by the fact that there are still uncertainties associated with the emissions and the effects on BC.
- With regard to NRMM emissions the Regulation (EU) 2016/1628 makes a significant contribution to emission reductions, harmonising at the same time the market for NRMM.
- The air quality situation does not support general EU-wide NRMM retrofitting measures, as the potential contribution of NRMM retrofitting measures to improving air quality is too varied; an EU measure cannot make an optimal contribution, but the situation needs to be assessed at regional or local level.
- Currently a fitness check is looking at the performance of the EU Ambient Air Quality Directives. The findings of the fitness check will be presented in 2019/20 and will be used to assess whether the AAQ Directives are still fit for purpose. A change of the air quality requirements could have an impact on the conclusions of this report.

3 Measures taken at Member State, State or local level

3.1 Introduction

EU Member States are required to maintain the levels of air pollutants below the defined air quality standards or agreed national emission levels, and to take action in order to comply with the adopted standards. In order to reduce air pollution effects, particularly in cities where the majority of the European population lives, it is important to define effective planning strategies for air quality improvement.

More specifically, the ambient air quality Directive (European Commission, 2008) requires Member States to have air quality plans (AQP) to keep exceedances as short as possible. The AQP should include:

- General information and details on measuring stations;
- Nature and assessment of pollution, including trends;
- Techniques used for air quality assessments;
- Origin of pollution, including source apportionment;
- Details of measures and estimate of improvement of air quality and the expected time required.

AQP should be established for the air quality zone(s)[42] in exceedance, outlining the methods, steps, and measures to be undertaken in order to bring the air pollutant concentration levels below the standards that were exceeded. Moreover, the formulation and implementation of an AQP should imply the prioritizing of the sources that need to be tackled.

Reducing NO_x or PM emissions requires the active involvement of policy makers at the EU, the national and regional levels. Local-level authorities typically implement individual programs based on local needs and emission reduction targets. Central and local governments play a critical role in the development of coordinated campaigns and building stakeholder support for emission reductions.

However, the complexity of the issue which includes varying contribution of sources (national, regional, local), which are partly not all well identified and understood, atmospheric transport including chemical and physical processes and varying geographical and meteorological conditions, as shown in chapter "Air pollution problems", is also mirrored by the measures actually taken by Member States, regions or cities. Moreover, it is inherently difficult to determine isolated effects of a measure by measurement data. This means it is often difficult to verify the efficiency of an individual measure taken.

Local authorities report also problems with regard to the administrative capacity available, the coordination with neighbouring regions and the fact of limited jurisdiction.

The Commission is aware of these problems; European institutions support the development Air Quality Plans actively (European Environment Agency, 2013c).

In a Pilot study the EEA studied the implementation of air quality policy in 12 European cities, and thereby draw lessons of wider relevance (European Environment Agency, 2013a). The lessons learnt from this exercise are:

[42] These zones are: The air quality (AQ) zone is a territorial unit, defined as 'a part of the territory of a Member State, as delimited by that Member State for the purposes of air quality assessment and management'. The 'agglomeration' is a special zone category. It is defined as 'a zone that is a conurbation with a population in excess of 250 000 inhabitants or, where the population is 250 000 inhabitants or less, with a given population density per km^2 to be established by the Member States'.

- Although 11 of the 12 cities have emission inventories, there is a great variety of methodologies used to compile these inventories. This variety means that the cities' emission inventories are often not comparable with one another, or with the emission inventories of the regions within which they are located. Cities have problems in appropriately quantifying different sources.
- Cities expressed the difficulties they encountered in trying to classify appropriately the monitoring stations according to the criteria in the directives, as these criteria seem to be quite generic.
- representativeness of stations (the spatial area over which the value measured at the station can be taken as meaningful).

Miranda et al. (2015) studied a number of these Plans and concluded, inter alia. that:

- at emission inventory level, much work still needs to be done at the urban scale. Consistency between emission inventories developed at different scales, based on both bottom–up and top–down approaches, is an objective not accomplished yet.
- efforts for the development of a consistent and flexible approach that allows cost–efficiently determining air quality levels and their impacts at urban/local scale are still required. In particular the effectiveness of both technical and non–technical measures in different spatial domains in a comprehensive multi–scale system has to be addressed, as well as the synergy between measures.

In summary, to develop sound AQPs is a complex task which still suffers under a number of shortcomings, as listed above. Nevertheless, Member States, regional and local authorities work actively, partly supported by European institutions, on these plans, wherever necessary, in order to comply with European legislation. Most important parts of the AQPs are measures designed to improve air quality. The measures have to take into account the appropriate level of decision making. Coordinating these measures at the different levels is one of the most difficult tasks. To achieve an overall cost-efficiency of all measures is nearly impossible.

3.2 List of measures against PM and NO_2 pollution

There are many proven measures to tackle air pollution, but the question is where they will be most efficient, at city level and if so in which city, or at a regional level, but then again which region? It is clear though that, in order to solve air quality problems, regional and trans-boundary policy coordination remains necessary. Local actions are an effective means of improving air quality, but this need to be supported by regional and national (sectoral) emission reductions.

3.2.1 PM measures

For PM understanding chemical regimes that drive the chemical processes in the atmosphere and a good knowledge of emissions are essential to promote the best control decisions. A large part of $PM_{2.5}$ concentrations in cities is secondary PM formed by reaction of NH_3 with other pollutants, such as NO_x and SO_x. To tackle this, reduction of NH_3 emissions is required, especially in areas where other pollutants are in excess in the atmosphere. Progress can also be achieved by reduction of emissions from other sources in the region and nationwide.

The German UBA studied measures to reduce air pollution polluted areas in Germany (Diegmann et al., 2015). These plans offer an extensive overview of the current situation in Germany regarding air quality. Diegmann et al. (2015) concluded that most of the measures concentrate on local road traffic which is named as the biggest NO_x polluter in 68 % of the cases with 46 % having at least 50 % from this source group. NRMM is also identified as a polluter of NO_x and - with less importance - PM but only very few measures were considered at this point of time. According to Diegmann et al 2015[43] 80 % of the measures mentioned in these AQP refer to the source group road traffic, and only 2,2 % to NRMM and 1,5 % to other traffic which includes rail and inland waterways and 0,4 % refer to agriculture. 16 % of the measures are aimed at the source group stationary sources which include construction activities. Only in about 1 % of the AQPs the usage of low emission technologies for non-road mobile machinery is mentioned. Moreover, in about 0,5 % the usage of low emission technologies for mobile machinery at construction sites and in about 0,6 % low emission ship engines are mentioned[44].

It is therefore no surprise that there are no harmonised national measures taken in Germany with regard to NRMM emissions from non-road machinery. Specific measures to reduce emissions from NRMM concentrate on the forced usage of machinery from Stage IIIB onwards. Nowhere Diesel Particulate Filter (DPF) retrofitting of NRMM is required as a mandatory measure to take; there is always the alternative to use late or latest Stage new NRMM instead. With regard to the Länder there is a recommendation from the Environmental Ministers of the Länder to require the use of low emission construction machinery as part of public call for tenders in areas with high PM concentrations and to use such machinery for the public machinery fleet[45]. Moreover, the Environment Ministers of the Länder ask the Federal government to develop a national regulation for labelling low emission construction work machinery[46]. Labelling is required in order to survey the application of Länder or local legislation which requires in some parts of Germany to use machinery which complies with certain emission characteristics[47]. Labelling of NRMM is already in force on a voluntary basis in the Land "Berlin" since 2016.

At city level only primary PM can be controlled. Application of DPF has been successful in reducing primary PM emissions. The most important measure results from action at EU level: The setting of emission standards for road vehicles. This is now further enhanced by the EU NRMM Regulation. In the long term only very few combustion engines will be operated without particle filter. In addition, in Germany open particulate filters for older diesel passenger cars are required for entering low emission zones. The purchase of the equipment was financially supported by the German government.

The fact that older diesel passenger cars had to be retrofitted in order to be allowed to enter LEZ was also one of the driving forces to tackle NRMM particle emissions. It was difficult to explain to the public why NRMM are allowed to continue emitting "black plumes" while many on-road vehicles not complying with certain Euro classes or not being retrofitted with particle filters are not allowed to enter the city.

3.2.2 NO_2 measures

NO_2 air pollution problems occur, as a rule, at local level in the overwhelming part of the cases.

For NO_2 the importance of road transport emission is obvious. Often breaches of limit values occur at stations located at highly frequented roads. It is therefore no surprise that measures concentrate on this source category. Nowhere in the EU mandatory retrofitting of NRMM with the objective to reduce NO_x emissions is required.

Local measures in Member States concentrate on emissions from non-road diesel vehicles. These measures aim with priority at reducing NO_x and PM emissions but are at the same time also helpful for

[43] Please note: NRMM as relevant source of pollution has been identified quite late and often this source category is not at all or not fully included in AQPs.

[44] This does, however, not mean that measures to reduce NRMM emissions are not considered in Germany. For example, the German Sachverständigenrat für Umweltfragen proposed in its 2012 "Gutachten" usage restrictions for NRMM in cities.

[45] Please note: Public procurement is not part of this study. The issue is studied elsewhere, see http://susproc.jrc.ec.europa.eu/Public_space_maintenance/documents.html

[46] NRMM are no part of 35. BImSchV which regulates the labelling of road vehicles in polluted areas.

[47] Bund/Länder-Arbeitsgemeinschaft für Immissionsschutz, 2017.

reducing traffic as such. A number of cities have introduced "low emission zones", "city charges" or "T-charge". T&E (2018) analysed such measures in 11 European cities: Amsterdam, Athens, Berlin, Brussels, Lisbon, London, Madrid, Milan, Oslo, Paris and Stockholm and identified large differences in the environmental zones implemented so far, see Figure 3-1[48].

City	Measure	Minimum standard allowed	Entry into force
Amsterdam	LEZ (taxis)	Euro 5	Jan 2018
Athens	odd-even rationing + LEZ aspect	Euro 5	May 2012
Berlin	LEZ	Euro 3 + DPF / Euro 4	Jan 2010
Brussels	LEZ	Euro 2	Jan 2018
Lisbon	LEZ (two sub-zones)	Euro 3 / Euro 2	Jan 2015
London	CC, T-charge / ULEZ	All vehicles*/Euro 6	Feb 2003 / April 2019
Madrid	parking LEZ	All vehicles	Mar 2012
Milan	CC, LEZ	Euro 4 + DPF	Oct 2017
Oslo	CC, LEZ	Electric vehicles	Oct 2017
Paris	LEZ	Euro 3	July 2017
Stockholm	CC	All vehicles	Aug 2007

LEZ = Low Emission Zone; CC = City Charge;
T-charge = new emissions surcharge (dubbed the 'T charge') for all vehicles with pre-Euro 4 emissions standards entering central London.

Figure 3-1 Examples of measures taken by Cities in order to reduce emissions from road transport (T&E, 2018)

A number of Member States have adopted national LEZ legislation (France, Germany, Greece, Italy, Netherlands, Denmark, Sweden, and Czech Republic) which provide a harmonised legal framework for local measures. Based on this background, cities are free to implement their tailor-made local measures. However, in some cases national legislation prevents cities from taking far-reaching action desired at local level.

There is no EU regulation which aims at harmonising the national LEZ legislation. In consequence vehicles allowed entering a LEZ in one country are not automatically allowed to enter a LEZ in another country. Some Member States like Germany have laid down national legislation establishing a labelling system in order to overcome the problem.

3.2.3 Specific measures against NRMM pollution

As shown above measures on NRMM, as a rule, are not a priority in Member States and cities. This was recently confirmed by a report of the EAA which compiled measures reported by Member States in order to reduce PM_{10} and NO_2 ambient air concentrations (European Environment Agency, 2018b). Most measures concentrate on road transport and only 2% of the measures addressed pollution due to the sector off-road, see Figure 3-2 below.

[48] Please note. This list is incomplete. The establishment of LEZ is a dynamic process. Recently T&E updated the list, see *"City bans are spreading in Europe".* Moreover, on 8 October 2018, the French government announced it has agreed with 15 local authorities that they will restrict access to urban areas for dirtier vehicles as part of efforts to reduce NO_2 pollution. Under the plan, by the end of 2020, the 15 cities, which represent 20 million inhabitants, will either introduce new low emission zone programmes or ramp up an existing plan to improve air quality. Low Emission Zone access restrictions to the more polluting vehicles will refer to Crit'air labels based on the Euro standards to which the vehicles are certified. An overview on access restrictions can be obtained on: http://urbanaccessregulations.eu/

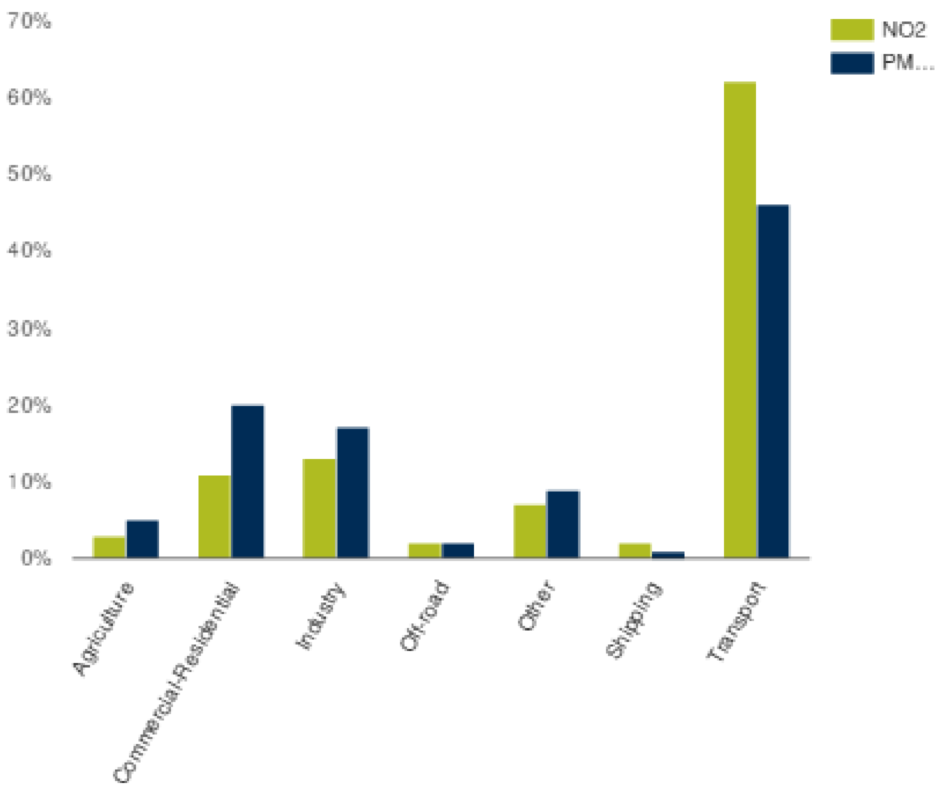


Figure 3-2 Sectors addressed by the reported measures for PM_{10} and NO_2 by Member States (and Norway)

Nevertheless, there are a number of measures taken in some European countries, regions and cities. Nationwide measures are in Austria[49] and Switzerland (Swiss Federal Council, 2018). The following Table 3-1 provides an overview on NRMM emission reduction measures taken at the different levels[50]:

Table 3-1 NRMM reduction measures taken at national regional or city level

Country	State/ Department	City	Specific measures against NRMM pollution
Switzerland			At all construction sites with the exception of quarries and gravel pits new engines > 19 kW must meet the PN limit value of $1*10^{12}$ #/kWh. Existing mobile machines > 37 kW used at the site must be equipped with OAPC conform DPF
Austria	Burgenland, Carinthia, Lower Austria, Upper Austria, Styria, Vorarlberg	Vienna	In areas in which the EU AQL values for PM are exceeded non-road engines > 19 kW must be at least complying with Stage II/IIIA limit values or must be retrofitted with certified DPF.

[49] BUNDESGESETZBLATT FÜR DIE REPUBLIK ÖSTERREICH: Verordnung über Verwendung und Betrieb von mobilen technischen Einrichtungen, Maschinen und Geräten in IG-L-Sanierungsgebieten; Jahrgang 2013 Ausgegeben am 20. März 2013 Teil II; see http://www.offroadverordnung.at/
[50] Information partly taken from Soot free city ranking 2015

			In 2019, Stage IIIA or higher will be compulsory for all machinery in order to access polluted areas (Sanierungsgebiete). New machinery purchases need to meet the diesel Stage IIIB standard as the minimum requirement.
Germany			Public call for tenders for building constructions require the use of low emission NRMM or retrofitted NRMM. Moreover, general guidelines for the use of NRMM in polluted areas have been published which also apply for public call for tenders for construction works in the States and cities which desire to take measures.
	Baden-Württemberg[51] (Germany)	Stuttgart Tübingen Ludwigsburg Markgröningen Reutlingen	New machinery must comply with latest EU Emission limit value. Older machinery must be equipped with approved DPF.
	Bayern[52]	To be applied in polluted areas (Luftreinhaltegebieten) in Bavaria[53]	In air pollution control areas, construction machinery with a capacity of 19 kilowatts (kW) up to 560 kW may only be operated on construction sites if they meet the following requirements: 19 kW to less than 37 kW: Stage IIIA or 37 kW to 560 kW: Stage IIIB of Directive 97/68 / EC. Construction machinery which does not comply with these requirements may only be used in air pollution control areas if they had already been placed on the market before these requirements came into force, and are retrofitted with a sufficient particle reduction system[54].
		Aachen	Public call for tenders for construction works require the use of low emission NRMM or retrofitted NRMM.

[51] Verordnung der Landesregierung zur Verbesserung der Luftqualität in Gebieten mit hoher Luftschadstoffbelastung (Luftqualitätsverordnung-Baumaschinen, GBl. 2015, S. 1249)
[52] Bayerische Verordnung zur Verbesserung der Luftqualität in Luftreinhaltegebieten (Bayerische Luftreinhalteverordnung – BayLuftV) Vom 20. Dezember 2016 (GVBl. S. 438)
[53] Areas in Germany declared as polluted are listed on http://gis.uba.de/website/umweltzonen/lrp.php
[54] Exceptions: If an entrepreneur threatens to threaten the existence of a business by the provisions of this Ordinance, if retrofitting is not possible for technical reasons, the cost of retrofitting would appear out of proportion to the air pollution to be expected due to the frequency of use of the construction machinery in an air pollution control area or if there is an unreasonable hardship for other reasons, the district administrative authority may allow exceptions in a particular case, but no later than 31 December 2022, if the exception is justifiable in consideration of the objectives of the Clean Air Design. If an entrepreneur uses three or more construction machines with a capacity of 19 kW or more on a construction site, exemptions from are permitted for individual construction machines if the proportion of construction machinery fulfilling the requirements of § 2 is rounded down to whole machines at least 70 % in 2017, in 2018 at least 80 % and at least 90 % in 2019.

		Berlin	Since 2014 construction machinery which is used on construction sites have to fulfil emission standard IIIB/IIIA (IIIA for machines <37KW). Older construction machinery has to be equipped with approved DPF. Public call for tenders for construction works require the use of low emission NRMM or retrofitted NRMM. The city runs a funding programme to incentivise modernisation of engines: In the framework of a trial programme three passenger ships were retrofitted with particulate filter systems. Their monitoring afterwards showed positive results.
		Bremen	Public call for tenders for construction works require the use of low emission NRMM or retrofitted NRMM.
		Darmstadt	Public call for tenders for construction works require the use of low emission NRMM or retrofitted NRMM.
		Dresden	Public call for tenders for construction works require the use of low emission NRMM or retrofitted NRMM.
		Düsseldorf	Tenders state a preference for offers using construction machines with diesel particulate filters. Düsseldorf asks for a national NRMM conception and to implement it as soon as possible. 51 construction machines are owned by the municipality, but none is retrofitted with a particulate filter. The city is active in additional measures to address emissions from ships, in particular by creating landline electric charging points at ship berths
		Erfurt	Public call for tenders for construction works require the use of low emission NRMM or retrofitted NRMM.
		Frankfurt	Public call for tenders for construction works require the use of low emission NRMM or retrofitted NRMM.
		Leipzig	Low emission zone for NRMM. Public call for tenders for construction works require the use of low emission NRMM or retrofitted NRMM.
		Zürich	City regulation requires diesel-powered machinery over 18 kW to be equipped with an approved particle filter when working on municipal construction sites. For private construction sites, an obligation for particle filters is in place for machinery > 37 kW.

		Copenhagen	Private contractors carrying out public work must have particle filters on non-road mobile machines (NRMM). There are no general filter requirements for construction sites.
		Stockholm	Since 1999, Stockholm has run a programme to reduce emissions of off-road engines. The programme applies to a variety of engines, ranging from construction machines, wheel tractors and excavators to lawn mowers and hedge cutters. Contractors have to meet certain environmental requirements to be eligible to bid for municipal contracts. The contractor has to either use only new engines that meet the latest emissions standards, or to retrofit older engines with a certified emission control device.
		London	A best practice guide for construction and demolition with recommendations on how to reduce dust and soot emissions from construction and demolition work was published in 2006 and substantially updated in 2014. It now includes a Low Emission Zone (LEZ) for non-road mobile machinery, which was introduced in 2015. The LEZ requires construction machinery between 37 kW and 560 kW to meet at least Euro Stage IIIA regulation when working in Greater London and Stage IIIB when working in central London or Canary Wharf. From 2020, regulations require Euro IIIB emissions standards when working in Greater London and Euro IV when working in central London or Canary Wharf. But there is no obligation to use particulate filters in addition to IIIA and IIIB-standards.
		Lyon	An emission reduction target of 10% in the construction sector has been developed. To achieve this target, a guide on clean construction sites was published and must be respected by companies working on public construction sites. An obligation to use filters for machinery has not yet been considered.
		Barcelona	The city has developed a Green Construction Work plan with several measures including the use of special pavement, street sweeping and washing as well as the use of additives, some of which do not target emissions at the source but merely target concentration levels. Additionally, the city chose specifically to monitor the emissions from big construction projects. Retrofit

			programmes or particulate filter requirements were not developed at that time.
		Milan	There is no general local legislation which regulates the emissions of non-road mobile machinery. However, when Environmental Impact Statements or Assessments need to be undertaken for certain projects; the public authority often mandates the use of particulate filters. Also, the city is evaluating the possibilities for local regulation within the current legal framework in Italy.
		Madrid	There are a few programmes on non-road emission sources. Madrid created information measures like information brochures that inform about air quality issues in construction, maintenance and demolition of buildings. Furthermore, a best-practice guide for construction has been created. With these publications the city aims at creating awareness of the problem and promoting measures.

The picture shown in Table 3-1 is incomplete and might not be fully up-to-date. In order to obtain a better insight into measures taken by Member States with regard to NRMM retrofitting the Commission distributed in October 2018 a questionnaire to Member States, see Annex I. 16 Member States answered to the questionnaire.

According to the answers obtained only Germany requires retrofitting measures to be taken under certain circumstances in polluted zones. The majority of Member States which answered to the questionnaire are moving towards the application of UNECE R 132 for certification. A summary of replies is shown in Annex II.

In the following further details are provided on Member States, regions and cities which take measures:

A) Switzerland: Switzerland has been very active in regulating the particulate emission and requiring DPF in tunnel machines, extending the requirement to all construction sites in the late 2000s. Since 2009, due to the Ordinance on Air Pollution Control (OAPC)[55], Swiss construction equipment[56] has had to meet a PM standard similar to the one in the NRMM Directive, but also comply with a PN limit value set at $1x10^{12}$ solid particles per kWh. This requires DPF retrofitting for nearly all construction machines since the DPF requirement was extended to all construction sites in Switzerland, regardless of size. The Ordinance retrofit provisions are applicable to the following categories of engines:

- Engines of 18-37 kW built since 2010, and
- Engines ≥ 37 kW from 2015 all engines regardless of age.

Particulate filters and other PM emission control devices used programs must meet certain performance criteria and receive an official approval/certification. An important performance requirement for particulate

[55] Ordinance on Air Pollution Control (OAPC) of 16 December 1985 (Status as of 1 January 2018)
[56] It should be mentioned that the Swiss came in 2007 to the conclusion that the retrofitting of agricultural tractors is not cost efficient, see https://www.admin.ch/gov/de/start/dokumentation/medienmitteilungen.msg-id-13784.html

filters used in the Swiss retrofit programs is that emissions must be reduced by at least 95% in terms of solid particle numbers in the size range of 20-300 nm (measured according to SN277206[57],[58]).

First DPF performance criteria and specifications were developed by VERT (old meaning of the abbreviation: Verminderung der Emissionen von Real-Dieselmotoren im Tunnelbau, Curtailing Emissions from Diesel Engines in Tunnel Construction; now: Association for Verification of Emission Reduction Technology), a research program conducted in the period 1994-2000, sponsored by Swiss, German, and Austrian occupational health authorities. Initially, VERT also administered the DPF approval process and maintained a list of approved filter systems. Later, the administration of the DPF approval process and the publication of the approved filters list became the responsibility of the Swiss Federal Office for the Environment (FOEN)[59].

New off-road engines above 18 kW used in machinery operated within any construction site in Switzerland must meet particle number emission requirements. Two alternative compliance options are available:

1. Engines must meet a solid PN emission limit of 1×10^{12} kWh^{-1} over NRSC and NRTC. PN measurement is conducted according to PMP procedures (ECE R-49, Annex 4C), or
2. The machine must be fitted with a DPF system conforming to the Ordinance DPF retrofit requirements.

Construction engines complying with the 2008 Ordinance are also subject to bi-annual field inspections (BAFU, 2010). Regulatory requirements for instruments to meet the field inspection requirements are defined in Swiss Regulation SR 941.242. Responsible for the implementation of OAPC are the Swiss Kanton. Market surveillance is in the hand of the Federal government, represented by Bundesamt für Umwelt (BAFU).

Based on these requirements Switzerland has successfully retrofitted many tens of thousands of diesel engines in operation and is maintaining an online information database to identify filter manufacturers meeting every possible need (Swiss Federal Office for the Environment, 2012).

As mentioned, the OAPC specifies two ways in which the requirements on emissions from construction machines can be met. The first is that construction machine manufacturers can provide evidence that their machines comply with the limit levels for particles in accordance with the OAPC.

Based on the current status of technology, this is only possible if a particle filter has already been installed at the factory. Alternatively, the requirements of the OAPC can be met by retrofitting a machine with a tested and approved filter system. The Particle Filter List consists of two parts:

- a list of particle filter system types with a filtering rate of at least 97%, in particular for ultrafine particles; they have passed a rigorous technical test and are suitable for retrofitting diesel engines of construction machines, other non-road mobile machines and appliances, stationary systems and heavy motor vehicles;
- a list of engine types which are OAPC conform, i.e. which have been tested with their in-built particle reduction system in accordance with Directive 97/68/EC (so-called original equipment

[57] Internal Combustion Engines – Exhaust Gas After-treatment – Particle Filter Systems – Testing Method; see also:
Testing and certification of particle filters in accordance with the Ordinance on Air Pollution Control (OAPC) Notes on the application of Standard SN 277206. From 1.1.2014 on, only SN 277206 compliant test reports are accepted for OAPC conformity assessments.
[58] UNECE Regulation No 132 is considered as equivalent by Article 32 (2) to the OAPC.
[59] Which does not mean that VERT requirements are equal to the requirements of the Swiss legislation. In fact, FOEN requirements are not same as VERT requirements and the filter list is different.

manufacturer (OEM) machines) and have been certified as meeting the requirements of the OAPC.

The main purpose of these two lists is to provide the authorities responsible for the enforcement of the OAPC with a helpful tool, but they can also be used as a source of information concerning efficient and reliable particle filter systems for the retrofitting of diesel engines. Experience to date has shown that with the right choice and proper maintenance of the particle filter systems included in the FOEN filter list it is possible to find a technically reliable solution for effectively eliminating soot emissions from diesel engines.

Included in the lists are types of particle filter systems and engines which have been issued a certificate of conformity to the effect that they meet the requirements of the Ordinance on Air Pollution Control (OAPC). Both lists are updated regularly.

Engines compliant with the newest European emission regulations for heavy duty (EURO VI) and light duty (EURO 6) vehicles as well as passenger cars (EURO 6) satisfy the requirements on construction machines according to annex 4 section 31 of the OAPC. Laboratories and certification bureaux have to be certified.

In Switzerland, due to the national legislation almost all construction machinery is equipped with DPF, see Figure 3-3.

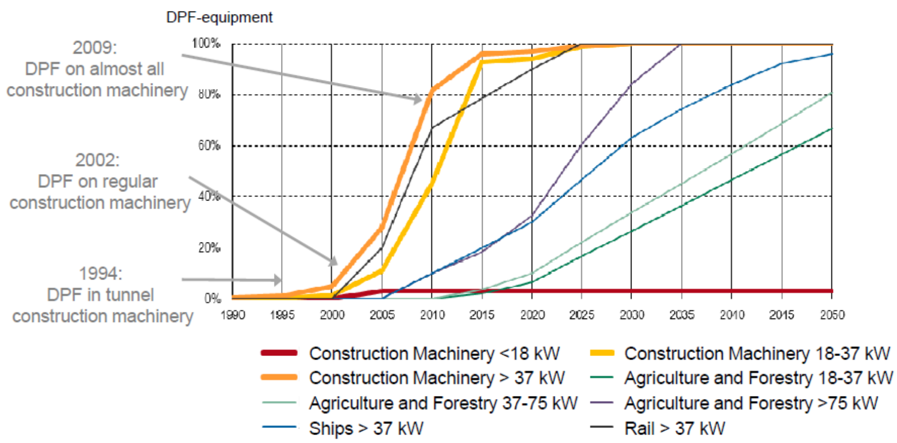


Figure 3-3 DPF fitted engines in Switzerland[60]

Retrofitting measures contributed to the observed $PM_{2.5}$ emission reduction of 29 % between 2005 and 2016 in Switzerland[61].

B) Austria the Ordinance on the Use and Operation of Mobile Technical Equipment, Machinery and Equipment in IG-L Polluted Areas (IG-L Off-RoadV)[62] provides for restrictions of use of mobile machinery[63]. The use of old machinery and equipment with high particulate emissions in polluted areas is progressively restricted under this Regulation. The restriction is gradually extended to increasingly better emission classes between October 2013 and October 2019. Ultimately, only newer machines with significantly lower particulate emissions may be used in these areas. The timetable was chosen in such a way that the latest

[60] Krahenbühl VERT Forum 2018
[61] FOEN 2018: Switzerland's Informative Inventory Report 2018 (IIR), Submission under the UNECE Convention on Long-range Transboundary Air Pollution
[62] "Verordnung über die Verwendung von mobilen technischen Einrichtungen, Maschinen und Geräten"
[63] NRMM is defined as in EU Directive 97/68/EC but the following machines are excluded: handlers for universal lifting and transport tasks with long ranges and heights, rotary drilling rigs, road milling, push and crawler loaders with special bodies, such as a cable plow or pipe laying.

generation of engines with particularly low particulate emissions is already available on the respective dates. In addition, the operators of the machines were given the opportunity to retrofit the engines with particulate filter systems. This means that even very old diesel engines can achieve significantly better emission performance and thus continue to be used in these areas.
The provinces define the polluted areas concerned. Currently polluted areas are located in Burgenland, Carinthia, Lower Austria, Upper Austria, Styria, Vorarlberg and Vienna. They cover an area of approximately 15,500 km^2 in which about 4 million people are living.

The restrictions on use are limited to the winter half-year (1 October to 31 March each).

In practical terms mobile machinery used in these areas must comply with the following limits:

- power class > 19 kW = no restriction
- power class 19 to <130 kW = Stage II emission limits, and Stage IIIA from 1.10.2019 onwards
- power class 130 to 560 kW = Stage IIIA emission limits

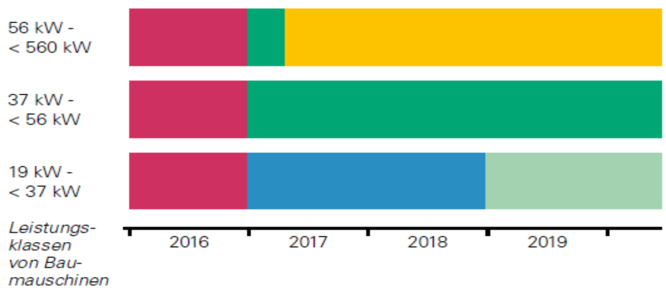
Applicable for all Stages, devices retrofitted with particulate filters may also be used in polluted areas all year round. Exact regulations on retrofitting are contained in § 4 in connection with Annex 1 and 2 IG-L Off-Road-VO.

However, it is unclear to which extend retrofitting is taking place. Since the requirements of the legislation are quite weak it is not very likely that a large number of machines have been retrofitted.

C) Germany: There is no mandatory nation-wide requirement to retrofit NRMM. However, the environmental Ministers of the States[64] have adopted guidelines for the use of low emission NRMM in zones with high PM emissions and for public call for tenders[65]. At federal level public call for tenders to apply these guidelines for the building of constructions[66]. At State or local level, the guidelines are applied in polluted zones and for call for tenders related to construction works[67]. As a rule, retrofitting requirements are designed in such a way that either NRMM meet defined limit value Stages or are retrofitted in accordance with a defined certification procedure.

D) Baden-Württemberg: The regulation of the regional government to improve air quality in areas[68] with high levels of air pollution[69] came into force on December 30th, 2015. According to the air quality regulation construction machinery must meet special emission requirements at construction sites in municipal areas which are within the scope of an AQP. Such plans are required in zones in which an excess or a danger of excess of the PM_{10} limit value is given is. The regulation affects a defined list of non-road mobile machinery, e.g. all types of loaders, forklifts, all types of excavators, compressors, hydraulic units, generators, mortar conveyors, plastering equipment and concrete pumps, pumps for water management, dump trucks, bulldozers, tractors, rollers, vertical and horizontal drills of all types[70]. Depending on the performance class and time graduated, the subsequent emission requirements, which are related to the exhaust gas levels Directive 97/68/EC of the European Union apply, see Figure 3-4.

[64] 83. Umweltministerkonferenz 2014
[65] „Empfehlungen für den Einsatz von emissionsarmen Baumaschinen bei öffentlichen Ausschreibungen und in Gebieten mit hohen Feinstaubbelastungen‟ of 4.8.2014
[66] To support activities the German Umweltbundesamt published a "Guide on Green Public Procurement: Construction Machines".
[67] In addition, Deutsche Bahn AG has defined nation-wide requirements to be met on its construction sites.
[68] These are: Ludwigsburg, Markgröningen, Reutlingen, Stuttgart und Tübingen
[69] Verordnung der Landesregierung zur Verbesserung der Luftqualität in Gebieten mit hoher Luftschadstoffbelastung (Luftqualitätsverordnung-Baumaschinen, GBl. 2015, S. 1249)
[70] Not affected are: lifting platforms, winches, Ramming, Graders, Road paver and its feeder, Mastic asphalt cooker, Mobile and mobile cranes, mixing plants for blackcaps, as well as other, not listed among the persons concerned mobile machinery and equipment.



red: no requirement; blue: Stage IIIA, green: Stage IIIB; orange: Stage IV, light green: Stage IIIA with DPF

Figure 3-4 Requirements of the legislation

The particulate reduction systems need certification, e.g. for the filtration efficiency (at least 90 %) and long-lasting operation. The following certificates or test procedures listed are accepted: UNECE Regulation No. 132 (class I and II, level 01), certificate of FAD e.V., certificate of VERT, requirements of TRGS 554[71], requirements of Appendix XXVII of the StVZO, Swiss BAFU certificate. From 1.1.2018 only class I of reduction level 01 of UNECE 132 is accepted. In practical terms this results - in theory - in a certain disharmonisation within Germany: NRMM retrofitted in one part of Germany in accordance with VERT, FAD, Appendix XXVII or TRGS 554 after 1.1.2018 could not be operated anymore in Baden-Württemberg. The issue is of theoretical character in so far as retrofitting activities are at very low level. Moreover, the issue is most likely of temporal character since it can be assumed that all areas in Germany which currently require retrofitting as an option to the alternative of using NRMM which comply with defined limit values will move to UNECE 132. Hesitation to take this step has to do with the fact that there are no certified retrofitting systems on the market complying with UNECE 132.

E) Berlin: Although road traffic is considered as the main contributor to local PM_{10} and NO_2 pollution, emphasis is also given to PM exhaust control of mobile machinery. Berlin carried out demonstration projects with DPF retrofitting in order to demonstrate that retrofit is technically and economically feasible. New local procurement rules have been laid down. These concern diesel-powered construction machines with an engine power of >19 kW and ≤ 560 kW and public works, regardless of whether they are approved for road traffic or not. These rules require that non-road machinery need to meet EU particle emission standard:

- 19 – 37 kW Stage IIIA,
- 37 – 56 kW Stage IIIB,
- 56-560 kW Stage IIIB or Stage IV,

or to retrofit with an efficient regulated/closed particle filter. Moreover, NRMM equipped with on-road engines must meet at least EURO IV standards and all NRMM with constant RPM have to have a DPF.

Diesel particle filters have to be certified with at least one of the following certifications:

- Stage PMK 2 according to „Anlage XXVII zur Straßenverkehrs-Zulassungs-Ordnung(StVZO)"
- Class 1 or 2, reduction Stage 01 of UNECE guideline No. 132 (REC-guideline)
- FAD Quality seal
- Listed on VERT filter list and/or conformity according to Swiss OAPC (BAFU List)
- Machines which have been retrofitted to fulfil the requirements of TRGS 554.

[71] TRGS 554 is not further discussed in this report because it applies for occupational health situations

Berlin also initiated discussions at LAI level[72] on the labelling of NRMM in order to facilitate the surveillance and to allow the usage of retrofitted NRMM in different areas/cities as it is the case in Germany for on-road vehicles. No decision has been taken yet. However, at LAI level some general guidelines on the use of low emission NRMM have been laid down which include retrofitting aspects[73]. This step helped harmonising measures in Germany to a certain extend.

Moreover, the local government in Berlin aims at DPF retrofitting of cruising passenger ships. In a pilot project 3 ships were retrofitted with different filter systems. This project was co-funded by the EU regional funds. After having completed successfully this demonstration project the local government offered financial incentives to ship owners for retrofitting. These, however, were not much used.

Ship owners argue that there is not enough space for the bulky filter equipment on the relatively small passenger vessels. Currently the Senat of Berlin is undertaking a new attempt to convince ship owners that retrofitting or new hybrid powertrains are an option to be considered, offering again financial support.

F) UK/London: In UK there is no legislation that forces retrofit. However, the Greater London Authority does allow retrofitting as a method of compliance with their NRMM Low Emission Zone. The zone is designed and enforced through planning conditions rather than specific legislation. The overarching document is the London Plan and the scheme design is specified through a Supplementary Planning Guidance (SPG) document.

In 2010 construction activity was responsible for 12 % of NO_x emissions and 15 % of fine particulate (PM_{10}) emissions in Greater London. Consequently, non-road mobile machinery such as construction excavators and bulldozers are the second largest source of ultra-fine particulate matter ($PM_{2.5}$) emissions in London and the fifth largest source of oxides of nitrogen.

From the 1st of September 2015 the Greater London Authority (GLA) has introduced a Low Emission Zone which affects a large number of construction machines being used within the Capital. With an estimated 10,000 active construction sites in London at any one-time NRMM has been identified by the GLA as one of the largest contributors to poor air quality in London.

Beginning in 2015, requires non-road mobile machinery between 37 and 560 kW operating in Greater London and Central London must meet Stage IIIA and IIIB emission standards, respectively.

A Supplementary Planning Guidance was introduced on September 1st, 2015 and applies to all NRMM with a net power rating of between 37 kW and 560 kW. The minimum emission standards for NRMM within London are detailed below:

- NRMM used on the site of any major development, as defined in the London Plan within Greater London will be required to meet emission Stage IIIA as a minimum;
- NRMM used on any site within the Central Activity Zone or Canary Wharf will be required to meet emission Stage IIIB as a minimum;
- All eligible NRMM should meet the standards above unless it can be demonstrated that a comprehensive retrofit to meet both PM and NO_x emission standards is not feasible. In this situation every effort should be made to use the least polluting equipment available including retrofitting technologies to reduce particulate matter emissions;

[72] In LAI the Bundesländer and the Federal Government exchange views on all sorts of air quality questions.
[73] LAI 2014: Empfehlungen für den Einsatz von emissionsarmen Baumaschinen bei öffentlichen Ausschreibungen und in Gebieten mit hohen Feinstaubbelastungen

From 2020 any development site in Greater London will be required to meet Stage IIIB. Central London and Canary Wharf will need to meet Stage IV[74].

In addition, somewhat stricter requirements (as a rule one Stage stricter than what is required for London) have been laid down for the HS2 project which includes construction works in London (and other parts of the UK)[75]. In case retrofit is used to satisfy the requirements for the London construction equipment LEZ or for HS2 both PM and NO_x retrofit is required.

For the city of London only retrofitting technologies that have been registered and endorsed by the Energy Saving Trust NRMM certification scheme should be fitted to machinery. The London Authority has developed a NRMM register to simplify enforcement[76].

For HS2 project in certain cases, retrofit emission control devices applied to the previous Stage of engine may be permitted. In this case, the retrofit emission control device shall be approved to (United Nations Economic Commission for Europe) UNECE Regulation R 132. HS2 Ltd shall set and periodically review best practice R 132 class approvals for its contractors. When setting best practice class approvals, preference will be given to particulate matter retrofit with zero permitted absolute increase nitrogen dioxide emission classes.

The mayor of London has given local authorities £400,000 to enforce the zone. The rules of the NRMM LEZ shall be applied retroactively to existing planning permissions and to other users of NRMM. Moreover, the major of London asked the UK environment secretary setting out the additional powers to set minimum emission and technical standards for all NRMM used in London. This could be done by amending the GLA Act so that the mayor can use their powers to regulate NRMM in the same way as for road vehicles.

G) Sweden: There are no mandatory retrofitting programmes in Sweden. However, the procurement regulation from the Swedish Transport Administration and the major municipalities accept NRMMs that have been retrofitted to a higher emission Stage. For the procurement regulation there is no difference between retrofitted and non-retrofitted machinery as long as it meets the same emission level. The retrofit has to be type-approved. The national implementation of the European emission regulation on NRMM allows the machinery owner to modify the engine/after-treatment as long as he can prove that the engine still complies with the type approval against which the engine was originally approved. Apart from UNECE R 132, there are no national laws for retrofitting NRMM. Although UNECE R 132 is ratified, Sweden does not have a national approval/certification authority.

H) Denmark: There is no financial support scheme for retrofitting non-road machinery in Denmark.

However, the Danish Environmental Technology Development and Demonstration Programme (MUDP) promote development and demonstration of eco-efficient solutions addressing prioritised environmental challenges and support growth as well as employment through:

1) funding for developing, testing and demonstrating new environmental technology and funding for projects that can test new environmental technology at full-scale installations or in connection with new building and construction projects,

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[74] This requirement is somewhat unclear since Stage IV applies to the power class 56 to 560 kW only, but not to all NRMM categories.

[75] The UK government High Speed 2 project (HS2) is the only example identified which sets specific requirements for NRMM used within the project, irrespective of special local requirements. It is the biggest earthmoving infrastructure project in the UK in the coming years, see https://www.gov.uk/government/publications/hs2-information-papers-environment

[76] The Greater London Authority are planning to specify the 8178 [D2] test cycle for retrofit solutions. They note that it has been argued by the retrofit industry that R 132 is unduly onerous given that the base engine must already be R 132 compliant before a retrofit is installed.

2) establishing new innovation partnerships that actively promote cooperation between relevant stakeholders,
3) launching projects that support international and bilateral cooperation on activities in the area of the environment and innovation and that actively prepare the framework for Danish exports of environmental technology, and
4) building and disseminating knowledge within and about the environmental technology sector. Through the MUDP program financial support has been given to some projects where retrofit solutions are developed and tested.

In addition, a partnership promoting cooperation between the retrofit industry, the building industry and the motor/machine construction industry has been ongoing since 2016. Recently, a workshop has been conducted, and a report on the non-road industry in Denmark will be published in the coming months.

3.3 Conclusions

- As a rule, measures on NRMM do not play a major role in national, regional or local air pollution abatement plans. The only country in Europe which has taken severe measures, including obligatory retrofitting of existing NRMM with DPF, is Switzerland.
- From EU countries only Austria has taken nationwide measures which include existing NRMM. This measure is, however, relatively weak, requiring that in some regions in a given time period (winter time) NRMM must meet early emissions Stages. Retrofitting is an alternative, but most likely not used much in practice.
- Regional measures have been taken in Germany (Baden-Württemberg and Bavaria) which, however, do not target the whole area of the State but aim at harmonising retrofitting measures within these Länder.
- Specific measures have been taken in a number of cities, in particular in Germany, often because these cities have to take all measures available in order to meet the air quality limit values.
- In general, the regulatory approach taken is to require that NRMM used in defined areas have to meet specific emission limit values or have to be retrofitted. Nowhere in the EU retrofitting of existing NRMM is an unavoidable obligatory measure.
- Requirements are often taken in Low Emission Zones or zones defined under Directive 2008/50/EC. However, in contrast to on-road vehicles in some Member States, no labelling systems have been established which would allow identifying retrofitted NRMM.
- Currently all measures concentrate at Diesel Particulate Filter (DPF) retrofitting; Selective Catalytic Reduction (SCR) retrofitting is not required at all in any European country.
- Based on the experiences gained with retrofitting programmes, the practical implementation of retrofitting programmes requires a number of prerequisites. Apart from the certification procedure, see below, guidance needs to be given to the owner of NRMM and an inspection/surveillance system needs to be established in order to ensure enforcement. For new engines surveillance/inspection covers just the placing on the market. Therefore, to require the establishment of an inspection/surveillance system for retrofitted engine which are already on the market is in conflict with the fact that such a system is not required for new engines.
- Single measures, e.g. measures focusing on NRMM only, have generally only small effects which are difficult to quantify in terms of improved air quality. As a rule, measures taken at European, national, regional and local level must be combined to solve local air pollution problems.

4 Emission estimates

4.1 Introduction

The scope is to simulate the fleet turnover for the main NRMM categories for the EU28 and to develop a complete emissions inventory. The emissions inventory focuses on the calculation of NO_x and PM[77] emissions for all NRMM categories, power classes, and emission stages. The equation used for the calculations is the following:

$$Emissions = machiney\ population * average\ engine\ power * operating\ hours * load\ factor * emissions\ factor$$

The general methodology used for developing the emissions inventory includes the following steps:

- Collection of vehicle/machinery stock data
- Collection of activity data (i.e. useful lifetime, operating hours, load factors)
- Simulation of vehicle/machinery fleet turnover
- Collection of data on emission factors, based on respective emission limits
- Calculation of NO_x and PM emissions for all NRMM categories, power classes and emission stages.

In the following sections the calculations are presented separately for the agricultural and construction machinery and for railways and inland waterways.

4.2 Agricultural and Construction Machinery

4.2.1 Fleet turnover

The first step towards developing the emissions inventory on the construction and agricultural machinery was to collect recent machinery stock data for the EU-28. There is no complete and consistent dataset on the NRMM stock readily available at the EU level. Hence, the methodology for developing the emission inventory has been based on the sales of NRMM machinery, as presented in a relevant study by the Joint Research Centre (2008).

For the agricultural tractors, total sales for the EU-15, 2016 were retrieved from the European Agricultural Machinery Association (CEMA, 2017), amounting to 160,000 tractors (Table 4-1). Additionally, the total stock for agricultural tractors and harvesters and the corresponding share for EU-15 and non-EU-15, were obtained from Eurostat for the EU-28, 2013 (Eurostat, 2018). These data are displayed in Table 4-2 and Table 4-3. The sales for EU-28 have been estimated proportionally from the EU-15 sales based on the relative shares for EU-15 and non-EU-15 of the total tractors and harvesters' stock.

For the construction machinery stock estimation, total sales from the Committee for European Construction Equipment (CECE, 2017) and VDMA (Mechanical Engineering Industry Association) (VDMA, 2016) for the EU-15, 2016 were retrieved (Table 4-1), and the data for the EU-28, 2016 were calculated proportionally to Eurostat data on agricultural machinery, as presented in Table 4-2 and Table 4-3.

The fleet data for both the agricultural and the construction machinery were then distributed to power and technology classes for the whole timeseries, resulting to the disaggregated machinery stock data for the entire EU-28.

[77] In this and the subsequent chapters PM refers to PM_{10}.

Table 4-1 Sales of agricultural tractors and construction equipment EU-15, 2016

Category	EU-15, 2016 sales
Agricultural tractors	160,000
Construction equipment	150,000

Table 4-2 Total fleet of tractors for EU-28, 2013 (Eurostat)

	Tractor fleet	Share
EU-15	5,501,200	69 %
non-EU-15	2,427,740	31 %

Table 4-3 Total fleet of harvesters, EU-28, 2013 (Eurostat)

	Harvester fleet	Share
EU-15	331,400	19 %
non-EU-15	1,449,080	81 %

The selected useful life of each machinery category is presented in Table 4-4 and is in line with the methodology presented in the JRC study.

A comparison of the different lifetimes found in the literature is presented in FVB (2015) and it shows that IFEU (2014) and FVB (2014) reported lifetimes ranging from 10-16 years. A study of the Department of Transport of the United Kingdom (McGinlay, 2004) suggests lifetimes in the range of 4-12 years, whereas the corresponding lifetimes of the NRMM of Switzerland are lower (in the range of 4-9 years), as reported by BAFU (2008). Hence, the lifetime functions used in the present study, which are primarily based on the JRC study, are consistent with those used by individual Member States.

Table 4-4 Selected useful life for the agricultural and construction machinery

Category	Selected Useful Life
Small Equipment (Agricultural)	10 years
Small Equipment (Construction)	10 years
Generator Sets <37kW	10 years
Generator Sets >37kW	16 years
Agricultural Tractors	16 years
Agricultural Harvesters	16 years
Light Construction Equipment <37kW	10 years
Light Construction Equipment >37kW	16 years
Heavy Construction Equipment <130 kW	12 years
Heavy Construction Equipment >130 kW	10 years

To calculate the total number of machineries based on the number of sales, the methodology presented by the JRC was used, with the following assumptions:

- Stable market conditions, i.e. the number of sales in all sub-sectors and power classes remain constant across the years.
- The evolution of machinery population over time is described by the survival probability curves depicted in Figure 4-1 for the selected useful lifetimes of Table 4-4.

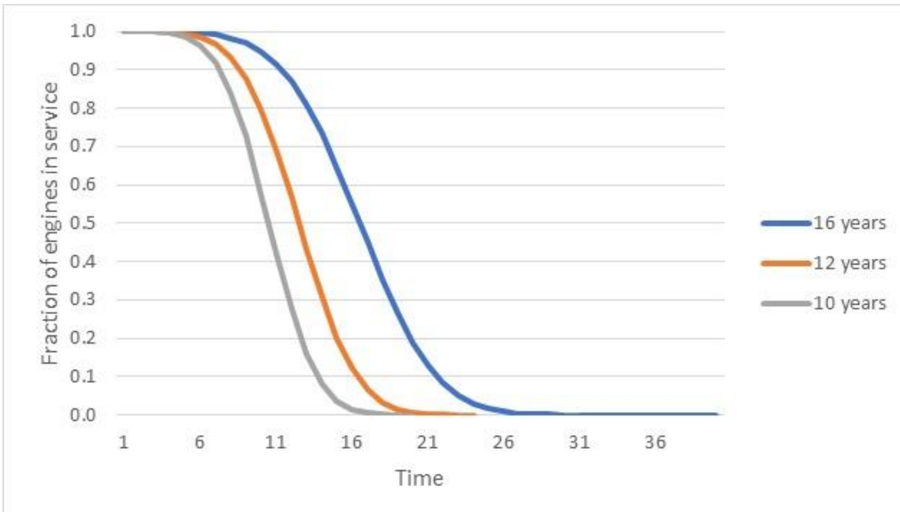


Figure 4-1 Survival probability curves for the selected lifetime (10, 12 and 16 years)

The survival rate for each machinery type is presented in Figure 4-2, which follows the distribution of Figure 4-1. For all categories, after the useful life, less than 10 % of the original fleet survives.

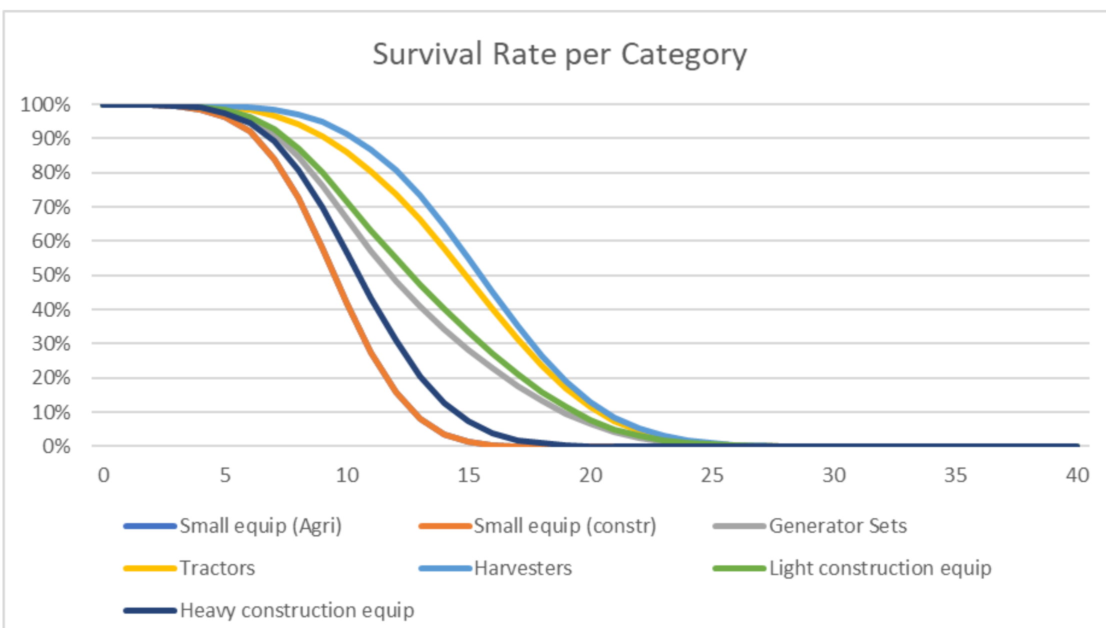


Figure 4-2 Survival rates per machinery type

By combining the above information, a complete fleet turnover has been developed for the timeseries 1990-2050. Figure 4-3 displays the evolution of the fleet per emission Stage over the same period. The total fleet is considered stable through the whole timeseries, whereas the share of the machinery in the different emission Stages obviously changes over time. Unregulated machinery is gradually phased out of the fleet, whereas in 2050 only Stage V machinery exist.

For the introduction of Stage V a transition period of two years was assumed, based on (Troppmann and Wolska, 2007). More specifically, in the first year of the mandatory application of Stage V to the various power classes, 30% of the new registrations is considered to be Stage V, whereas the remaining 70% belong to the previous emission Stage (depending on the power class). In the second year the percentage of new registrations complying with Stage V is increased to 60% and in the third year, all new registrations are Stage V.

It is repeated again that very few statistical data covering the entire EU are available and hence the fleet turnover has been simulated by combining all the information presented above.

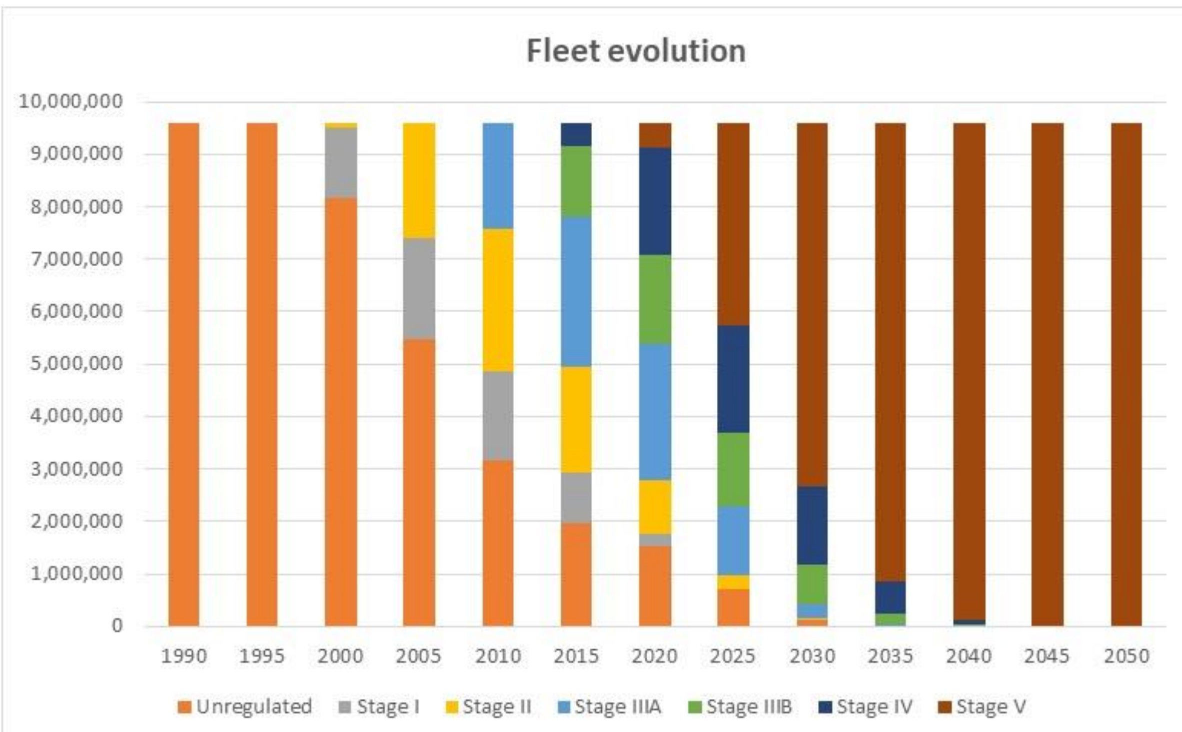


Figure 4-3 Fleet evolution for the timeseries 1990-2050

As an example of total fleet calculation for one year, Table 4-5 shows total sales by machinery category and by power class for the EU-28 for the year 2019, whereas Table 4-6 presents the machinery population for the same year. A total of 9.6 million machinery are operated in the EU-28, with the highest share of 26% in the power class 56-75 kW, followed by the power class 75-130 kW, with a share of around 17%. The largest power class (>560 kW) constitute only a small part of the overall fleet (about 1%).

Table 4-5 Sales per category for the EU-28, 2019

Category	Sales	<19 kW	19-37 kW	37-56 kW	56-75 kW	75-130 kW	130-560 kW	>560 kW
Small Equipment (Agricultural)	**27,385**	27,385	0	0	0	0	0	0
Small Equipment (Construction)	**72,066**	50,446	21,620	0	0	0	0	0
Generator Sets	**108,098**	20,431	33,510	18,377	12,972	10,810	7,567	4,324
Agricultural Tractors	**230,610**	20,755	4,612	46,122	69,183	69,183	20,755	0
Agricultural Harvesters	**51,577**	0	0	0	0	4,126	46,419	1,032
Light Construction Equipment	**177,210**	35,442	35,442	30,126	76,200	0	0	0
Heavy Construction Equipment	**38,986**	0	0	0	0	21,442	16,764	780
Total	**705,932**	**154,458**	**95,184**	**94,624**	**158,355**	**105,561**	**91,505**	**6,135**
Share		**22 %**	**14 %**	**13 %**	**22 %**	**15 %**	**13 %**	**1 %**

Table 4-6 Total fleet per category for the EU-28, 2019

Category	Total fleet	<19 kW	19-37 kW	37-56 kW	56-75 kW	75-130 kW	130-560 kW	>560 kW
Small Equipment (Agricultural)	**273,850**	273,850	0	0	0	0	0	0
Small Equipment (Construction)	**720,657**	504,460	216,197	0	0	0	0	0
Generator Sets	**1,404,200**	204,306	335,105	294,028	207,549	172,958	121,070	69,183
Agricultural Tractors	**3,537,560**	207,549	46,122	737,952	1,106,929	1,106,929	332,079	0
Agricultural Harvesters	**825,233**	0	0	0	0	66,019	742,710	16,505
Light Construction Equipment	**2,410,065**	354,421	354,421	482,013	1,219,209	0	0	0
Heavy Construction Equipment	**432,748**	0	0	0	0	257,310	167,641	7,797
Total	**9,604,312**	**1,544,586**	**951,846**	**1,513,993**	**2,533,687**	**1,603,215**	**1,363,500**	**93,485**
Share		**16 %**	**10 %**	**16 %**	**26 %**	**17 %**	**14 %**	**1 %**

The estimated fleet is in good agreement with the figures of the JRC study, as shown in Table 4-7 for the EU-15, 2005. The small differences, e.g. for light and heavy construction equipment, are due to adjustments made to match more recent statistical data as discussed previously.

Table 4-7 Fleet comparison for EU-15 with the results of the JRC study

Category	Total fleet EU15, 2005 (JRC study)	Total fleet EU15, 2005 (present study)
Small Equipment (Agricultural)	190,000	190,000
Small Equipment (Construction)	500,000	500,001
Generator Sets	974,999	974,252
Agricultural Tractors	2,500,420	2,454,404
Agricultural Harvesters	153,598	153,600
Light Construction Equipment	2,040,000	1,672,134
Heavy Construction Equipment	366,300	300,246
Total	**6,725,317**	**6,244,637**

4.2.2 Emissions inventory

The emissions have been calculated by using the following equation:

$$Emissions = machiney\ population * average\ engine\ power * operating\ hours * load\ factor * emissions\ factor$$

Data on operating hours for new machinery per category and power class were retrieved from the JRC inventory and are presented in Table 4-8. A step function was used to describe the decrease of operating hours for the machinery over their full life, which is presented in Figure 4-4.

Similar operating hours for new machinery are reported in BUWAL (2003). The operating hours are not distinguished per machinery category but only per power class and they are equal to 195, 344, 400, 518 and 623 for the first six power classes <19, 19-37, 37-56, 56-75, 75-130 and 130-560 kW respectively. In the same study, even though a different reduction rate was considered for each power class, the surviving machinery after 30 years is less than 30 % for all power classes.

A more detailed approach on the operating hours per machinery category is presented in IFEU (2014). A comparison between the reported hours of the JRC study and of the TREMOD model was conducted, and in most cases the reported operating hours are in good agreement. It is noted that TREMOD is a database containing data for Germany only, thus data are in some cases not directly comparable to the JRC data, which refer to EU-15.

Table 4-8 Operating hours by machinery type and power class

Category	<19 kW	19-37 kW	37-56 kW	56-75 kW	75-130 kW	130-560 kW	>560 kW
Small Equipment (Agricultural)	150	-	-	-	-	-	-
Small Equipment (Construction)	150	500	-	-	-	-	-
Generator Sets	150	250	500	500	500	500	500
Agricultural Tractors	150	400	500	700	700	750	-

Agricultural Harvesters	-	-	-	-	500	550	650
Light Construction Equipment	600	600	600	900	-	-	-
Heavy Construction Equipment	-	-	-	-	1100	1300	1300

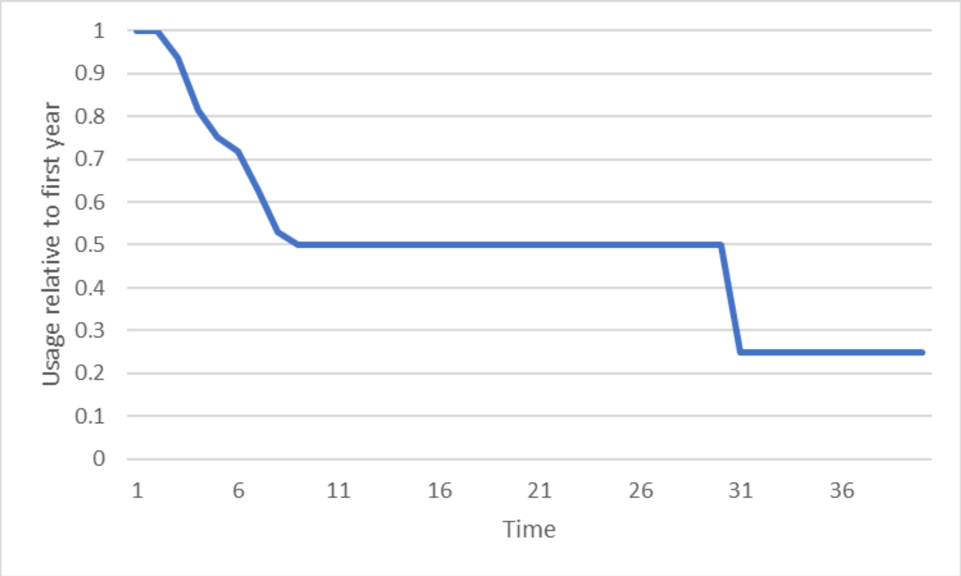


Figure 4-4 Decrease of operating hours over time

Figure 4-5 displays the usage hours for each category as a function of machinery age. All categories follow the step function of Figure 4-4. The usage hours of generators <37 kW, small equipment, light construction equipment <37 kW and heavy construction equipment are equal to zero after the end of their lifetime. For tractors, harvesters, generators >37 kW and light construction equipment >37 kW the usage hours are equal to 25 % of their original usage hours after 30 years and until the end of their lifetime.

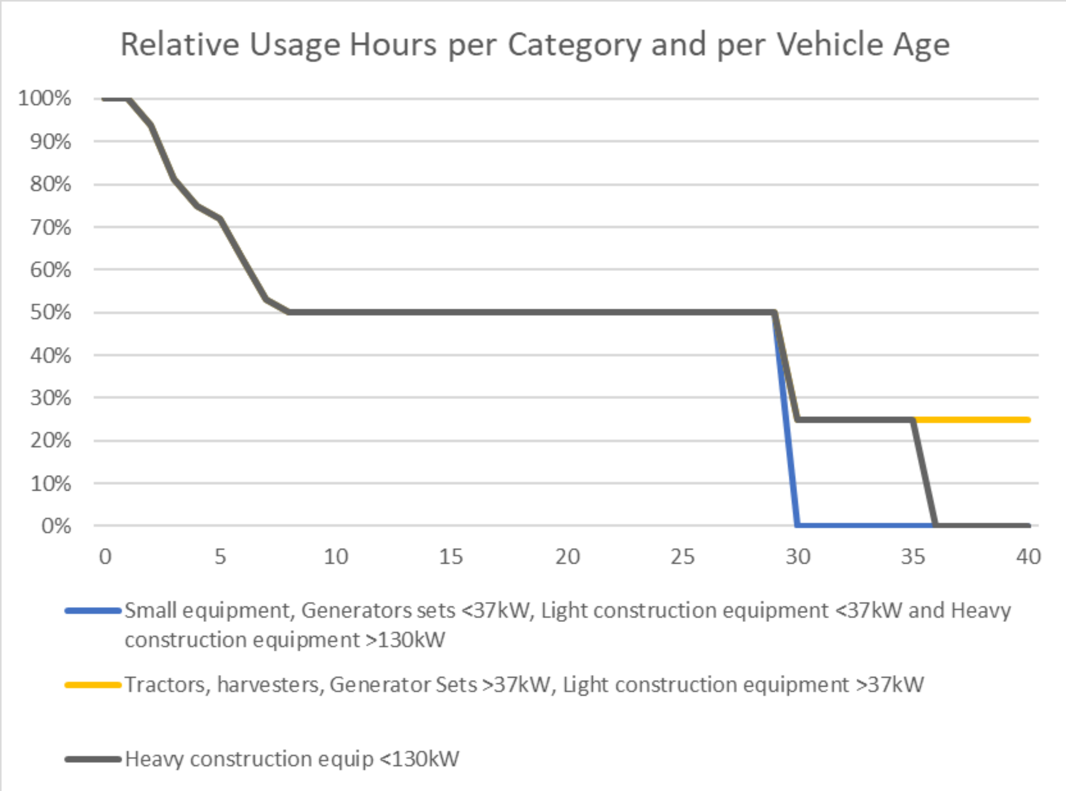


Figure 4-5 Usage hours per category and per machinery age

The emission limits per power class are displayed in Table 4-9, along with their introduction date, based on Directive 97/68/EC (European Commission, 1997), Directive 2004/26/EC (European Commission, 2004b) and on Regulation (EU) 2016/1628 (European Commission, 2016c). For calculating the emissions, the emission limits were multiplied with a correction factor of 0.8 for both PM and NO_x to account for the fact that the expected average emissions are somewhat lower than their respective limit values. For unregulated engines emission factors from the JRC study were used. For the power class >560kW, updated emission factors for machinery after 2004 were used, based on literature review. Even though the EU did not regulate these engines until 2019, most manufacturers use global designs, thus producing engines around US Tier 2 or US Tier 1 emission level. These emission factors used for the calculations are presented in Table 4-10.

Table 4-9 Emission limits (g/kWh) and their introduction dates

Power Class	Pollutant	Stage V	Stage IV	Stage IIIB	Stage IIIA	Stage II	Stage I
<19 kW		Jan2019					
	NO_x	7.5					
	PM	0.4					
19-37 kW		Jan2019			Jan2007	Jan2000	
	NO_x	4.7			7.5	8	
	PM	0.015			0.6	0.8	
37-56 kW		Jan2019		Jan2013	Jan2008	Jan2003	Jul1998
	NO_x	4.7		4.7	4.7	7	9.2
	PM	0.015		0.025	0.4	0.4	0.85
		Jan2020	Oct2014	Jan2012	Jan2008	Jan2003	Jul1998

56-75 kW	NO_x	0.4	0.4	3.3	4.7	7	9.2
	PM	0.015	0.025	0.025	0.4	0.4	0.85
75-130 kW		Jan2020	Oct2014	Jan2012	Jan2007	Jan2002	Jul1998
	NO_x	0.4	0.4	3.3	4	6	9.2
	PM	0.015	0.025	0.025	0.3	0.3	0.7
130-560 kW		Jan2019	Jan2014	Jan2011	Jan2006	Jan2001	Jul1998
	NO_x	0.4	0.4	2	4	6	9.2
	PM	0.015	0.025	0.025	0.2	0.2	0.54
>560 kW		Jan2019					
	NO_x	3.5					
	PM	0.045					

Table 4-10 Emission factors (g/kWh) per power class

Power Class	Pollutant	Stage V	Stage IV	Stage IIIB	Stage IIIA	Stage II	Stage I	Unregulated
<19 kW	NO_x	6						11.2
	PM	0.32						1.6
19-37 kW	NO_x	3.76			6	6.4		9.8
	PM	0.012			0.48	0.64		1.4
37-56 kW	NO_x	3.76		3.76	3.76	5.6	7.36	11.5
	PM	0.012		0.02	0.32	0.32	0.68	0.8
56-75 kW	NO_x	0.32	0.32	2.64	3.76	5.6	7.36	11.5
	PM	0.012	0.02	0.02	0.32	0.32	0.68	0.8
75-130 kW	NO_x	0.32	0.32	2.64	3.2	4.8	7.36	13.3
	PM	0.012	0.02	0.02	0.24	0.24	0.56	0.4
130-560 kW	NO_x	0.32	0.32	1.6	3.2	4.8	7.36	11.2
	PM	0.012	0.02	0.02	0.16	0.16	0.432	0.4
>560 kW	NO_x	2.8						7.8
	PM	0.036						0.37

By combining all the above data for the fleet of agricultural and construction machinery, detailed emissions calculations have been carried out for all machinery categories, power classes and emission stages (see equation in section 4.1). A load factor of 0.5 for all machinery types and classes has been assumed for the calculations. Also, the average engine power for each power class has been defined as the average between the minimum and maximum power within each class. The average power for the lower class (<19 kW) has been set equal to 18 kW and for the higher (>560 kW) equal to 600 kW.

NO_x and PM emissions for the time period from 1990 to 2050 are presented in Figure 4-6 and Figure 4-7 respectively. NO_x emissions are constantly declining since the introduction of Stage I limits for certain power classes in 1999. Emissions from unregulated machinery have dominated total NO_x emissions until 2006. After that, emissions decrease monotonically until about 2020 due to normal fleet renewal. After 2030 almost all pre-Stage V are phased out and the emissions tend to stabilise until 2050. This is based on the assumption that there is no post-Stage V limit introduced until 2050.

Emissions of PM are even more drastically reduced over the examined time period. This is due to the much higher reductions brought by the different emission stage steps. This, in turn, has been enabled by the introduction of DPF which have a very high reduction efficiency (on the order of 99%) in many power classes already since Stage IIIB.

Calculated NO_x and PM emissions for 2019 per category and per emissions Stage are presented in Table 4-11, Table 4-12, Table 4-13 and Table 4-14. For NO_x emissions a total amount of 535.67 kt has been calculated for the EU-28. The highest contribution comes from the power class 130-560 kW, with a share of 31%. When considering the emission stage classes, Stage IIIA and Stage II machinery have the highest shares, 28% and 21% respectively.

A similar situation is observed for PM emissions, with 27.66 kt PM emitted in the same year. The power class 130-560 kW contributes the most, having a share of 25% to total PM emission. The highest contribution comes from Stage IIIA machinery (37%), followed by unregulated machinery with a share of 24%.

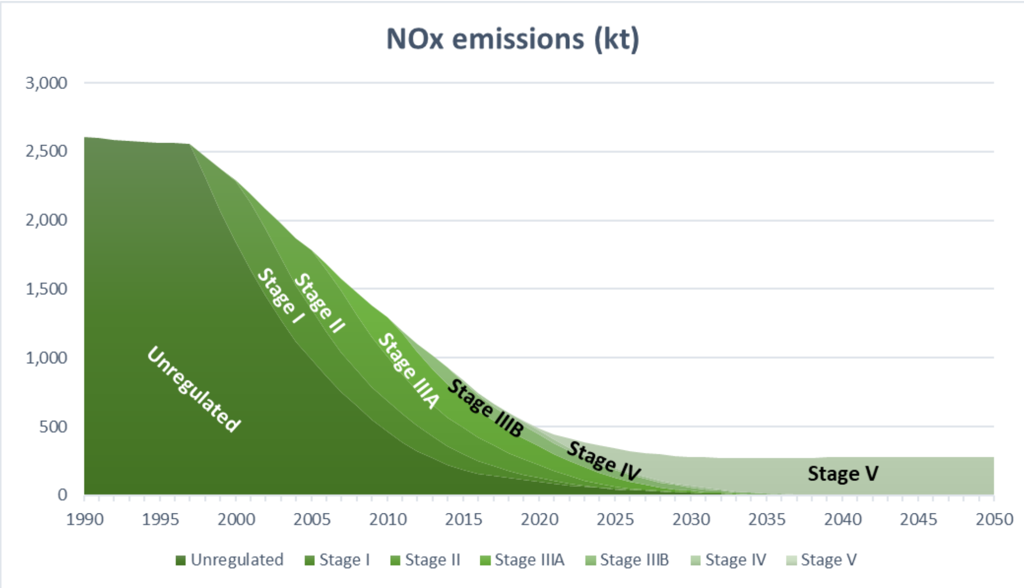


Figure 4-6 Evolution of NO_x emissions (kt) from agriculture/construction, 1990-2050

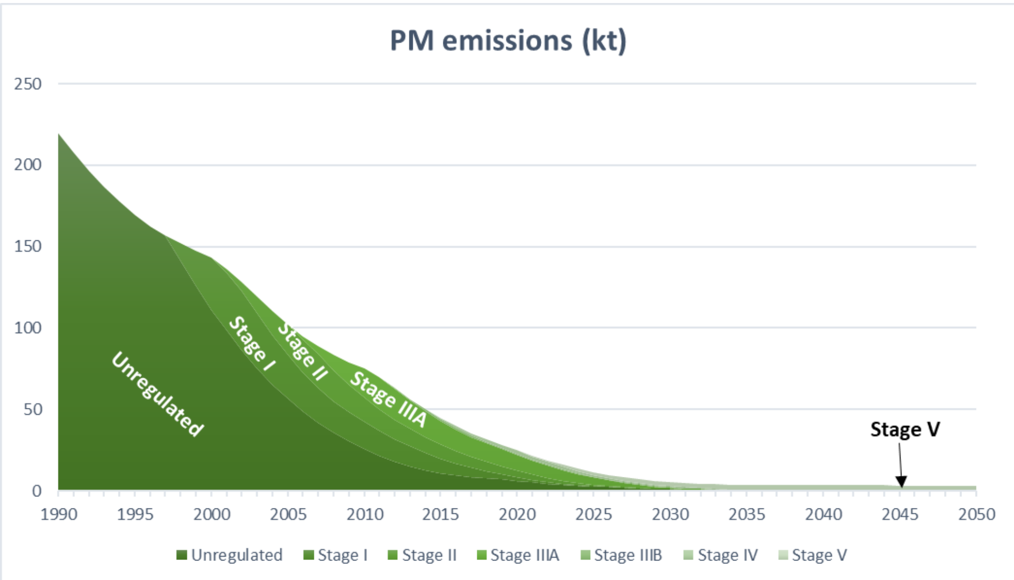


Figure 4-7 Evolution of PM emissions (kt) from agriculture/construction, 1990-2050

Table 4-11 Calculated NO_x emissions (kt) per category for the EU-28, 2019

Category	Total NO_x emissions	Share	<19 kW	19-37 kW	37-56 kW	56-75 kW	75-130 kW	130-560 kW	>560 kW
Small Equipment (Agricultural)	**1.50**	**0.3%**	1.50	0.00	0.00	0.00	0.00	0.00	0.00
Small Equipment (Construction)	**9.11**	**1.7%**	2.77	6.34	0.00	0.00	0.00	0.00	0.00
Generator Sets	**92.45**	**17.3%**	1.12	4.91	9.45	5.67	6.47	12.20	52.63
Agricultural Tractors	**176.42**	**32.9%**	1.14	1.08	23.71	42.30	57.99	50.19	0.00
Agricultural Harvesters	**101.12**	**18.9%**	0.00	0.00	0.00	0.00	2.47	82.32	16.32
Light Construction Equipment	**98.74**	**18.4%**	7.79	12.46	18.59	59.91	0.00	0.00	0.00
Heavy Construction Equipment	**56.34**	**10.5%**	0.00	0.00	0.00	0.00	16.26	24.17	15.91
Total	**535.67**	**100%**	**14.32**	**24.79**	**51.74**	**107.88**	**83.19**	**168.88**	**84.87**
Share			**3%**	**5%**	**10%**	**20%**	**15%**	**31%**	**16%**

Table 4-12 Calculated NO_x emissions (kt) per Stage for the EU-28, 2019

Emission Stage	Total NO_x emissions	Share	<19 kW	19-37 kW	37-56 kW	56-75 kW	75-130 kW	130-560 kW	>560 kW
Stage V	**14.65**	**2.7%**	1.11	2.23	4.40	0.00	0.00	3.68	3.23
Stage IV	**27.14**	**5.1%**	0.00	0.00	0.00	5.82	5.86	15.46	0.00
Stage IIIB	**89.39**	**16.7%**	0.00	0.00	21.26	19.83	19.82	28.48	0.00
Stage IIIA	**150.17**	**28.0%**	0.00	22.31	10.44	28.15	27.19	62.07	0.00
Stage II	**110.36**	**20.6%**	0.00	0.26	10.45	36.12	20.92	42.61	0.00
Stage I	**38.42**	**7.2%**	0.00	0.00	4.42	15.26	7.19	11.56	0.00
Unregulated	**105.54**	**19.7%**	13.21	0.00	0.78	2.69	2.21	5.02	81.64
Total	**535.67**	**100%**	**14.32**	**24.79**	**51.74**	**107.88**	**83.19**	**168.88**	**84.87**
Share			**3%**	**5%**	**10%**	**20%**	**15%**	**31%**	**16%**

Table 4-13 Calculated PM emissions (kt) per category for the EU-28, 2019

Category	Total PM emissions	Share	<19 kW	19-37 kW	37-56 kW	56-75 kW	75-130 kW	130-560 kW	>560 kW
Small Equipment (Agricultural)	**0.20**	**0.7%**	0.20	0.00	0.00	0.00	0.00	0.00	0.00
Small Equipment (Construction)	**0.84**	**3%**	0.38	0.46	0.00	0.00	0.00	0.00	0.00
Generator Sets	**4.72**	**17.1%**	0.15	0.36	0.38	0.35	0.33	0.50	2.65
Agricultural Tractors	**8.81**	**31.9%**	0.15	0.08	0.95	2.58	3.00	2.05	0.00

Agricultural Harvesters	**4.31**	**15.6%**	0.00	0.00	0.00	0.00	0.13	3.36	0.82
Light Construction Equipment	**6.37**	**23%**	1.06	0.91	0.75	3.65	0.00	0.00	0.00
Heavy Construction Equipment	**2.42**	**8.7%**	0.00	0.00	0.00	0.00	0.76	0.94	0.73
Total	**27.66**	**100%**	1.95	1.82	2.08	6.57	4.22	6.84	4.20
Share			**7%**	**7%**	**7%**	**24%**	**15%**	**25%**	**15%**

Table 4-14 Calculated PM emissions (kt) per Stage for the EU-28, 2019

Emission Stage	Total PM emissions	Share	<19 kW	19-37 kW	37-56 kW	56-75 kW	75-130 kW	130-560 kW	>560 kW
Stage V	**0.26**	**0.9%**	0.06	0.01	0.01	0.00	0.00	0.14	0.04
Stage IV	**1.70**	**6.1%**	0.00	0.00	0.00	0.36	0.37	0.97	0.00
Stage IIIB	**0.77**	**2.8%**	0.00	0.00	0.11	0.15	0.15	0.36	0.00
Stage IIIA	**10.21**	**37%**	0.00	1.78	0.89	2.40	2.04	3.10	0.00
Stage II	**5.15**	**18.6%**	0.00	0.03	0.60	2.06	1.05	1.42	0.00
Stage I	**3.04**	**11%**	0.00	0.00	0.41	1.41	0.55	0.68	0.00
Unregulated	**6.53**	**23.6%**	1.89	0.00	0.05	0.19	0.07	0.18	4.15
Total	**27.66**	**100%**	1.95	1.82	2.08	6.57	4.22	6.84	4.20
Share			**7%**	**7%**	**7%**	**24%**	**15%**	**25%**	**15%**

4.2.3 Comparison to other sources

The results presented above are compared with calculated NO_x and PM emissions as officially reported by EU Member States in their emissions inventories submitted under the Convention on Long-Range Transboundary Air Pollution (CLRTAP) for the European Monitoring and Evaluation Programme (EMEP, 2018). The most recent (2016) reported emissions for the EU-28, were collected. Results of this comparison are summarised in Table 4-15. Whereas there is good agreement for PM emissions, NO_x emissions calculated in this study are about 45% higher compared to emission data reported by EU Member States. This might be due to different methods and emissions factors used across Member States.

Table 4-15 Comparison for NO_x and PM emissions, EU-28

Source	NO_x emissions (kt)	PM emissions (kt)
EMEP	506.9	42.0
Current calculations	745.8	39.8

In addition to the above, emissions results from the present study have been also compared against the JRC study. To this aim, emissions for the EU-15, 2005 were calculated for each machinery category and power class. The calculated NOx emissions from the present study and the JRC study are displayed in Table 4-16and Table 4-17 respectively, whereas PM emissions are displayed in Table 4-18 and Table 4-19 respectively.

For both pollutants, total emissions calculated in this study are somewhat lower, being about 20% lower for NO_x and 14% lower for PM. This is to a very large extent due to the lower fleet size assumed in this study, as previously discussed and shown in Table 4-7. The distribution of emissions across the different machinery types and power classes is very similar in the two studies (see the relevant "Share" rows and columns in the tables below).

Table 4-16 Calculated NO_x emissions (kt) per category for EU15, 2005 (present study)

Category	Total NO_x emissions	Share	<19 kW	19-37 kW	37-56 kW	56-75 kW	75-130 kW	130-560 kW	>560 kW
Small Equipment (Agricultural)	**1.1**	**0.1%**	1.11	0.00	0.00	0.00	0.00	0.00	0.00
Small Equipment (Construction)	**7.8**	**0.8%**	2.05	5.71	0.00	0.00	0.00	0.00	0.00
Generator Sets	**145.8**	**14.%**	0.83	4.43	12.67	12.60	17.18	36.79	61.27
Agricultural Tractors	**433.0**	**42%**	0.84	0.97	31.80	94.06	153.93	151.36	0.00
Agricultural Harvesters	**73.4**	**7%**	0.00	0.00	0.00	0.00	1.76	66.60	5.10
Light Construction Equipment	**175.1**	**17%**	5.77	11.24	24.92	133.20	0.00	0.00	0.00
Heavy Construction Equipment	**195.9**	**19%**	0.00	0.00	0.00	0.00	53.77	122.59	19.54
Total	**1,032**	**100%**	**10.61**	**22.35**	**69.39**	**239.9**	**226.6**	**377.3**	**85.90**
Share			**1%**	**2%**	**7%**	**23%**	**22%**	**37%**	**8%**

Table 4-17 Calculated NO_x emissions (kt) per category for EU15, 2005 (JRC study)

Category	Total NO_x emissions	Share	<19 kW	19-37 kW	37-56 kW	56-75 kW	75-130 kW	130-560 kW	>560 kW
Small Equipment (Agricultural)	**1.47**	**0.1%**	1.47	0.00	0.00	0.00	0.00	0.00	0.00
Small Equipment (Construction)	**8.4**	**0.7%**	2.71	5.72	0.00	0.00	0.00	0.00	0.00
Generator Sets	**183.7**	**14.2 %**	1.10	4.43	14.10	14.02	20.28	44.18	85.61
Agricultural Tractors	**515.2**	**40%**	1.14	0.99	36.05	106.64	185.15	185.17	0.00
Agricultural Harvesters	**89.2**	**7%**	0.00	0.00	0.00	0.00	2.08	79.98	7.12
Light Construction Equipment	**231.8**	**18%**	9.29	13.73	33.84	174.93	0.00	0.00	0.00
Heavy Construction Equipment	**255.2**	**20%**	0.00	0.00	0.00	0.00	70.64	156.99	27.57
Total	**1,285**	**100%**	**15.72**	**24.88**	**83.99**	**295.6**	**278.2**	**466.3**	**120.3**
Share			**1%**	**2%**	**7%**	**23%**	**22%**	**36%**	**9%**

Table 4-18 Calculated PM emissions (kt) per category for EU15, 2005 (present study)

Category	Total PM emissions	Share	<19 kW	19-37 kW	37-56 kW	56-75 kW	75-130 kW	130-560 kW	>560 kW
Small Equipment (Agricultural)	**0.16**	**0.3%**	0.16	0.00	0.00	0.00	0.00	0.00	0.00
Small Equipment (Construction)	**0.96**	**1.5%**	0.29	0.67	0.00	0.00	0.00	0.00	0.00
Generator Sets	**9.54**	**15.4%**	0.12	0.52	1.01	1.00	0.85	1.56	4.48
Agricultural Tractors	**24.33**	**39.2%**	0.12	0.11	2.53	7.48	7.66	6.42	0.00
Agricultural Harvesters	**3.29**	**5.3%**	0.00	0.00	0.00	0.00	0.09	2.83	0.37
Light Construction Equipment	**14.72**	**23.7%**	0.82	1.31	1.98	10.60	0.00	0.00	0.00
Heavy Construction Equipment	**9.08**	**14.6%**	0.00	0.00	0.00	0.00	2.68	5.00	1.40
Total	**62.06**	**100%**	1.52	2.61	5.52	19.08	11.28	15.81	6.25
Share			**2%**	**4%**	**9%**	**31%**	**18%**	**26%**	**10%**

Table 4-19 Calculated PM emissions (kt) per category for EU15, 2005 (JRC study)

Category	Total PM emissions	Share	<19kW	19-37 kW	37-56 kW	56-75 kW	75-130 kW	130-560 kW	>560 kW
Small Equipment (Agricultural)	**0.21**	**0.3%**	0.21	0.00	0.00	0.00	0.00	0.00	0.00
Small Equipment (Construction)	**1.01**	**1.4%**	0.39	0.62	0.00	0.00	0.00	0.00	0.00
Generator Sets	**11.49**	**16%**	0.16	0.48	1.00	0.99	0.94	1.81	6.12
Agricultural Tractors	**26.53**	**37%**	0.16	0.11	2.55	7.55	8.58	7.58	0.00
Agricultural Harvesters	**3.88**	**5.4%**	0.00	0.00	0.00	0.00	0.10	3.27	0.51
Light Construction Equipment	**17.63**	**24.7%**	1.33	1.50	2.40	12.41	0.00	0.00	0.00
Heavy Construction Equipment	**10.91**	**15.2%**	0.00	0.00	0.00	0.00	3.16	5.86	1.89
Total	**71.67**	**100%**	**2.25**	**2.71**	**5.94**	**20.95**	**12.78**	**18.52**	**8.51**
Share			**3%**	**4%**	**8%**	**29%**	**18%**	**26%**	**12%**

4.3 Railways and Inland Waterways

4.3.1 Fleet turnover

Similar to the agricultural and construction machinery the first step was to collect recent stock data on the railways and inland waterways for the EU-28. For the time-series 2007-2016 data on the stock of both railways and inland waterways were retrieved from Eurostat (Eurostat, 2018). For some

Member States, data on the railways stock were not available in Eurostat's database, thus other sources were used. More specifically, for total diesel locomotives for Germany, relevant information was retrieved from the official web-page of the Deutsche Bahn (Deutsche Bahn, 2017). For the United Kingdom, the number of railways rolling stock was obtained from the Briefing paper on Railway rolling stock (Butcher, 2017).

The collected data for EU-28, for the time period 2007-2016 are presented in Table 4-20. As mentioned in the JRC study, each railcar can have more than one engine, thus the numbers provided by Eurostat were multiplied with 1.7 in order to take this fact into account.

Table 4-20 Total fleet of railways (diesel locomotives and railcars) and inland waterways (self-propelled barges) for EU-28, 2007-2016

Category	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Inland Waterways (self-propelled barge)	9644	9642	9628	9585	9601	9499	9343	9293	9116	8832
Railways (diesel locomotives)	16991	16685	16459	16266	16141	15864	15804	15705	15568	15594
Railways (diesel railcars)	19211	19130	19199	19265	19409	19338	19406	19254	19302	19254

The above table shows very small fluctuations in the total fleet from 2007 to 2016. To simulate the evolution of the fleet after 2016, the total stock for both railways and inland waterways has been kept constant, very close to the values of the above table.

To split the fleet into emissions Stages and to allocate the new registrations to the corresponding emission Stages, an average sales value was used. The number of sales of self-propelled barges was retrieved from CCNR (CCNR, 2018) and was adjusted to match the data of the total fleet as obtained from Eurostat. For railways, the number of sales was obtained from the UIC -Rail Diesel study (UIC, 2006). It is repeated that total stock was considered stable; thus, the number of de-registrations was considered equal to the average sales number. The average number of sales per category, which is used for all years in the time-series, is presented in Table 4-21..

Table 4-21 Average annual sales of inland waterways and railways per category

Category	Sales
Inland Waterways (self-propelled barge)	272
Railways (diesel locomotives)	600
Railways (diesel railcars)	936

The total stock was split into emission Stages according to their corresponding introduction dates. The emission limits, along with their introduction date are presented in Table 4-22.

Table 4-22 Emission limits (g/kWh) and their introduction dates

Category	Pollutant	Stage V	Stage IIIB	Stage IIIA	
Vessels		Jan2020		Jan2009	Jan2007
	NO_x	1.8		8.7	7.5
	PM	0.015		0.5	0.4

Railcars		Jan2021	Jan2012	Jan2006	
	NO_x	2	2	4	
	PM	0.015	0.025	0.2	
Locomotives (130 - 560 kW)		Jan2021	Jan2012	Jan2007	
	NO_x	4	4	4	
	PM	0.025	0.025	0.2	
Locomotives (560 - 2000 kW)		Jan2021	Jan2012	Jan2009	
	NO_x	4	4	6	
	PM	0.025	0.025	0.2	
Locomotives (> 2000 kW)		Jan2021	Jan2012	Jan2009	
	NO_x	4	4	7.4	
	PM	0.025	0.025	0.2	

By combining the above information, a complete fleet turnover has been developed for the timeseries 1990-2050. It should be noted that a transition scheme for Stage V machinery was followed to build the fleet turnover.

For the introduction of Stage V a transition period of two years was assumed, based on (Troppmann and Wolska, 2007). More specifically, in the first year of the mandatory application of Stage V to the various power classes, 30% of the new registrations is considered to be Stage V, whereas the remaining 70% belong to the previous emission Stage (depending on the power class). In the second year the percentage of new registrations complying with Stage V is increased to 60% and in the third year, all new registrations are Stage V.

Figure 4-8 displays the evolution of the fleet per emission Stage from 1990 to 2050 for inland waterways; the change in the share of the fleet in the different emission Stages over time can be seen in this figure. Unregulated fleet is gradually phased out of the fleet, but a small amount, around 11%, is still present in 2050. For railways, the situation is slightly different, since for all categories (railcars, locomotives and shunting locomotives) unregulated stock is completely phased out of the fleet after 2030 for railcars and after 2040 for locomotives, as shown in Figure 4-9, Figure 4-10 and Figure 4-11 respectively. It is reminded that very few statistical data covering the entire EU are available and hence the fleet turnover has been simulated by combining all the information presented above. The category "diesel locomotives" was split to shunting locomotives and locomotives with a share of 40% and 60% respectively.

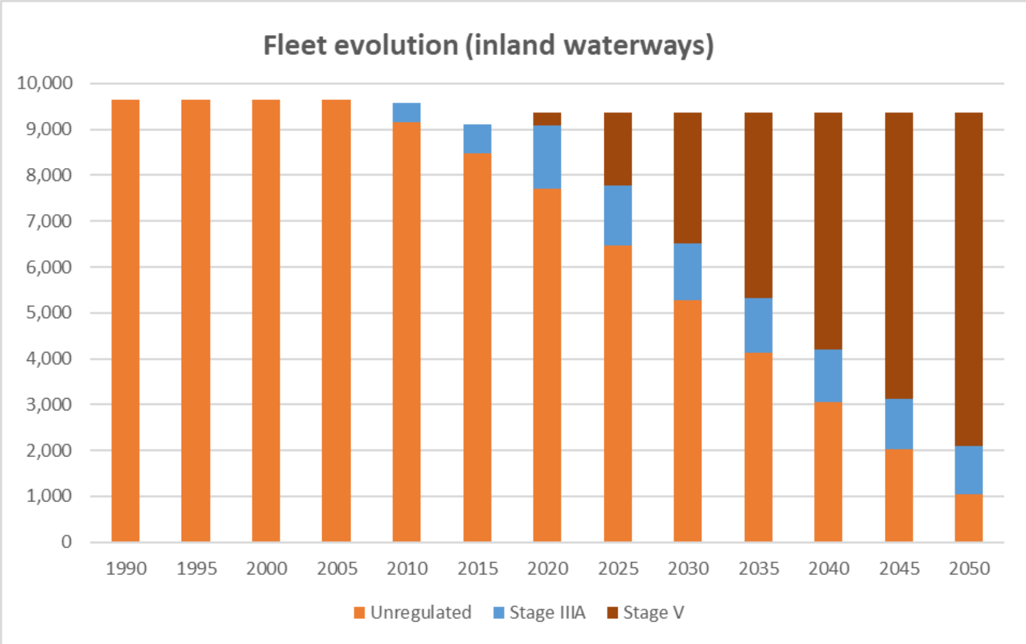


Figure 4-8 Inland waterways fleet evolution, 1990-2050

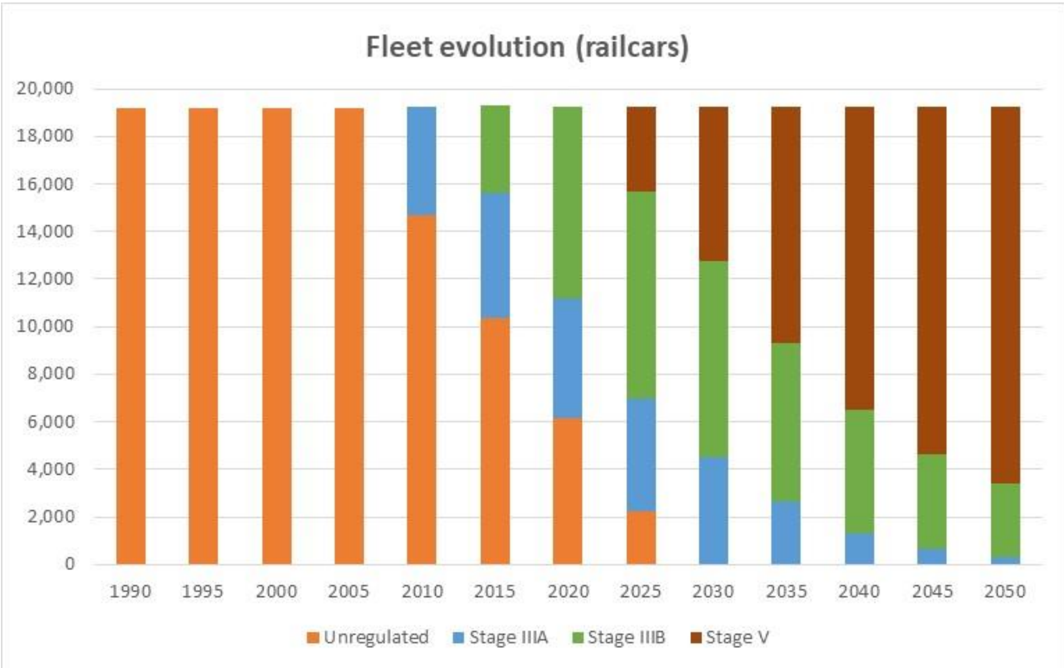


Figure 4-9 Railcars fleet evolution, 1990-2050

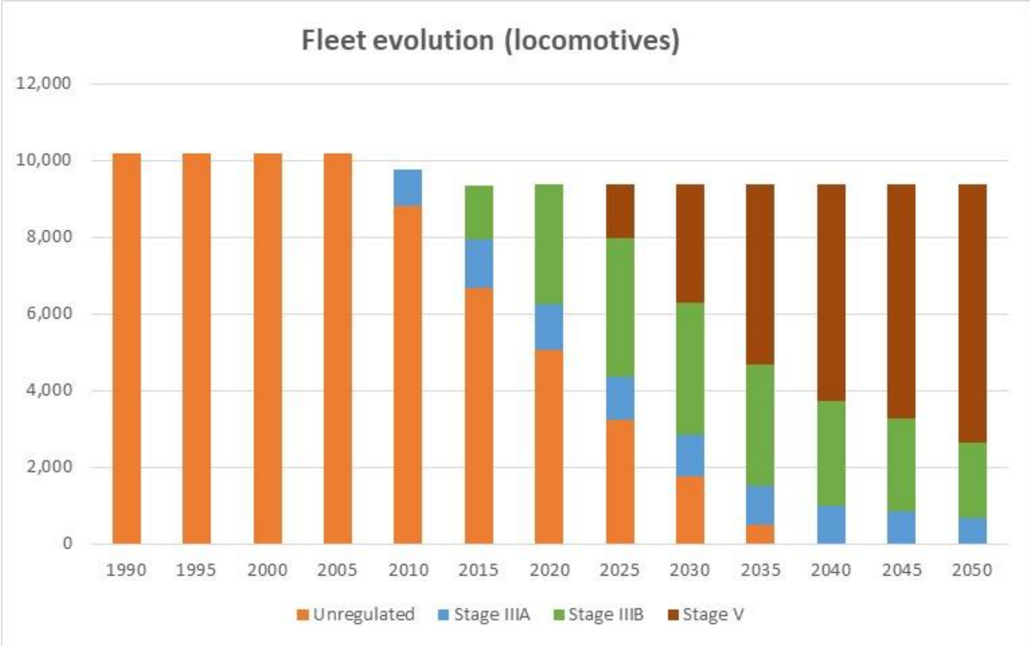


Figure 4-10 Locomotives fleet evolution, 1990-2050

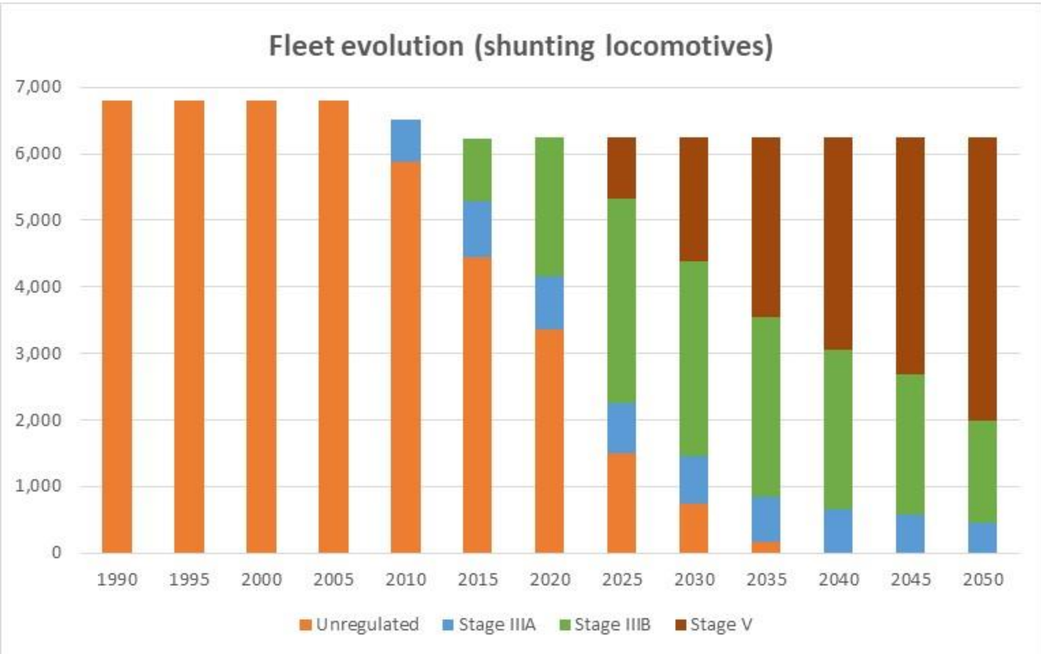


Figure 4-11 Shunting locomotives fleet evolution, 1990-2050

4.3.2 Emissions inventory

The emission inventory for railways and inland waterways was carried out using a simplified approach. The reason is that, as stated in the JRC study, the inland waterways vessels are used over long periods of time, their engines are replaced several times and specific engine data are not available. The lack of precise and comprehensive data on the engine composition of the fleet is also supported by the Commission Staff working document-NAIADES II (European Commission, 2013c). A similar situation exists for railways; thus, a simplified approach was also selected for building the emission inventory for this category.

The emissions have been calculated by using the following equation:

$$Emissions = fleet\ stock * average\ engine\ power * operating\ hours * load\ factor * emissions\ factor$$

Data on average engine power, operating hours and load factors were obtained from the JRC study, as well as from the ARCADIS study (Arcadis, 2009) and are presented in Table 4-23. For inland waterways only vessels with engine power above 300 kW are of interest, thus the average engine power considered for the calculations is equal to 440 kW.

Table 4-23 Fleet characteristics by category

	Average engine power (kW)	Operating hours	Load factor
Vessels	440	4,000	0.5
Railcars	350	3,000	0.58
Locomotives (130 - 560 kW)	345	3,500	0.3
Locomotives (560 - 2000 kW)	1,280	3,500	0.3
Locomotives (> 2000 kW)	2,200	3,500	0.3

For calculating the emissions, the emission limits, as presented in Table 4-22, were multiplied with a correction factor of 0.8 for both PM and NO_x to account for the fact that the expected average emissions are somewhat lower than their respective limit values. For unregulated engines for inland waterways, emission factors from the JRC study were used, whereas for railways the corresponding values were obtained from the UIC -Rail Diesel study (UIC, 2006). The emission factors, used for calculating the emissions, are presented in Table 4-24.

Table 4-24 Emission factors (g/kWh) per category

Category and power class	Pollutant	Stage V	Stage IIIB	Stage IIIA		Unregulated
Inland Waterways	NO_x	1.44		6.96	6	14
	PM	0.012		0.4	0.32	0.5
Railcars	NO_x	1.6	1.6	3.2		7
	PM	0.12	0.02	0.16		0.14
Locomotives (130 - 560 kW)	NO_x	3.2	3.2	3.2		11.3
	PM	0.02	0.02	0.16		0.215
Locomotives (560 - 2000 kW)	NO_x	3.2	3.2	4.8		11.3
	PM	0.02	0.02	0.16		0.215
Locomotives (> 2000 kW)	NO_x	3.2	3.2	5.92		11.3
	PM	0.02	0.02	0.16		0.215

By combining all the above data for the fleet of inland waterways and railways, detailed emissions calculations have been carried out. NO_x and PM emissions for the time period from 1990 to 2050 for inland waterways are presented in Figure 4-12 and Figure 4-13 respectively.

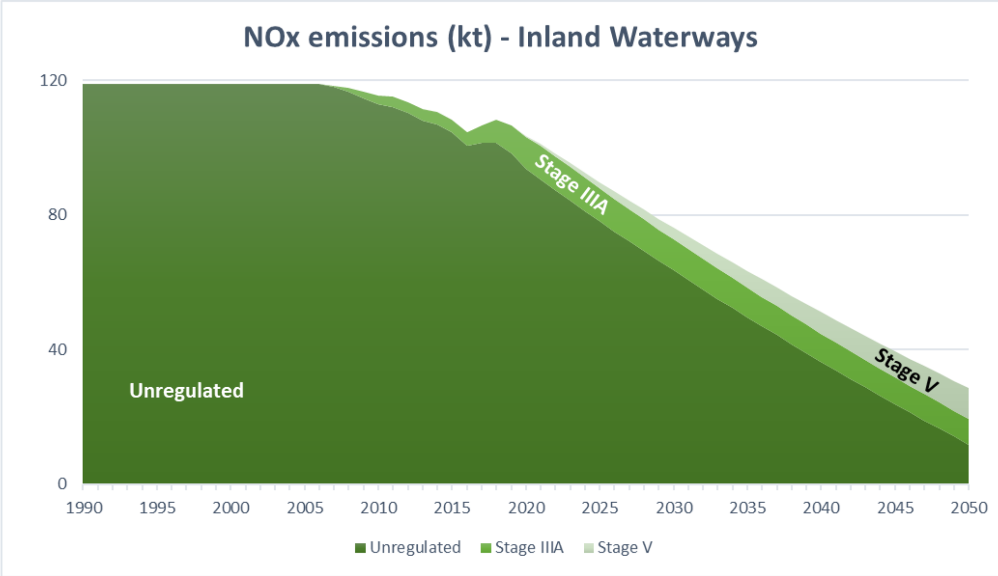


Figure 4-12 Evolution of NO_x emissions (kt) from inland waterways, 1990-2050

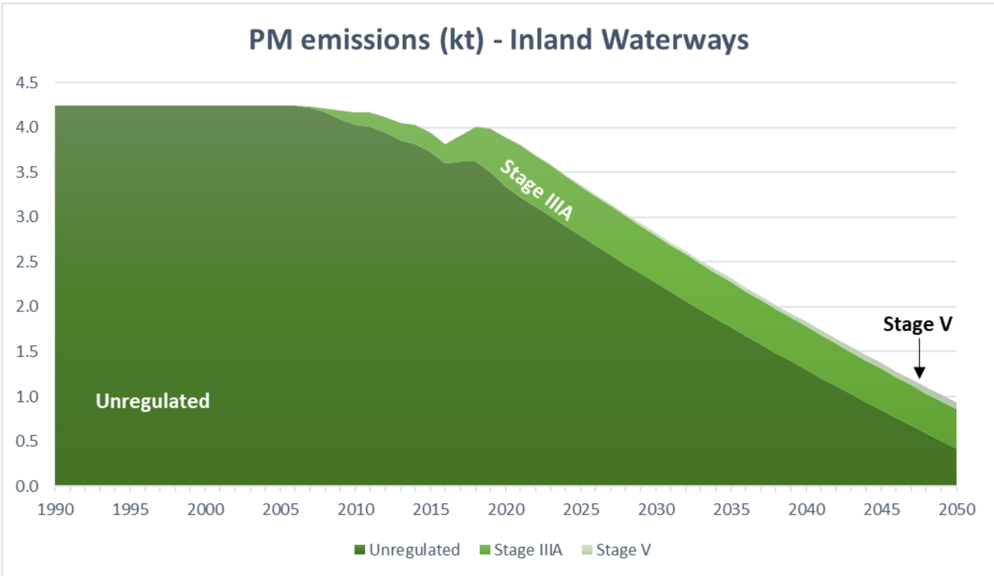


Figure 4-13 Evolution of PM emissions (kt) from inland waterways, 1990-2050

For inland waterways, NO_x emissions are constantly declining since the introduction of Stage limits around 2008. Emissions from unregulated fleet dominate total NO_x emissions until 2050, since the unregulated fleet is still present in 2050, though with a smaller contribution to the total fleet. An almost similar situation is observed for PM emissions, with a slightly greater reduction in total PM emissions over the examined time period.

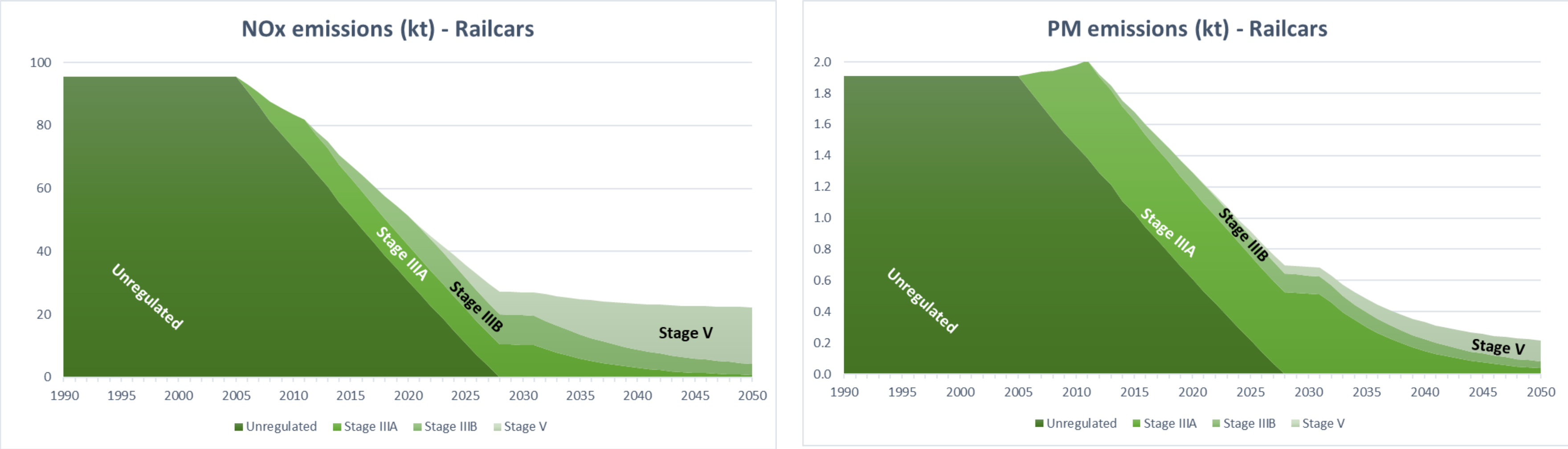


Figure 4-14 Evolution of NO_x and PM emissions (kt) from railcars, 1990-2050

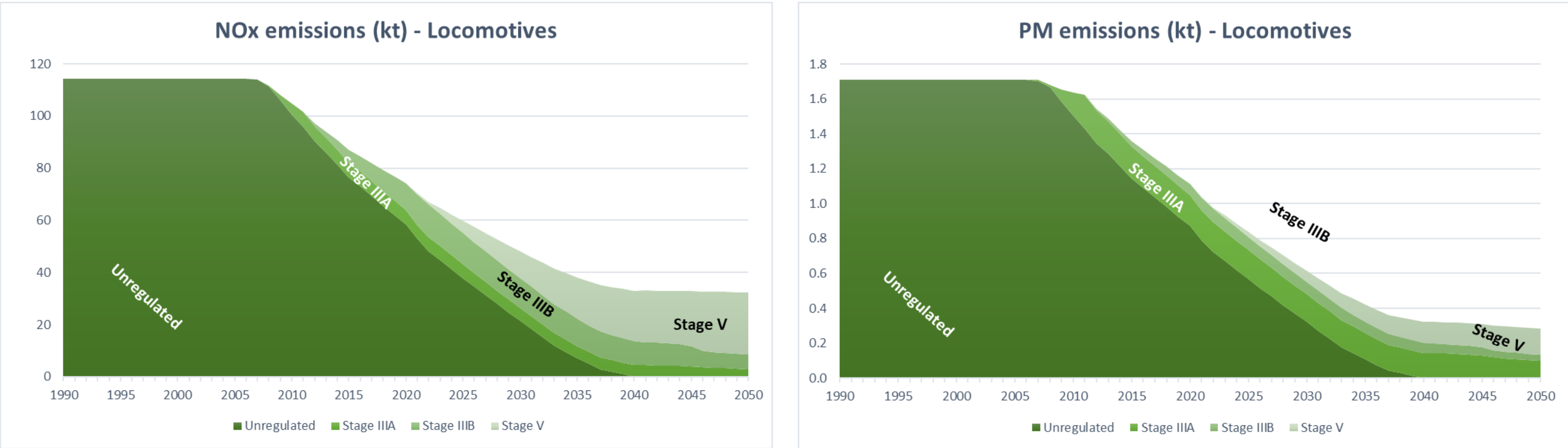
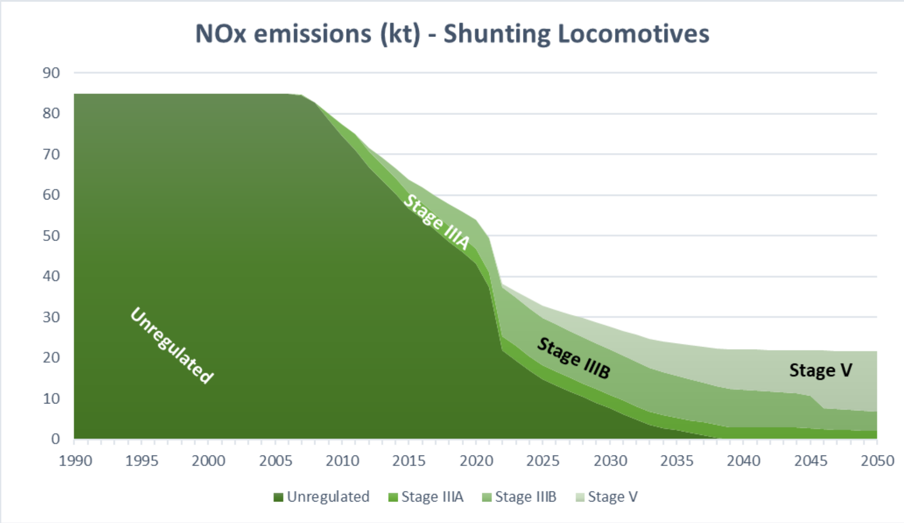


Figure 4-15 Evolution of NO_x and PM emissions (kt) from locomotives, 1990-2050



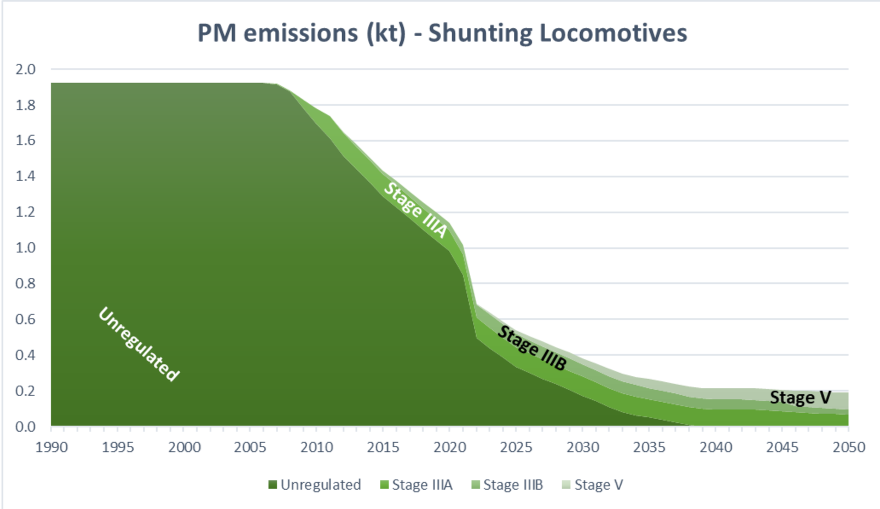


Figure 4-16 Evolution of NO_x and PM emissions (kt) from shunting locomotives, 1990-2050

For railways, the evolution of NO_x and PM emissions for railcars, locomotives and shunting locomotives are presented in Figure 4-14, Figure 4-15 and Figure 4-16 respectively. All unregulated engines are phased-out in some time in the future, thus emissions after 2028 for railcars and 2040 for locomotives result only from post-Stage IIIA engines. Emissions of PM are more drastically reduced over the examined time period, due to the much higher reductions brought by the different emission Stage steps.

4.3.3 Comparison to other sources

The results presented above are compared with calculated NO_x and PM emissions as reported in the JRC study and in the ARCADIS report. As presented in Table 4-25 and Table 4-26, for railways a good agreement with the Arcadis study is observed for both NO_x and PM emissions. Whereas, total emissions calculated in this study are somewhat lower, being about 26% lower for NO_x and 45% lower for PM, compared to calculations presented in the JRC study. This is to a very large extent due to the older fleet, with higher emission factors, considered in the JRC study.

Table 4-25 Railways - NO_x emissions (kt) for EU28

Source	2005	2010	2020
JRC study	401	-	-
Arcadis study	300	240	160
Current calculations	295	265	179

Table 4-26 Railways - PM emissions (kt) for EU28

Source	2005	2010	2020
JRC study	11	-	-
Arcadis study	7	5	3
Current calculations	6	5	4

For inland waterways a working document by the Commission staff was also reviewed and the calculation of NOx and PM emissions of all studies is included in Table 4-27 and Table 4-28 respectively. The Arcadis study, as well as the Commission Staff working document were drafted in 2009 and 2013 respectively, thus the evaluation of the emissions was based on assuming lower NOx emission limits as the ones introduced later on. For this reason, total NOx emissions calculated in this study are somewhat higher. The results for PM emissions are almost similar across all studies.

Table 4-27 Inland waterways - NO_x emissions (kt) for EU28

Source	2005	2010	2012	2020	2050
JRC study	134	-	-	-	-
Arcadis study	-	97	-	88	-
Commission Staff Working Document (NAIADES II)	-	-	94	75	34
Current calculations	119	115	113	103	28

Table 4-28 Inland waterways - PM emissions (kt) for EU28

Source	2005	2010	2012	2020	2050
JRC study	4.8	-	-	-	-
Arcadis study	-	5.6	-	4.8	-
Commission Staff Working Document (NAIADES II)	-	-	5.2	3.8	1.3
Current calculations	4.2	4.2	4.1	3.9	0.9

4.4 Conclusions

Agriculture and Construction

- The total size of the agricultural and construction machinery fleet has remained almost constant over the years, with very small variations. The fleet replacement however has been rather quick for many machinery types (such as small equipment and heavy construction equipment) with newer technologies replacing older ones. This is due to the relatively short lifetime of these machinery types.
- The total fleet amounts to 9.6 million, dominated by mid-size machinery: 26% are in the 56-75 kW power class, followed by 17% in the 75-130 kW class and 16% in the 37-56 kW class.
- NO_x emissions are constantly declining since the introduction of Stage I and are projected to further decrease until about 2030 and remain constant afterwards if no post-Stage V limit are introduced.
- Emissions of PM are even more drastically reduced over the examined time period. This is due to the much higher reductions brought by the different emission stage steps. This, in turn, has been enabled by the introduction of DPF which have a very high reduction efficiency (on the order of 99%) in many power classes already since Stage IIIB.
- NRMM with stage IIIA or earlier will disappear by about 2030.

Railways and inland waterways

- For all categories the total fleet size remains almost constant over the years. For railways and inland waterways, unregulated engines are an important part of the fleet, being projected to be phased-out only after 2040.
- NO_x and PM emissions are constantly declining since the introduction of Stage limits, with PM emissions showing a slightly higher reduction. For railways, NO_x and PM emissions remain almost constant after around 2040, when all unregulated engines are phased-out of the fleet. For inland waterways, the situation is slightly different, since unregulated engines are still present until 2050, thus NO_x and PM emissions are constantly declining over the examined time period.

5 Technologies of new NRMM engines complying with the different limit value Stages

5.1 Literature review

The increasing environmental demands and requirements are an important driver for OEMs. The technology trend is driven primarily by regulation, which has been the focus of OEMs' R&D work for European home markets for many years.

However, NRMM also has to meet a number of other requirements. Technologies that are suitable for meeting emission limits must also function in a comparatively harsh operating environment, e.g. with high levels of dust and dirt, vibrations and shocks. In addition, off-road engines have to meet a wide variety of mechanical requirements and operate over a broad spectrum of work cycles. Another challenge is the space in the engine compartment, which is sometimes difficult to find with certain equipment. After all, non-road equipment must meet safety, visibility and functional requirements that place special demands on engine compartment size and packaging.

Emission compliance technologies also have an impact on retrofitting options, as some technologies are easier to retrofit than others. The increasingly stringent regulatory programmes for off-road diesel engines have driven the development of engine design and after-treatment technologies to control air pollutant emissions. Figure 5-1 gives a general overview and also takes a look at the expected future developments[78,79].

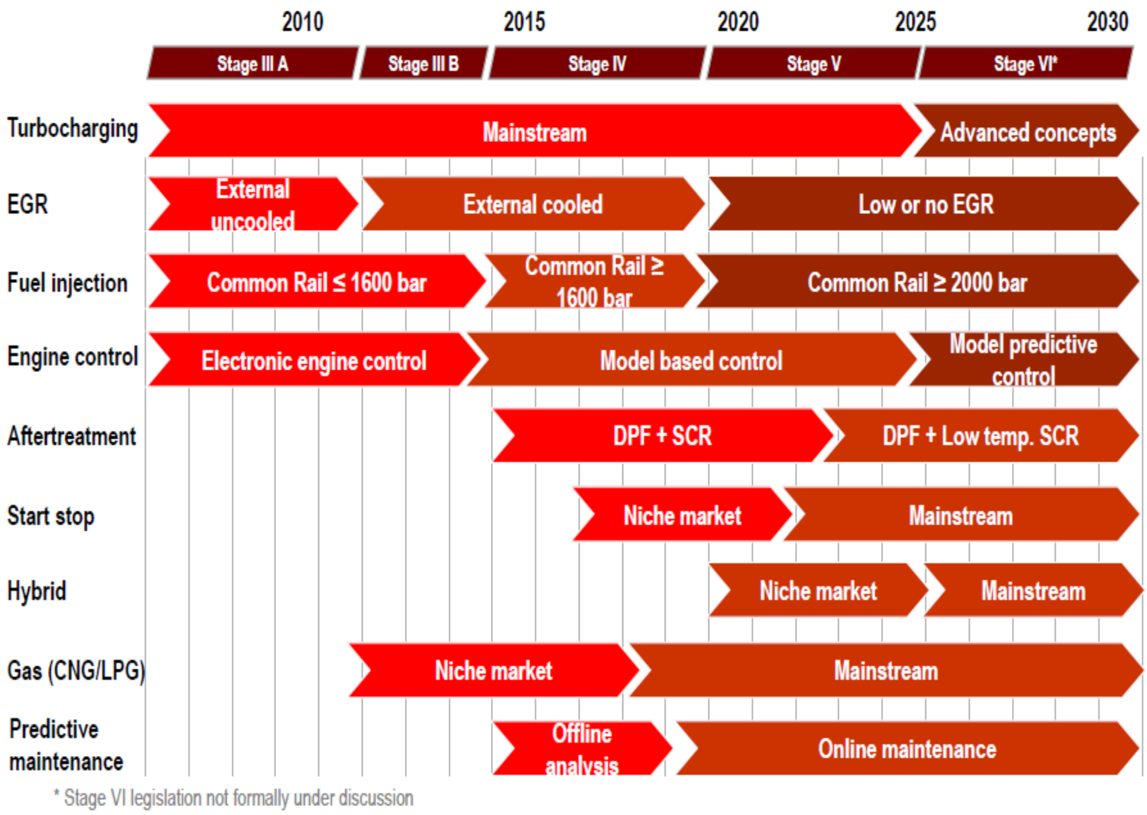


Figure 5-1 Development of technologies with increasing stringency of limit value legislation

[78] Rajamani 2017: Die Zukunft des Dieselmotors.
[79] Please note: The Figure does not include battery powered concepts although there are developments into this direction as well, see for example Bellona Europa 2018: ZERO EMISSION CONSTRUCTION SITES: THE POSSIBILITIES AND BARRIERS OF ELECTRIC CONSTRUCTION MACHINERY

Compliance with early emission limits required to make changes to the design of the internal combustion engine. The reduction in emissions has been achieved mainly through developments and modifications to the fuel injection and ventilation systems, although the approaches in the cylinder also include changes to the engine geometry to promote better mixing of air and fuel. In addition, NO_x emissions have been reduced through the use of exhaust gas recirculation (EGR). The internal measures have been driven by the widespread use of electronic engine controls, which enable advanced control of the combustion process.

However, internal measures are limited as they are confronted with the well-known trade-off problem between particle control and nitrogen oxide emissions. Internal control strategies for one pollutant tend to have a negative impact on emissions of the other pollutant due to fundamentally different formation mechanisms of NO_x and PM.

While the technological possibilities up to Stage IIIA all had internal character, e.g. Common Rail with electronic control and exhaust gas recirculation, the step to Stage IIIB/IV was accompanied by more demanding measures. Among the most important after-treatment technologies used in some categories of the non-road sector are diesel oxidation catalyst (DOC) and diesel particulate filter (DPF) for PM control and selective catalytic reduction (SCR) for NO_x control[80]:

- Diesel oxidation catalyst (DOC) for PM, HC and CO reduction. This is a flow-through catalytic converter composed of a monolith honeycomb substrate coated with a platinum group metal catalyst. DOC treats the soluble organic fraction of exhaust PM only.
- Diesel particulate filter (DPF) for PM reduction. This is a wall-flow filtration device. Filters are regenerated using active and/or passive regeneration methods to oxidize and remove collected particles.
- Selective catalytic reduction (SCR) for NO_x reduction. Catalytic reduction of NO and NO_2 to N_2 and H_2O using ammonia as reducing agent. Catalysts types include vanadium, iron-exchanged zeolite, and copper exchanged zeolite. Ammonia is generated from a urea solution (AdBlue).
- Ammonia slip catalyst (ASC) for NH_3 reduction. This is an oxidation catalyst used for the control of ammonia passing through the SCR system.

A pre-requisite for the usage of after-treatment technologies are ultra-low-sulphur diesel fuels of no more than 15 ppm, better 10 ppm or less; this is given in the EU since many years (European Commission, 2009b)[81].

The major challenge for the use of exhaust after-treatment systems is that systems must operate in a narrow temperature window in order to be effective. Diesel particulate filters need to be operated above a certain temperature to ensure regeneration, and NO_x after-treatment has both a low and high temperature requirement. The effectiveness of all NO_x control systems declines dramatically at exhaust temperatures below approximately 250 °C. This presents a problem for non-road equipment that experiences frequent periods of low-load operation or idling, when exhaust temperatures can drop to 150 °C or lower.

For some Stage IIIB categories, the manufacturer had to decide whether to opt for exhaust gas recirculation with external cooling and DPF or whether to use SCR. Since the step to Stage IV was planned with a short delay and extended by flexibility rules, many manufacturers also developed Stage IV systems directly. Here, too, there was a choice between advanced SCR and DPF systems. More specifically, one option included tuning engines for low PM emissions and controlling relatively high NO_x emissions with SCR or using PM post-treatment equipment such as DPF and/or DOC together with cooled EGR for NO_x control. The main advantage of the low PM option is that the engine design also optimises efficiency and reduces fuel consumption. If, on the other hand, SCR is used to treat the

[80] Scherm/Euromot 2017: Technologies for European Non-road emission limit Stages IIIB, I and V
[81] Sulphur content in fuels for mobile non-road vehicles — including mobile machinery, agricultural and forestry tractors, as well as inland waterway vessels and recreational craft —is 10 ppm from 2011 (certain flexibilities apply).

resulting higher NO_x emissions, the engine owner incurs additional costs for the urea solution and the engine designs must provide space for a urea storage tank. This also includes the construction of an additional infrastructure.

There are no official EU statistics on the technologies actually used. The choice was mainly influenced by the operating conditions of the engine, as the duty cycle influences important operating parameters for after-treatment technologies such as exhaust temperature and power class. In addition, practical aspects such as the state of development of SCR technology and the availability of AdBlue at NRMM sites also played a role. In general, DPF appears to be the preferred choice for engines used in construction machinery, while engines used in agriculture appear to be more often equipped with SCR. Some manufacturers often developed both options, depending on the expected use of the engine.

Although no statistical figures are available for the EU, it can be estimated that the cooled EGR+DOC+DPF option was chosen in most cases for Stage IIIB for engines 130 to 560 kW. However, advances in SCR systems and the general advantage that high NO_x engines are more economical have led to a wider application of this technology, particularly in the 56 to 130 kW power class. In addition, Stage IV emission standards for NO_x emissions are stricter but not stringent enough to force the use of DPF and SCR systems. As a result, engine manufacturers have moved slightly away from Stage IV emission control systems with DPF to SCR systems. Cooled EGR is used together with SCR in some engine designs to reduce the NO_x conversion efficiencies required for the SCR system and to reduce urea consumption. In-cylinder and DOC control are generally sufficient to meet PM emission requirements, but DPFs are also present in some engine designs, particularly in larger engines or engines designed for applications where passive filter regeneration is possible, such as agricultural tractors.

This general technology picture applies to the power class 56-560 kW; it differs somewhat for other power classes since these had to comply with different or no limit values. The following Figure 5-2 of the following studies (Dallmann and Menon, 2016; Dallmann et al., 2018) provides a more detailed overview.

<table>
<tr><th>Power class</th><th>System component</th><th>Tier 1/Stage I</th><th>Tier 2/Stage II</th><th>Tier 3/Stage IIIA</th><th>Tier 4i/Stage IIIB</th><th>Tier 4f/Stage IV</th><th>Stage V[a]</th></tr>
<tr><td rowspan="4">< 19 kW[b]</td><td>FIE</td><td colspan="6">IDI or MDI; injection timing delay; upgrades to mechanical fuel injection systems</td></tr>
<tr><td>AH</td><td colspan="6">NA</td></tr>
<tr><td>EGR</td><td colspan="6">None</td></tr>
<tr><td>ATD</td><td colspan="6">None</td></tr>
<tr><td rowspan="4">19-37 kW[c]</td><td>FIE</td><td colspan="4">IDI or MDI; injection timing delay; upgrades to mechanical fuel injection systems</td><td>IDI or CR</td><td>EDI: CR</td></tr>
<tr><td>AH</td><td colspan="4">NA</td><td colspan="2">NA or TC</td></tr>
<tr><td>EGR</td><td colspan="4">None</td><td>iEGR, cEGR</td><td>cEGR</td></tr>
<tr><td>ATD</td><td colspan="4">None</td><td>DOC+(DPF)</td><td>DOC+DPF</td></tr>
<tr><td rowspan="4">37-56 kW</td><td>FIE</td><td colspan="2">IDI or MDI; injection timing delay; upgrades to mechanical fuel injection systems</td><td colspan="2">IDI or MDI; fuel injection system upgrades with limited application of ECU</td><td colspan="2">EDI, CR</td></tr>
<tr><td>AH</td><td colspan="2">NA, limited use of TC (FG)</td><td colspan="2">TC (FG or WG), limited NA</td><td colspan="2">TC (FG or WG)</td></tr>
<tr><td>EGR</td><td colspan="2">None</td><td colspan="2">Increased EGR application</td><td>iEGR, cEGR</td><td>cEGR</td></tr>
<tr><td>ATD</td><td colspan="4">None</td><td>DOC+(DPF)</td><td>DOC+DPF</td></tr>
<tr><td rowspan="4">56-75 kW</td><td>FIE</td><td colspan="2">MDI; injection timing delay; upgrades to mechanical fuel injection systems</td><td>MDI; increasing use of EDI</td><td colspan="3">EDI: CR</td></tr>
<tr><td>AH</td><td colspan="2">Increasing application of TC (FG, WG)</td><td colspan="4">TC (FG, WG)</td></tr>
<tr><td>EGR</td><td colspan="2">None</td><td colspan="4">Moderate iEGR, cEGR application</td></tr>
<tr><td>ATD</td><td colspan="3">None</td><td>DOC+(DPF)</td><td>(DOC)+SCR / DOC+DPF+SCR</td><td>DOC+DPF+SCR</td></tr>
<tr><td rowspan="4">75-130 kW</td><td>FIE</td><td>MDI; injection timing delay, upgrade to mechanical fuel injection systems</td><td>MDI, increasing use of EDI: electronic EUI or CR (P_{inj} = 1200 bar)</td><td>EDI: EUI or CR (P_{inj} = 1600 bar); limited MDI</td><td colspan="3">EDI: CR (P_{inj} = 2000 bar)</td></tr>
<tr><td>AH</td><td colspan="3">TC (FG, WG)</td><td colspan="3">TC (WG, VGT)</td></tr>
<tr><td>EGR</td><td colspan="2">None</td><td colspan="4">cEGR used in ~50% of engine families</td></tr>
<tr><td>ATD</td><td colspan="3">None</td><td>DOC+(DPF) / SCR</td><td>(DOC)+SCR / DOC+DPF+SCR</td><td>DOC+DPF+SCR</td></tr>
<tr><td rowspan="4">130-560 kW</td><td>FIE</td><td>MDI, limited EDI; injection timing delay,</td><td>Increasing use of EDI: EUI or CR (P_{inj} = 1200 bar)</td><td>EDI: EUI or CR (P_{inj} = 1600 bar);</td><td>EDI: CR or EUI (P_{inj} = 2000 bar)</td><td colspan="2">EDI: CR (P_{inj} = 2000 bar)</td></tr>
<tr><td>AH</td><td colspan="2">TC (FG, WG)</td><td>TC (FG, WG, VGT)</td><td colspan="3">TC (WG, VGT, 2stT)</td></tr>
<tr><td>EGR</td><td colspan="2">None</td><td colspan="4">cEGR in ~50% engine families</td></tr>
<tr><td>ATD</td><td colspan="3">None</td><td>DOC + DPF / SCR</td><td>(DOC)+SCR / DOC+DPF+SCR</td><td>DOC+DPF+SCR</td></tr>
</table>

(Dallman & Menon, 2016)
[a]Projected technology packages for Stage V engine designs.
[b]Emissions from non-road diesel engines with power ratings < 19 kW are regulated for the first time in Stage V standards.
[c]No Stage IIIB or IV emission standards adopted for 19-37 kW engines in Europe.
Fuel injection equipment (FIE): IDI=indirect injection; MDI = mechanical direct injection; EDI = electronic direct injection; CR = high-pressure common rail; ECU = electronic control unit; EUI = electronic unit injector; Air handling (AH): NA = naturally aspirated; TC = turbocharged; WG = wastegated; VGT = variable geometry; 2stT = 2-stage; FG = fixed geometry; Exhaust gas recirculation (EGR): cEGR = cooled external EGR; iEGR = internal EGR; Aftertreatment devices (ATD): DOC = diesel oxidation catalyst; DPF = diesel particle filter; SCR = selective catalytic reduction

Figure 5-2 Non-road engine technologies used for compliance with the different emission limit value Stages according to Dallmann et al. (2018)

Dallmann et al. (2018) also tried to provide estimates on the Tier4f engines equipped with DPF, see Figure 5-3.

Power class	Tier 4f certified engine families	Engine families equipped with DPF	DPF-equipped engines meeting Stage V PM and NO_x limits
19–37 kW	162	48%	95%
37–56 kW	315	41%	82%
56–75 kW	13	0%	NA
75–130 kW	117	32%	78%
130–560 kW	339	41%	94%

Figure 5-3 Assessment of the use of diesel particle filters in Tier4f (equal to Stage IV for 56 -560 kW and close to Stage IIIB for 37-56 kW) certified engine families (Dallmann et al., 2018)[82]

Since no official statistics are available it is reasonable to assume in summary a 50/50 split between the two technology pathways mentioned for compliance with Stages IIIB/IV for all power classes but 75 to 130 kW which is closer to 1/3 of engines equipped with DPF.

Most important, however, is the fact that practically all Stage IIIB/IV engines between 56 -560 are already equipped with after-treatment devices and that retrofitting these engines is not straight forward.

Dallmann et al. (2018) estimated the actual costs for the engine manufacturer, assuming defined technology pathways. Starting from a pre-Stage IIIB baseline, Dallmann et al. (2018) reported the cost figures shown in Figure 5-4 below[83].

	Standard	<19 kW	19-37 kW	37-56 kW	56-75 kW	75-130 kW	130-224 kW	224-447 kW	447-560 kW
Total costs	Baseline	$223	$251	$485	$850	$1,366	$1,627	$1,941	$2,731
	Stage IIIB	–	$265	$862	$1,569	$2,227	$2,859	$3,621	$5,933
	Stage IV	$229	$1,035	$1,412	$2,544	$2,808	$3,797	$4,787	$7,759
	Stage V	$229	$1,250	$1,697	$3,201	$3,574	$4,877	$6,191	$10,366
Incremental cost with respect to baseline	Stage IIIB	–	$14	$377	$719	$861	$1,232	$1,680	$3,202
	Stage IV	$6	$785	$927	$1,694	$1,442	$2,171	$2,845	$5,028
	Stage V	$6	$999	$1,212	$2,351	$2,208	$3,520	$4,250	$7,635
Incremental costs with respect to previous standard	Stage IIIB	–	$14	$377	$719	$861	$1,232	$1,680	$3,202
	Stage IV	$6	$770	$550	$975	$581	$939	$1,165	$1,826
	Stage V	$6	$215	$285	$657	$766	$1,080	$1,405	$2,607

Figure 5-4 Estimates of costs for the manufacturer, expressed in US $2017, for new engine technology to be applied in order to meet EU limit values for NRMM engines

Retrofitting technology has to take into account the technology applied on new engines. Obviously, it is easier to retrofit engines of Stages I to IIIA than engines of Stage IIIB or IV, see chapter "Retrofit technologies and costs". The development of technologies is also reflected in the certification of retrofit technologies, in particular in the procedures and requirements laid down in UNECE R 132, see chapter "Approval and testing of after-treatment devices".

[82] Please note: DPF in the power class 19-56 kW means as a rule DOC

[83] Please note: Cost definition differs from those used in chapter „Retrofitting technologies and costs"

5.2 Conclusions

- The technical potential of retrofitting depends, inter alia, on the technology used for new engines;
- Best suited for after-treatment from the technical point of view are Stage I to Stage IIIA engines and those more recently marketed engines which had to comply with no limit values (< 19 kW) although there are additional constraints for very small engines including low cost/value of machine to be retrofitted, lack of space and more severe use/vibration/handling and safe installation requirements;
- Pre-Stage engines, i.e. engines made available to the market before the turn of the century, are less suited since, as a rule, the technical state of these engines is often too poor;
- New NRE engines between of Stages IIIB/IV in the power class 56 – 560 kW together with Stage IIIB engines for locomotives and railcars above 130 kW use already after-treatment systems, e.g. either SCR or DPF or both. In these cases, it is more complex to add after-treatment devices or to modify the original technology applied;
- In such cases, as a rule, retrofitting is more complex and close co-operation with OEMs is needed for retrofitting.

6 Retrofitting technologies and costs

6.1 Introduction

A large number of after-treatment technologies are available to reduce PM and/or NO_x emissions from engines used in non-road mobile machinery. There is also no doubt that this technology works in general: both road and non-road retrofit diesel technologies have proven their ability to significantly reduce unwanted emissions (Kubsh, 2017).

Of interest for this study are NRMM retrofit technologies that achieve high emission reduction rates, as retrofitting in the current EU situation only makes sense if emission levels are close to Stage IV or Stage V of the EU Regulation.

This means that with regard to PM reduction only DPF systems (namely high efficiency wall-flow particulate filters) can be used, as DOC (Diesel Oxidation Catalysts with flow-through) only reduces the soluble fraction of PM emissions; it is not effective in reducing black carbon or elemental carbon emissions (but it is effective in reducing CO and gaseous hydrocarbon emissions) and open filter systems (also called partial oxidation catalysts, mostly metal wire mesh structures or tortuous flow metal substrates that employ sintered metal filtering sheets) do not achieve the required reductions.

For the same reason, with regard to NO_x reductions, only SCR systems (namely urea-SCR) are considered. In addition, combined systems with PM and NO_x emission reduction are considered, which may also include other less efficient technologies such as DOC. Reduction efficiencies of these technologies are about 90 % to 99 % for PM, 60% to about 90 % for SCR and > 95 % for PM /> 85 % for NO_x when using combined systems.

Although there are easily applicable "retrofit kits" on the market, retrofitting is usually a tailor-made technology. Many aspects need to be considered to ensure that the chosen retrofit technology fits the machine or equipment. For example, the design must adapt to the available space and comply with engine back pressure restrictions. The technical status of the engine is also of importance. The engine must be well maintained before considering it as a candidate for a retrofit. Older vehicles and equipment with high exhaust emissions, excessive oil consumption, and poor maintenance histories are generally poor candidates for retrofits[84].

Each candidate retrofit engine needs to be assessed for its engine-out emission levels and exhaust temperature profiles. More rigorous operating environment of NRMM (vibrations, dust, uneven surfaces) may require extensive use of high-grade vibration isolators. In addition, off-road packaging bottlenecks are a problem as the visibility and safety of the operator must be ensured.

Retrofitting by the OEM or in close cooperation with the OEM is considered an optimal option as the OEM has full access to the engine control system. This offers the best opportunity to exploit the full potential of the emission reduction measures while accepting the lowest possible impact on other parameters (fuel consumption, reliability, etc.). The OEM has the best access to all the data for the installation and implementation of an after-treatment system, e.g. an optimized adaptation between the interactions of EGR, injection timing and - in case on SCR - AdBlue - metering and knowledge for a reconciliation of the retrofitted system with all neighbouring components. (DOC, including storage catalytic converter, silencer) is fully available.

6.2 PM emission reduction technologies

Most common retrofit DPF employs a wall-flow filter. A number of filter substrate materials have been used in diesel particulate filters. Wall-flow filter substrates (cordierite, mullite, aluminium titanate and silicon carbide) as well as filters made from sintered metal sheets are available in a variety of cell densities, wall thicknesses, wall porosities, and cell shapes.

[84] Moreover, as shown in BUWAL 2003, the cost-efficiency of retrofitting decreases rapidly for engines older than about 20 years

Wall-flow filter design employs a porous honeycomb structure with alternating flow channels plugged at opposite ends. This forces the exhaust gases containing the particles through the cell walls causing the particles to be filtered and deposited on the inside wall[85]. Since a filter substrate can fill up over time, filter systems must provide a means of burning off or removing accumulated particulate matter. As a rule, disposed particulate matter is burned or oxidized on the filter when exhaust temperatures are adequate. Burning at lower temperatures is facilitated by the use of catalyst coatings. Catalysts used are platinum and/or palladium or base metal catalysts.

"Passive" filter regeneration is used for exhaust temperatures in the range of 220-250 °C It cannot be used in all applications. Consequently, data-logging of exhaust temperatures is necessary to determine if an application can use a passively regenerating DPF. Generally catalysed, passively regenerated retrofit DPFs are desired for many and off-road applications because of their lower level of system complexity and cost. The application of interest must, however, meet the exhaust temperature duty cycle criteria to ensure regeneration of the filter.

Alternative diesel fuels, lubricant formulations, and fuel additives may contain potential catalyst poisons that could impact filter regeneration characteristics or ash forming constituents that could impact the build-up of filter backpressure or filter maintenance intervals.

Therefore, retrofit DPF systems are designed to minimize backpressure on the engine[86]. Experience has shown that properly designed DPFs typically result in backpressure-related fuel penalties on the order of one percent or less.

"Active" filter regeneration includes on-board fuel burners or electrical heaters upstream, sometimes combined with a catalysed substrate iron, cerium or combinations of iron and cerium compounds.

Active filter systems are more complex and typically more expensive than passive DPFs. The preferred type of active regeneration scheme deployed by the retrofit DPF may depend on a number of factors including available electrical infrastructure to utilize electrical heaters, the ability to stop the vehicle to conduct filter regenerations, cost/performance trade-offs and packaging constraints.

DUH provides a webpage (DUH, 2013) on which DPF retrofitted NRMM are listed. The list contains about 4000 individual retrofitting cases. This list allows getting an impression on retrofittings offered as a function of power output. It shows that the majority of retrofittings are in the power range of 37-75 kW (about 31 %) and 75-130 kW (about 30 %). The power ranges 130-130 kW (20 %) and 18-37 kW (14 %) follow. The least retrofittings are in the power range < 18 kW (3 %) and 300-560 kW (2 %).

6.3 NO_x emission reduction technologies

Applying SCR to diesel-powered vehicles provides reductions of NO_x and to a limited extend of PM, and HC emissions. Selective catalytic reduction (SCR) employing a urea/water solution (AdBlue) that breaks down to release ammonia has been used to control NO_x emissions from stationary sources for over 40 years.

A retrofit SCR system uses a metallic or ceramic wash coated, catalysed honeycomb substrate, or a homogeneously extruded catalyst honeycomb and a urea/water solution to convert nitrogen oxides to molecular nitrogen and water vapour in oxygen-rich exhaust streams.

Retrofit SCR systems can employ either zeolite-based or vanadia-based SCR catalyst formulations that are similar to the catalysts used in new engine SCR applications.

The urea solution is injected into the exhaust stream upstream of the SCR catalyst and hydrolyses to form ammonia and CO_2. AdBlue addition is controlled by an on-board control unit that initiates the

[85] Retrofitters developed technologies which in detail, e.g. particle filters with an arrangement of filter pockets, made from porous sintered metal. Due to the open structure this filter has an advantage in storage capacity for oil- or additive ashes and is easier to clean then ceramic based filter. This report, however, does not go into such a detail.

[86] Backpressure is a sensitive issue for engine operation. In particular for engines with EGR it is always necessary to contact the engine manufacturer.

ammonia addition based on the catalyst NO_x light-off characteristics (typically when the SCR catalyst inlet temperature reaches 200 °C or higher). AdBlue is added at a rate calculated by an algorithm that estimates the amount of NO_x present in the exhaust stream.

The challenge with an SCR catalyst lies in the metered addition of AdBlue. On the one hand, it is important for high catalyst efficiency that AdBlue is distributed as evenly as possible in the exhaust gas flow. On the other hand, the amount of AdBlue should be so large that it is just sufficient for a complete conversion of NO and NO_2. If too much AdBlue is injected, there will be an oversupply of ammonia. If the amount of AdBlue is too low, the reaction of NO and NO_2 will be incomplete, resulting in increased NO_x emissions. With a special catalyst layer (barrier catalyst), excess ammonia can be converted to N_2 and H_2O.

To achieve an adequate AdBlue dosing the exhaust gas mass flow and its NO_x content must be measured (or modelled) and made available to the controller for AdBlue dosing. A separate tank is required to store AdBlue in the vehicle. Since AdBlue is an aqueous urea solution, it freezes at a temperature of -11 ° C. Therefore, it is necessary to heat the AdBlue tank.

Aftermarket companies offer, as a rule, self-contained SCR systems. This means that a control unit for the AdBlue dosing strategy is included in addition to the hardware components. This creates independence from the NRMM or engine manufacturer. There are retrofit manufacturers switch the actual SCR catalyst to a so-called ammonia generator. There, the urea of AdBlue is converted into ammonia. This ammonia generator is also electrically heated (E-cat), so that an early start of the chemical reactions is given. Another advantage of this heater is the expansion of the operating range of the SCR catalyst to low temperatures. However, the use of an E-cat requires an electrical power of up to 500 W, which must be taken from the electrical system. The electrical energy required to heat the ammonia generator must be generated by the engine which might lead to an additional consumption of up to about 5 %. A further increase in fuel consumption is caused due to the additional components in the exhaust system which increases the engine back pressure. Other retrofit manufacturers use special containers that are able to store pure ammonia. The advantage is that no conversion of AdBlue to ammonia is necessary. This also leads to lower minimum working temperatures. On the other hand, this method requires a more complicated logistic, due to, that the containers have to be replaced and send to the manufacturer for refilling. A third method is the use of heated diesel oxidation catalysts or exhaust flaps which are able to increase exhaust gas temperature.

6.4 Combined DPF/SCR emission reduction technologies

There are examples of stand-alone retrofit SCR systems, DOC+SCR retrofit systems, and retrofit systems that combine either passive or active DPFs with SCR catalysts. In retrofit systems that combine DOCs or DPFs with SCR catalysts, the DOC or DPF is typically a separate element that is located upstream of the SCR catalyst. In most cases DPF+SCR retrofits have employed passive, catalyst-based DPF regeneration strategies.

In combined DPF+SCR retrofit systems, the DPF or DOC+DPF substrates are located upstream of the SCR catalyst to allow the DPF to be located in the hottest exhaust position to facilitate filtering.

Retrofit SCR systems are often open loop control-based (no feedback loop on NO_x performance). These open loop SCR systems can reduce NO_x emissions from 60 to 90 %. Closed loop control algorithms have been employed on stationary engines and can achieve NO_x reductions of greater than 95%. Combining DPFs with SCR catalysts can reduce PM, ultrafine particulates, and black carbon emissions by more than 90 % for a while.

In some cases, these passive DPF+SCR retrofit systems include added insulation to the exhaust system to allow the SCR system to function under thermally challenged, urban duty cycles. SCR catalyst temperatures of at least 200 °C are typically needed to achieve high conversion efficiencies for NO_x and urea injection is typically disabled when SCR catalyst temperatures are below this threshold for a while. It is more challenging to apply retrofit to engines which typically run at very low load for extended periods, e.g. constant speed engines like generator sets, since this leads to a cold exhaust that does not facilitate the necessary regeneration of a DPF and may be too cold for the SCR to operate effectively.

6.5 Retrofitting Stage IIIB/IV engines

The explanations given above apply in general to engines of all Stages. However, Stage IIIB/IV engines are, as described in the chapter "Technologies of engines complying with different limit value Stages", as a rule, equipped with after-treatment devices from the OEM side. As explained, this might be DOC, DPF or SCR devices in different combinations. In practical terms retrofitting such an engine would correspond to an upgrade of Stage IIIB/IV to Stage V. This is not required by any retrofit programme/legislation identified so far; see "Measures taken at Member States, States or local level".

Retrofitting such a Stage IIIB/IV machine, e.g. to achieve a higher particulate reduction, is theoretically possible, but in reality, it is not often done because it is quite expensive and technically difficult. This is particularly true for SCR retrofitting; PM retrofitting is somewhat simpler. OEMs or a retrofitter in co-operation with the OEM can accomplish this task best[87,88]. In addition, as explained in chapter "Potential problems associated with retrofitting due to existing legislation", there is a risk that such a step will require the opening of a new full type approval procedure.

6.6 Costs of retrofitting

6.6.1 Introduction

In the following the term "costs" is meant as price the owner of a non-road machine has to pay for retrofitting, excluding VAT. This is different from the costs an OEM has to pay since OEM get other prices from the engine maker (on top large OEMs use sometimes the OEM uses own engines) and have other possibilities to calculate margins. This is also different from the costs of the engine producer, see chapter "Technologies of new engines complying with the different limit value Stages".

Retrofitting costs for the NRMM retrofitter vary. Retrofitting measures require, as a rule, individual technical solutions. In theory a number of cost categories should be considered in the cost analysis, indicatively:

- Implementation costs
    - basic investment, including new facilities, equipment, tools and logistics investments
    - research and development (R&D) costs
        - development, including additional man-effort, computer simulation, prototyping and experimental testing work
        - certification / type approval
    - hardware costs for the production of retrofit devices
    - installation costs, including engine calibration where needed
- Repair costs for vehicles based on the impact of the fuel to the vehicle parts, split to
    - labour costs and
    - replacement parts costs
- Other costs

87 The Swiss filter list contained in 2014 72 certified retrofitting systems engine family systems, covering 628 engine types in the power range 21 to 446 kW; of these 12 engine families belong to Stage IV.
88 However, OEMs have little interest in retrofitting since each retrofitted machine is deemed not to be replaced by a new machine in near future

- service and maintenance
- warranty

The retrofitter has to add to these costs the margin. However, in the light of the large number of individual retrofitting cases it is not possible to carry out such a detailed analysis. Neither is it possible to study sub-classes of technologies, e.g. those for variable speed engines compared to those better suited for constant speed engines.

Therefore, reasonable cost ranges for investment costs which include, if not otherwise indicated, assembly costs, and running costs for the owner of the non-road machine are assigned to each power category, based on a literature review. These are considered in the cost/benefit calculations, see chapter "Cost/benefit calculations". As a rule, fuel consumption increases in the range of 1 % to 5 %; in this study 3 % are taken for the costs benefit calculations.

6.6.2 Literature review

There is a bulk of literature available on retrofitting costs, published at different points of times in different currencies. Although most of the costs are given in relatively wide ranges it is necessary to indicate the year of the estimate and, of course, the currency in order to be able to recalculate costs for 2018.

MECA (MECA, 2013; MECA, 2014) estimated that high-efficiency, passive filters for diesel retrofit applications are sold to the machine owner for about $10,000 to $16,000 each. Prices vary depending on the size of the engine being retrofit, the sales volume (the number of vehicles being retrofit), the amount of particulate matter emitted by the engine, the emission target that must be achieved, the regeneration method, and other factors. Cost can also be impacted by the amount of application engineering that is required for example on specialized off-road equipment. While passive filters rely solely on exhaust gas temperature to regenerate soot that accumulates during operation, actively regenerated, high-efficiency filter retrofit systems are generally more expensive ($15,000 - $30,000) due to the added complexity needed to achieve controlled regenerations with active technology such as burners, diesel fuel injection over a DOC, or electrical heaters. Limited information on costs figures for SCR systems costs vary depending on the size of the diesel engine that is being retrofitted. Retrofit SCR costs are expected to range from about $18,000 with a DOC to $30,000 with a DPF per vehicle.

In (EPA, 2007) - relying primarily on data from the NONROAD2005 model to determine the cost-effectiveness of installing DOCs, CDPFs, SCR systems and consultations with technology and engine manufacturers regarding retrofit technology cost effectiveness and applicability - came to similar cost ranges: It estimates passive retrofit DPFs for and off-road applications range in price from $8000-$20,000 depending on engine size. The addition of an active DPF regeneration strategy to a retrofit DPF can increase costs by about 50% above a passive DPF. DPF+SCR retrofit systems are in the $20,000-$30,000 price range for systems that employ a passive DPF regeneration strategy, with some additional premium for systems that employ an active DPF regeneration strategy.

Crossrails[89] published in 2013 a paper as intended as internal reference and guidance for its "Sustainability and Consents team and Delivery Environmental Advisors" (Crossrail, 2013b). The paper contains cost estimates supplied by some DPF suppliers. The costs supplied were representative of the purchase price of passive DPF and were considered indicative. The DPF retrofit costs medium range come in at around £4,500 per DPF unit, with additional installation and on-going maintenance costs. The consultation also revealed that larger excavators (in excess of 20 tonne lifting capacity) have DPF costs in excess of £10,000 while piling rigs and cranes; 80 tonne and upwards, the costs were between £20,000-£30,000 per DPF unit and fitting. Typical NRMM (i.e. excavators, telehandlers, and dumpers) purchase prices ranges between £30,000-£150,000 depending on size and age of

[89] Crossrail offers public transport across London. This includes construction work with long construction periods spread out across London, with each site having a range of large and medium size diesel engines working throughout the day.

machine. DPF costs can therefore represent a considerable percentage of purchase costs, especially for larger machines. The cost estimates are displayed in Table 6-1.

Table 6-1 DPF retrofitting costs, as estimated by Crossrail (2013b)

Power range In kW	DPF investment costs in £2012
37-80	3000-3200
60-140	3200-3700
140-210	4200-4600
160-260	4600-4800
170-300	4800-5700
250-360	5700-6300

Helms and Heidt (2014) studied in 2012 for the German government retrofitting option and estimated as part of the study the costs for retrofitting SCR and DPF systems based on literature and contacts with retrofitters and OEMs. It corrected older cost estimates from literature to the 2012 market situation and used for estimating operating costs own data on operation hours of the machines. The Table 6-2 and Table 6-3 show the results of the study.

Table 6-2 SCR retrofitting costs estimated by Helms and Heidt (2014)

Power range In kW	SCR investment costs in €2012		SCR operating costs p.a. in €2012
	System costs in €	**Assembly costs in €**	
37-75	9000	3000	180
75-130	11000	3667	220
130-300	13000	4333	260
300-560	15000	5000	300

Table 6-3 SCR retrofitting costs estimated by Helms and Heidt (2014)

Power range In kW	DPF investment costs in €2012		SCR operating costs p.a. in €2012
	System costs in €	**Assembly costs in €**	
> 18	4000	63	55
18-37	5000	94	135
37-75	6000	125	367
75-130	7500	156	823
130-300	9000	156	1746
300-560	10000	156	1527

The Berlin Senat retrofitted a number of Sate owned non-road mobile machines within a pilot programme. It summarises its experiences in 2015, based on the costs of the pilot programme and contacts with retrofitters (Senat Berlin, 2015). The cost estimates of Berlin Senate are shown in Table 6-4.

Table 6-4 DPF retrofitting costs, as estimated by Senat Berlin (2015)

Power range In kW	DPF investment costs in €$_{2015}$*	DPF operating costs p.a. in €$_{2015}$	
		Fix costs	Operating costs
19-37	2000-5000	90	130
37-75	3500-7500	125	350
75-130	4000-8000	150	800
130-300	5000-9000	150	1000
300-560	6000-12000	150	1500

* to add installation of 800 to 3000 €$_{2015}$; the higher total costs are in tendency for active, the lower for passive recuperation

DUH is a German NGO which calls for DPF retrofitting measures since many years. It co-operates with retrofitters and provides also estimates on retrofitting costs. DUH published own 2013 costs estimates which are shown in Table 6-5 (DUH, 2013).

Table 6-5 DPF retrofitting costs, as estimated by DUH (2013)

Power range In kW	DPF investment costs in €$_{2013}$*
< 37	2000-3000
37-130	3000-4500
130-300	4500-7500

* to add installation of 500 to 1200 €$_{2013}$

FVB studied in 2015 air pollution problems associated with emission from construction works. The results are shown in Table 6-6 below. Apart from the assembly costs the figures are identical with those reported by Helms et al. Moreover, FVB reported that OEM costs are about 50 % of retrofitting costs since no assembly costs and no engine specific temperature and load profile needs to be developed. Moreover, the economy of scale reduces costs (FVB, 2015).

Table 6-6 DPF retrofitting costs, as estimated by FVB (2015)

Power range In kW	DPF investment costs in €$_{2015}$	
	System costs in €$_{2015}$	Assembly costs in €$_{2015}$
0-37	2000 - 3000	500 to 3000
37-130	3000 - 4500	
130-300	4500 - 7500	

In the first costs study (BUWAL, 2003) in preparation of the Swiss legislation the following costs for the retrofitting of construction machinery is mentioned, see Table 6-7.

Table 6-7 Estimated installation, variable and fixed costs in BUWAL (2003)

Power class In kW	Installation costs in CHF$_{2001}$	Variable costs in CHF$_{2001}$/h	Annual fixed costs in CHF$_{2001}$/anno
<18	4150	1,01	100
18 - 37	6060	1,59	150
37 - 75	8375	2,29	200

75 - 130	11500	3,47	250
130 - 560	18750	5,62	250

BAFU (2011) carried out for Switzerland an additional study on the retrofitting of forest tractors. This was a real-world study in which machinery was equipped on the basis of offers from retrofitting firms and then accompanied for a while in order to collect data on operating costs. The results show that the operating costs are about 0,50 to 2,60 CHF_{2011} per hour of operation. The investment costs for the power range 80 to 100 kW are 15000 to 20000 CHF_{2011} with a highest value in the power band at 25000 CHF_{2011}, see Figure 6-1.

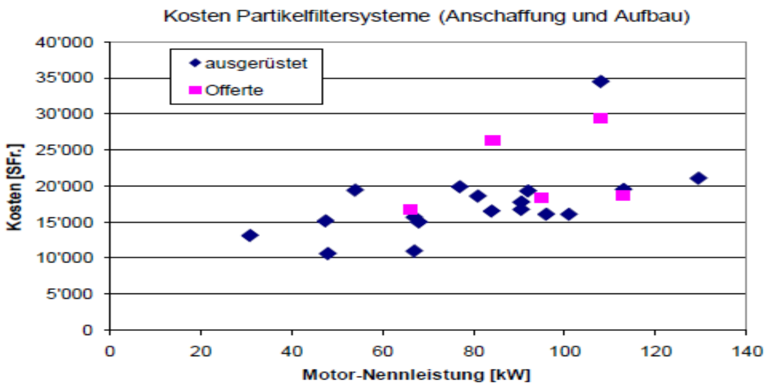


Figure 6-1 Investment costs (purchase of equipment and mounting) of particle filters (squares are the offers, diamonds are the actual costs)

Wagner (2013) reported as well about experiences gained with retrofitting for the city of Zürich and found increase in the operating costs between 6 to 10 CHF per hour of operation. Installation costs were in the range of 8000 to 18000 CHF, depending on power class and retrofitting case.

6.6.3 Costs taken in this study for the cost/benefit calculations

In summary, taking the costs estimates shown above and corrected them by exchange and inflation rates results in the following cost ranges and mean costs taken for the cost/benefit calculations:

Table 6-8 DPF cost ranges used for the cost/benefit calculations

Power range In kW	DPF investment costs in $€_{2018}$*	Mean DPF investment costs in $€_{2018}$	DPF operating costs p.a. in $€_{2018}$	Mean DPF operating costs p.a. in $€_{2018}$
<18	2500 – 4250	3500	130	130
18-37	3000 – 5250	4500	250	250
37-75	4000 – 7500	5500	450 – 500	475
75-130	4500 – 8000	6500	750 – 1000	875
130-300	5100 – 12500	7500	1300 – 1900	1600
300-560	6200 – 22500	12500	1700 – 2100	1900

For SCR retrofitting the assembly costs and operating costs reported by Helms et al. seem still to be the most reasonable. However, the recent discussions in Germany on SCR retrofitting of passenger cars, heavy duty vehicles and buses indicate that the investment costs could be somewhat lower, e.g. 2000 to 5000 € up to about 130 kW and 5000 to 8000 € between 130 to about 300 kW. NRMM NO_x retrofitting is somewhat more expensive due to the higher complexity and the significantly lower volume to be expected. Table 6-9 shows the SCR cost figures taken in this study.

Table 6-9 SCR cost ranges used for the cost/benefit calculations

Power range In kW	SCR investment costs in €2018		SCR operating costs p.a. in €2018
	System costs in €	Assembly costs in €	
19-130	6000	3000	180
130-300	10000	4000	220
300-560	15000	5000	300

Costs for combined DPF/SCR systems are about 20 % to 30 % lower than the sum of the individual single measure DPF and SCR costs.

Since information on the retrofitting of NRE engines > 560 kW is rare it is proposed to use averaged estimates expressed in €/kW, see Table 6-10.

Table 6-10 Estimated costs for retrofitting NRE engines > 560 kW

Power range > 560 kW	Investment costs in in €2018/kW	Operating costs p.a. in €2018
SCR	60	300
DPF	40	1900

It should be underlined that these cost estimates are valid for well-maintained engines. Older equipment may have to be overhauled before retrofitting, which results in additional costs.

6.6.4 Additional cost figures for comparison purposes

Other cost studies related the installation and operating costs to the PM mass reduced or calculated annual costs for defined periods.

Lichtbau et al. (2009), for example, studied PM retrofitting for Austria and reported the ranges of investment costs and operating costs for 5 or 10 years. The costs identified in this study are given in the following Table 6-11 and Table 6-12. The specific costs decrease with increasing power.

Table 6-11 Ranges of absolute total annual costs for NRMM DPF retrofitting

Power class in kW	Investment and annual operating costs p.a. in €2007 for 5 years	Investment costs and annual operating costs p.a. in €2007 for 10 years
<18	812 – 1560	512 – 865
18 - 37	1120 – 1758	690 – 1049
37 - 75	1198 – 1973	738 – 1203
75 - 130	1436 – 3346	876 – 2196
130 - 560	1809 – 4175	1079 – 2713

Table 6-12 Ranges of specific total annual costs for NRMM DPF retrofitting

Power class in kW	Investment and annual operating costs p.a. in €2007 /ton for 5 years	Investment costs and annual operating costs p.a. in €2007 /ton for 10 years
<18	594 – 1140	374 – 632
18 - 37	339 – 532	209 – 317
37 - 75	206 – 339	127 – 207
75 - 130	132 – 308	81 – 202
130 - 560	89 – 204	53 – 133

The US EPA (2007) studied retrofitting non-road mobile machinery and calculated the specific costs per kg PM or NO_x reduced. For diesel oxidation catalyst and catalysed diesel particulate filter the specific retrofitting costs ranged from 18,7 US $ to 87,6 US $ per kg of PM reduced. In addition, EPA calculated the cost effectiveness for both selective catalytic reduction systems and engine upgrade kits ranging from 1,9 US $ to 19,0 US $ per kg of NO_x reduced, see Figure 6-2 where figures are related to tons. Operating costs related to the application of the retrofit technologies are not accounted for in this analysis.

Equipment	Retrofit Technology	Range of $/ton PM Emission Reduced	
Off-highway Trucks	DOC	$21,700	$78,800
	CDPF	$24,200	$87,600
Tractors/ Loaders/ Backhoes	DOC	$25,900	$49,900
	CDPF	$28,800	$55,400
Excavators	DOC	$22,300	$61,900
	CDPF	$24,800	$68,800
Cranes	DOC	$20,900	$60,000
	CDPF	$23,300	$66,700
Generator Sets	DOC	$18,700	$46,100
	CDPF	$20,800	$51,300

Equipment	Retrofit Technology	Range of $/ton NOx Emission Reduced	
Tractors/ Loaders/ Backhoes	Upgrade Kit	$2,600	$4,900
	SCR	$6,500	$12,100
Excavators	Upgrade Kit	$2,300	$6,600
	SCR	$5,800	$16,400
Crawler Tractors/ Dozers	Upgrade Kit	$2,200	$6,600
	SCR	$5,600	$16,500
Cranes	Upgrade Kit	$2,100	$6,100
	SCR	$5,100	$15,100
Agricultural Tractors	Upgrade Kit	$1,900	$7,700
	SCR	$4,700	$19,000

Figure 6-2 Specific retrofitting costs in US $ per ton

Specific costs calculation carried out in Switzerland (BUWAL, 2013) show that the specific costs in CHF per kg PM abated decrease with increasing power (<18 kW: 222 CHF/kg, 18-37 kW: 182 CHF/kg; 37-75 kW: 169 CHF/kg; 75-130 kW: 149 CHF/kg; 130-560 kW: 133 CHF/kg PM).

FVB addressed also the issue of specific costs and concluded that retrofitting older engines is less cost efficient because these machines are less used. FVB estimates that specific costs are > 1000 €/kg PM.

6.6.5 Railways

The retrofitting of railcars and locomotives with closed particulate filters and or SCR systems is technically feasible (Clean European Rail Diesel, 2014; Sandor, 2013)[90] . However, is belongs to the most difficult retrofitting cases. There are certified (e.g. applying VERT) and specially designed systems for all kinds of rail bound vehicles with a performance up to 3000 kW offered on the market. These systems take into account the limited space and the specific operating conditions of rail bound vehicles, e.g. shunting strokes, dust, vibrations and extreme temperatures. DPF retrofitting can be

[90] Euromot concluded already in 2006 with regard to existing fleets that strategies based around re-engining would provide the greatest net benefits for existing fleets and that SCR and SCR+DPF technology would also provide net benefits.

considered as proven technology[91,92,93,94] already quite often applied. The retrofitting with SCR systems is more complex and expensive and not as often applied.

The applied original OEM technologies are also of importance to a certain extent: As a rule, for pre-1990 railcars, the feasible abatement measure would be open channel DPF only (and re-engining), whereas with the post-1990 railcars, SCR and SCR+DPF, may be possible. Similarly, for pre-1990 mainline locomotives, feasible measures included DPF (open channel only and re-engining) and for post-1990 mainline engines, DPF, SCR and DPF+SCR could be possible. With the pre-1990, shunting locomotives, ideal abatement measures include DPF (and re-engining), whereas with the post-1990 shunting engines, DPF, SCR and DPF+SCR may be possible.

Since railcar engines are most often derivatives of truck or industrial engines (typical power ~400kW) retrofitting technologies are quite similar to those used in these sectors. Engines for locomotive application are derivates from generator sets, military or ship applications (typical power: shunter locomotives ~750 kW; hauling locomotives ~2000 kW) are require a more individual design. However, each retrofitting case is an individual one and has to consider carefully the features of the locomotive or railcar to be retrofitted, e.g. in order to consider weight[95], allowed axle loads, space, vibration, temperature[96] and mechanical stress issues associated with retrofitting.

In terms of volume there is potential since the stock of equipment is often quite old. Deutsche Bahn (DB AG), for example, currently operates 4119 railcars or railcar trains and 3111 locomotives. Nearly 2400 railcars and locomotives are powered by diesel engines. These are usually diesel-electric drives in which large diesel generators on board the locomotive supply the energy for the electric traction motors. According to the Federal Government, of these 2400 diesel locomotives and 774 railcars comply with the old UIC 1 standard and 207 comply with the old UIC 2 standard; only the rest complies with more recent standards[97]. Regardless of the legal requirements the DB AG operates 7 railcars and 175 locomotives with diesel particulate filter which shows that retrofitting is an option in some cases. The German Umweltbundesamt studied in 2013 the DPF retrofitting potential of Deutsche Bahn AG and concluded that about 66 % of the locomotives and 88 % of the railcars could be retrofitted from the technical point of view.

Since retrofitting of railway vehicles are individual cases it is difficult to provide general cost estimates. In consequence the figures given in literature differ significantly.

In 2005, within the diesel rail study (Hill et al., 2005), a detailed assessment of technical measures for the existing fleet was carried out. The purpose of the analysis was to determine whether each of

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[91] According to International Union of Railways in 2008 the by far the largest application of particulate filtration to rail vehicles was on 73 locomotives built for SBB (Cargo and Infrastructure Division), 3 Locomotives G-1700 for BLS and 3 Locomotives G-1700 for Sersa and the repowering of 5 SNCF shunting locomotives. Furthermore the SBB Infrastructure Division has started in 2007 to equip all of their traction equipment and motorised vehicles (for example self propelled platform cars) with particulate filters. This counts for several hundred units. SBB has also equipped the DE-6400 locomotives from Eurotunnel with particulate filters.

[92] Manufacturers of Emission Controls Association 2006: Case Studies of the Use of Exhaust Emission Controls on Locomotives and Large Marine Diesel Engines

[93] Manufacturers of Emission Controls Association 2007: Emission Control Technologies for Diesel-Powered Vehicles

[94] For example: The SBB of Switzerland has retrofitted its diesel powered rail bound vehicles with DPF.

[95] The International Union of Railways stated in 2008 that the installation of after treatment devices would result in a weight increase, including a particulate filter and an SCR, of three to four tons for a four-axle locomotive, and four to five hundred kilograms for a 2-car railcar with two engines. In addition to the hardware itself, space and weight allowance must be found on rail vehicles for any additional reagents that must be carried. For example, estimates of the consumption of aqueous urea for an SCR device are in the range of one litre of urea for every twenty litres of fuel consumed, i.e. urea consumption is approximately 5 % of fuel consumption. A typical main line locomotive, with 5000 litres of fuel tank volume, would therefore also have to have tankage and space for 250 litres of aqueous urea solution.

[96] Railcars and locomotives spend much of their time at low power settings and at engine idle so that the exhaust temperature is fen quite low. This has also an impact on the reduction of air pollution at railway stations because in trains for 85% of the total running period SCR after-treatment device technology would not reach its operational temperature to work properly.

[97] For the EU level, according to Transport&Enironment 2008 (IA NRMM meeting with country representatives), about 60 % of all railcars are pre-2004

the technical options could be applied to the various representative traction units, and where possible to estimate the lifecycle costs and technical implications associated with each of the options. The main results and are summarised in the Table 6-13 below:

Table 6-13 Investment and operating costs for the after-treatment equipment of railway engines with DPF and/ or SCR

NRMM	Investment costs in €$_{2005}$			Annual operating costs in €$_{2005}$		
	DPF*	SCR	SCR+DPF	DPF*	SCR	SCR+DPF
Railcars Pre-1990	11000			510		
Railcars Post-1990	38000	58000	56000 to 96000	2785	5700	6756 to 10950
Shunting locomotives Pre-1990	53500		84000	5813		6800
Shunting locomotives Post-1990	64000	59500	102000	8250	5100	10350
Locomotives pre 1990	97000			7494		
Locomotives post 1990	128000		175000	14375		19531

* open DPF for pre-1990, closed DPF for post-1990

The report stressed that complex DPF/SCR retrofittings of mainline locomotives are often not feasible due to space and weight problems.

In 2008 UIC[98] estimated the DPF costs for a new 300 kW engine to be around 49 000 €, for a 900 kW engine to be about 95000 € and for a 2000 kW mainline locomotive to be approximately 200000 €, not considering any SCR equipment. DPF operating costs to increase by 15 % as far as maintenance is concerned. Moreover, fuel consumption is expected to increase by 5 %. For SCR an additional cost figure in the range of about 13000 € per year is given.

At an expert meeting in preparation of a revision of Directive 97/68/EC[99] the railway sector gave a market price of 190 000 € for a DPF system for a new locomotive, about 72500 € for a shunting locomotive, and about 36000 € for a railcar engine.

In 2008 UIC[100] estimated the DPF costs for a new 300 kW engine to be around 49 000 €, for a 900 kW engine to be about 95000 € and for a 2000 kW mainline locomotive to be approximately 200000 €, not taking into account any SCR equipment. DPF operating costs to increase by 15 % as far as maintenance is concerned. Moreover, fuel consumption is expected to increase by 5 %. For SCR an additional cost figure in the range of about 13000 € per year is given.

On behalf of the European Commission Arcadis studied costs for rail vehicles. In 2009 it estimated that DPF and SCR equipment would cost about 40000 to 80000 € for locomotives and 3000 to 13000 € for railcars (Arcadis, 2009). Shunting locs were placed in between. The additional operating and maintenance costs were, as far as locomotives are concerned, estimated to be 30000 € for PDF and 15000 € for SCR and, as far as railcars are concerned, 5000 € for DPF and 5000 € for SCR.

ARCADIS refined these figures somewhat in a subsequent study on the impact on possible inclusion of the flexibility scheme for railcars and locomotives (Arcadis, 2010) and reported the following costs

[98] UIC 2008: DIESEL ENGINES. Revision of Directive 97/68 EC in line with Directive 2004/26 EC
[99] NOTES STAKEHOLDERMEETING WITH ARCADIS ON THE NRMM IMPACT ASSESSMENT STUDY 20 November 2008
[100] UIC 2008: DIESEL ENGINES. Revision of Directive 97/68 EC in line with Directive 2004/26 EC

for the installation of railcars, shunting locomotives and mainline locomotives, see the following Table 6-14:

Table 6-14 Investment and operating costs for the after-treatment equipment of railway engines with DPF+ EGR or SCR

NRMM	Investment costs in €2010		Annual operating costs in €2010****	
	DPF + EGR	SCR	DPF + EGR	SCR
Railcars*	15000	15000	4000	5000
Shunting locs**	30000	30000	5000	4000
Locomotives***	80000	85000	30000	15000

*Lifetime 25000 hours, about 7 years
** Lifetime 25000 hours; about 13 years
*** Lifetime 30000 hours; 10 years; 15 % in power category 560-2000 kW; 15 % > 2000 kW
**** Includes maintenance, additional fuel consumption, urea consumption, filter cleaning and replacements

CARB (2009) compiled a Technical Options Report in order to reduce emissions from locomotives and railcars. CARB estimated that a DPF and SCR retrofit of locomotive costs about 200000 $ to 500000 $ depending on output power. Based on these figures ENVIRON Australia Pty Ltd (2013) estimated in 2013 for Australian conditions that retrofitting costs for a locomotive with DPF and SCR to be in the range of 300000 € to 500000 €. However, the average power of locomotives in the USA and Australia is higher than in the EU so that these figures have to be divided by a factor of 2 to 4.

Finally, the German Umweltbundesamt (UBA) estimated in 2013 the costs for DPF retrofitting to be partly much lower and provided the following ranges: locomotives 2000 kW about 58.000 €, locomotives 1000kW about 38.000 €, railcars <315 kW about. 20.000 € and railcars; 400 - 500 kW about. 30.000 €. No estimate on operating costs has been given by UBA.

In the light of these relatively wide ranges it is proposed to take the following costs for the cost/benefit analysis leaving the retrofitting of pre-1990 vehicles due to their limited remaining life time aside, see Table 6-15.

Table 6-15 Investment and operating costs for the after-treatment equipment of railway engines with DPF and/or SCR

NRMM	Investment costs in €			Annual operating costs in €		
	DPF	SCR	DPF+SCR	DPF	SCR	DPF+SCR
Railcars	25000	35000	45000	3000	5000	7500
Shunting locs	40000	50000	80000	6000	5000	9000
Locomotives	80000	100000	150000	10000	15000	20000

However, in case retrofitting measures for the railway sector are seriously considered by the Commission it is recommended to carry out additional investigations, in particular in order to identify the retrofitting potential and to narrow down costs in greater detail.

6.6.6 Inland waterway vessels

As for the other sub-sectors, retrofitting with DPF and/or SCR is also technically feasible in the inland waterway sector. Feasibility tests have been carried, e.g. by the German government[101] which proved the technically feasibility and subsequently financial support was granted to the industry for taking

[101] Abschlussbericht des BMVBS F&E-Vorhabens: „Erprobung von Partikelfiltern für den Einsatz in der Binnenschifffahrt“

such measures[102]. According to T&E over 500 marine SCR systems have been installed over the last 20 years; a lot of them in Germany, Norway and the Netherlands[103]. It is common practice to combine SCR with DPF: such DPFs come with active regeneration and are normally installed in front of SCR[104].

Retrofitting of inland waterway vessels has to take into account the particularities of the vehicle operation, e.g. very high number of lifetime operating hours, specific cooling requirements, by-pass options in case of emergency situations, very low allowed counter pressure of engines. Therefore, the retrofitting of the ships cannot be implemented quickly across the board due to individual adjustments.

The Panteia project studied also retrofitting aspects (Panteia, 2013; Zoetermeer, 2011). Panteia estimated the number existing vessels (2017-2026) which might fit for retrofitting to about 5000, about half of them above 300 kW. However, certain smaller vessels may face a problem of lack of space in the engine room, needed for the retrofitting equipment (filter, SCR, urea tank).

In practical terms each retrofitting case is an individual one which makes it difficult to provide average costs.

T&E estimated that SCR investment costs are between 15 € and 70 € per kW engine power: the larger the engine, the less expensive the installation per kW. For a typical 1000 kW 4-stroke diesel engine that would come to about 30000 – 35000 €[105].

ZKR estimated that DPF retrofitting would generate lifetime costs of about 500000 € and would not pay back within the lifetime of a vessel. The same holds for SCR retrofitting[106].

In Panteia study (Zoetermeer, 2011) the following costs for the retrofitting of inland waterway vessels have been given Table 6-16:

Table 6-16 Investment and operating costs for the after-treatment equipment of inland waterway vessels with DPF or SCR

NRMM	Investment costs in €$_{2010}$/kW		Annual operating costs in €$_{2010}$/kW	
	DPF	SCR	DPF	SCR
Vessels 1000-2000 kW	65 – 80*	40 – 60*	5– 15**	15 – 40**

* Higher costs for smaller vessels
**Higher costs for larger vessels

In addition, installation costs of about 50000 € are needed. The same holds for DPF. However, if both DPF and SCR are installed the same costs apply for the total installation.

The Panteia project concluded, inter alia, that retrofitting an inland waterway vessel causes significant additional investment costs and that operational costs rise through the use of these technologies without clear returns on investment for the vessel owner/operator.

An alternative to retrofitting is the equipment of the vessel with LNG dual-fuel combined with SCR and DPF and SCR and LNG mono-fuel combined with SCR. It is worthwhile noting that the PANTEIA study states that the actual life performance of dual-fuel or mono-fuel LNG engines is not known as of today in inland waterway transport applications given the lack of real-life data (currently, only one LNG-propelled vessel in operation in the EU). Moreover, before LNG can be widely applied, a number of requirements and technical guidance might be needed, e.g. with regard to the safe storage and use of LNG on vessels.

[102] BMVBS Motorenförderprogramm of 2007
[103] T&E 2015: NRMM: NOx emission limits for inland shipping in Europe.
[104] http://www.hug-eng.ch/en-nauticlean.html
[105] T&E 2015: NRMM: NOx emission limits for inland shipping in Europe.
[106] ZKR Marktbeobachtung Jahresbericht 2017

Another alternative offered to the market is the fuel-water emulsion technology[107]. This technology mixes water and fuel in order to influence the combustion characteristics. With increasing water content higher emission reduction can be achieved. Typical reduction rates are about 80 % for PM (70 % for PN) and 30 % for NO_x[108]. That means that this technology cannot meet the reduction level 01 of UNECE R 132 (PM reduction 90 % and NO_x reduction 60 %). The technology is used in a few cases on German inland waterway vessels[109].

Modern vessels often have several auxiliary engines on board which can be quite powerful. The largest of them, for example the bow thrusters, can easily have an output of a few hundred kW. These engines can be retrofitted with the technologies described for the NRE category and the estimated NRE cost ranges apply as well.

6.7 Conclusions

- Retrofitting technologies are available for both, PM and NOx reduction and are available for all subsectors considered in this study. Technologies are proven and there is, as a rule, no major technical problem which cannot be solved. In practice focus is given on PM reduction while NO_x retrofitting measures are by far less often taken and concentrate on on-road vehicles.
- The cost of REC certification is around 75,000 to 150,000 € for a single engine family; usually several families are needed to compete in a market[110]. This makes the test more expensive than for example VERT. Moreover, UNECE testing provides far less detailed information about the filter as such.
- Investment and running costs are a function of engine size: the larger the engine, the higher the costs.
- DPF and SCR retrofitting technologies cost estimates vary considerably, in particular for the subsectors rail and IWW. Nevertheless, ranges for costs have been identified for all sub-sectors valid for well-maintained engines which can be used in the cost/benefit analysis.
- When retrofitting, the technologies used in new engines must be taken into account. From a technical point of view, it is much easier to retrofit NRE engines of stages I to IIIA than those of stages IIIB or IV, since almost all of the latter are already equipped with after-treatment systems. Therefore, retrofitting Stage IIIB and IV engines usually requires active cooperation with the OEMs and often leads to the need to apply for a new type approval. This makes retrofitting stage IIIB and IV engine unattractive.
- Retrofitting inland waterway vessels and railway vehicles is more complex but possible in many cases. However, often retrofitting requires individual solutions and costs are more difficult to assess. These sectors with individual retrofitting cases the retrofitting potential needs further investigations, e.g. number of vessels or vehicles which could actually be retrofitted.

[107] Exomission Umwelttechnik GmbH
[108] Please note: Reductions of this magnitude depend upon the original engine having high emissions. This technology would not achieve this level of reduction on already low-emission engines
[109] In theory it could also be applied to rail bound vehicles in order to reduce emissions DPF filter and SCR; but applications are not known.
[110] TÜV NORD estimates that about 3 system families need to be tested on average

7 Approval and testing of after-treatment devices

7.1 Introduction

All national, regional local measures presented in chapter "Measures taken at MS, State or local level" after-treatment devices require certification. The certification serves the purpose of establishing minimum requirements to be met by retrofitting devices. It is a safeguard for the legislator and provides a quality requirement for the operator of non-road (and on road) machinery.

As a rule, retrofit devices which meet the certification requirements ensure that the equipped engine does not need a new type-approval. However, retrofitted engines which meet the emission limits of a particular set of limit values identical to those laid down for defined limit value Stages are not identical in all aspects to new engines meeting the respective requirements of a defined Stage. A retrofitted engine, by definition, is not a new engine.

In the following certification systems used in Europe[111,112] are briefly described. As a rule, these apply for NRE engines with a power range up to 560 kW.

7.2 The Swiss system

Based on the OAPC[113] Switzerland established a stringent national certification system which is well maintained and scientifically accompanied by State authorities. Only systems obtaining a certificate within this procedure are allowed to be used for retrofitting. The Swiss regulation SN 941.242 requires in-use compliance testing[114] of construction equipment fitted with DPFs (Federal Office for the Environment, 2014). More specifically the OAPC requires:

1. Particle filter systems for construction machines must:
   a. filter 97 % of solid particles with a diameter of 20-300 nm when new and after 1000 hours of operation in a typical application (endurance test);
   b. filter 90 % of solid particles during regeneration;
   c. have an electronic on-board control unit which records pressure losses that could compromise function and issues an alarm, and which switches off additive dosage in the event of filter damage;
   d. have an opacity coefficient of less than 0.15 m^{-1} during free acceleration of the engine;
   e. be designed in such a way that it is impossible for the filter element to be installed in the reverse direction;
   f. be supplied with cleaning and maintenance instructions;
   g. be operated without additives containing copper or catalytic coatings containing copper in the exhaust treatment system; and
   h. limit the secondary emissions arising during operation as far as is technically and operationally feasible and economically acceptable.

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111 Non European certification systems, e.g. Californian ARB Verification Classifications for Diesel Emission Control Strategies, Retrofit Device Verification Database Off-road Level 3. O, see http://www.arb.ca.gov/diesel/verdev/vt/cvt.htm are not taken into account

112 In the UK certification system only retrofit technology that has been registered and endorsed by the Energy Saving Trust NRMM certification scheme should be fitted to machinery to ensure the retrofit is correctly specified and fitted in order to prevent engine damage or any risk to the operator. Retrofit suppliers should issue a certificate for each individual retrofit with appropriate identifying information. This system not further discussed in this report.

113 Ordinance on Air Pollution Control (OAPC): See: https://www.admin.ch/opc/en/classified-compilation/19850321/index.html. Latest version (updated June 2018) is currently only available in DE/FR/IT.

114 Please note: This is very different to in-service monitoring. The required testing is a simple check that the DPF is present and is continuing to function. Moreover, this periodic in-use check is entirely independent of the granting of an OAPC approval and inclusion in the filter list.

2. The measurement methods and test procedures shall be based on the best available technology, specifically in accordance with SN 277206 or UNECE Regulation No 132.

At the request of the manufacturer or importer, a testing laboratory accredited and recognised[115] by the Federal Office for the Environment (FOEN) verifies the conformity of the filter system with the OAPC. The technical requirements are specified directly in the OAPC 814.318.142.1[116,117]. The laboratory then issues a test report which has to be submitted to an accredited and recognised certification bureau together with an application for certification of conformity. The certification bureau verifies the conformity of the particle filter system and the OEM machine respectively and issues a certificate of conformity to the applicant, who in turn issues a declaration of conformity in accordance with Article 19b, Paragraph 1b of the OAPC.

The manufacturer or importer is required to retain this declaration of conformity for a period of 10 years from the date on which the construction machine or particle filter system was first brought onto the market. The declaration of conformity must also be available on site so that it can be presented in the event of an inspection of the construction machine. The FOEN will add the filter system concerned to the FOEN Filter List as soon as it receives a copy of the certificate of conformity issued by the certification bureau[118].

OAPC describes two ways in which the air hygiene requirements for construction machinery can be met. On the one hand, the construction equipment manufacturers can prove that their machines comply with the particle number limit. This is according to the current state of the art only possible if a particulate filter is already installed and works. On the other hand, the requirements of the OAPC can also be met by retrofitting a machine with a tested filter system. Accordingly, the particle filter list contains two listings:

- List of particle filter system types: These particle filter systems have a separation efficiency of at least 97 %, especially for ultrafine particles. The particle filter systems have passed a demanding technical test and are therefore considered suitable for retrofitting diesel engines in construction machinery, in other non-road-bound mobile machines and equipment, in stationary systems and in heavy commercial vehicles[119].
- List of engine types: The list of OAPC-compliant engine types includes those engines that have been type-tested, including the particle reduction system in accordance with Directive 97/68 /EC (so-called OEM engines), and their conformity with the OAPC through compliance the particle number limit has been detected. For “OEM emission control technology” the declaration of limit values for the main emission components CO, HC, NO_x, PM and PN, to be fulfilled during a test cycle as part of the vehicle homologation are regarded to be the right way and European homologation will be accepted.

The purpose of the lists is to provide the enforcement authorities of this Regulation with an enforcement tool. In addition, the list can serve as a source of information for efficient and reliable particulate filter systems for retrofitting diesel engines. Certified filter systems in Switzerland are shown on the FOEN/Suva filter lists[120]. These lists provide information about particle filter systems that are recommended by the Swiss Federal Office for the Environment (FOEN) and of the Swiss National Accident Insurance Organisation (Suva) for retrofitting diesel engines.

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[115] The labs are accredited for conducting test and issuing a report, but not accredited for issuing a certificate.
[116] In 2014 the following laboratories are certified to carry out tests under the Swiss system: AFHB, CH; AVL-MTC, S; BOSMAL, P; SwRI, USA; JARI, J; TÜV NORD, D; TÜV Hessen, D; CATERPILLAR GED, USA.
[117] In addition, the standard SNR 277206 provides parts of the test methodology.
[118] BFH, Berner Fachhochschule Technik und Informatik, Abgasprüfstelle und Motorenlabor, Gwerdtstrasse 5, CH-2560 Nidau. See: https://www.bafu.admin.ch/bafu/en/home/topics/air/info-specialists/particle-filter-list/laboratories-and-certification-bureaux.html
[119] However, the performance is not demonstrated for such a wide range of equipment. It is simply assumed that if it works on one engine it will work on any engine. But especially larger equipment might need the after-treatment to be re-configured, often in a modular format.
[120] http: //www.bafu. admin.ch/partikelfilterliste/. Please note: Whilst Suva may recognise use of systems on the FOEN list it is not a joint list by the two organisations.

The experience gained so far shows that with proper selection and maintenance, the particle filter systems of the FOEN filter list represent a technically safe solution to effectively eliminate soot emissions from diesel engines. The basis for inclusion in the respective list is proof of conformity of the tested particulate filter system types or engines with the requirements of the Swiss Air Pollution Control Ordinance. The lists are updated periodically[121]. Currently about 130 after-treatment systems are certified which can be used for a large number of engines/engine families. About 30 of these after-treatment systems combine DPF with SCR[122].

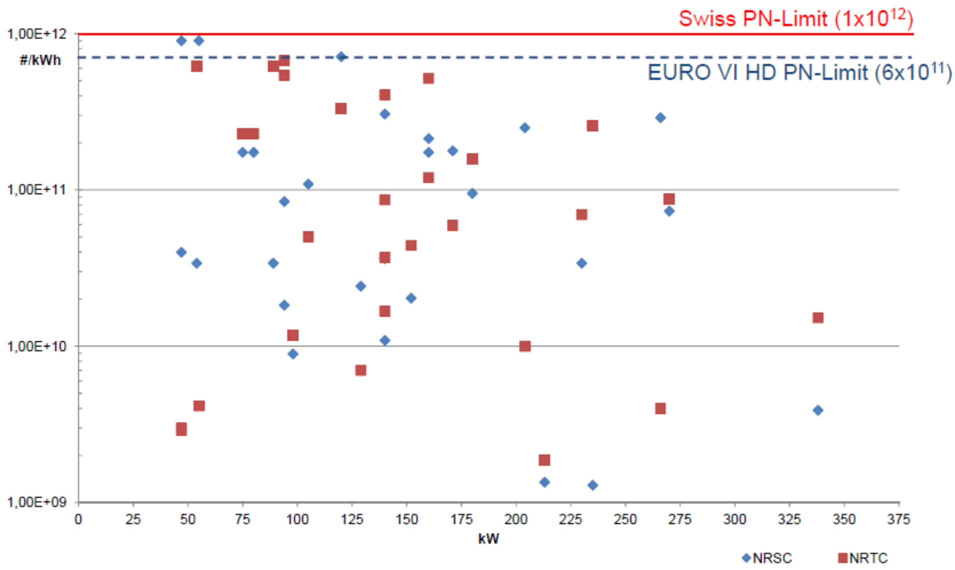

Figure 7-1 DPF test results in Switzerland (Schiess, 2012)

It should be mentioned that Switzerland has already declared to accept also REC certified under UNECE R 132 in parallel to the BAFU-conformity according to SN 277206 which is to day in force (Meyer, 2017). Should the EU follow with a similar declaration based on MRA between Switzerland and EU it would open the EU market for systems adopted in Switzerland[123].

7.3 The Austrian system

The Austrian certification system takes over to a large extent the requirements established in Switzerland, but without setting-up an own national certification body. In practice it is assumed that retrofitting used in Austria have passed the Swiss procedure. In the Austrian[124] legislation the same criteria as in the OAPC are laid down.

There must be a written proof that particle filter systems comply with the provisions mentioned above. The proof shall at least contain the relevant information like name and address of the manufacturer or importer, year, serial number and name of the type of a) the mobile device or device, b) the engine and c) the particulate filter system, and the name and address of the entity that has completed and confirmed compliance with the provisions.

[121] Following the introduction of Stage V FOEN will most likely not update these lists as regularly as in the past and may even discontinue these lists at some point.
[122] The combined devices are only approved for their ability to reduce particulate. There is no assessment of their ability to reduce NO_x.
[123] However, currently there is no equivalent EU approval for Switzerland to recognise since UNECE R 132 is not an EU approval.
[124] BGBl. II Nr. 76/2013

7.4 German systems

The German rules for certification are more open to other certification procedures, putting them at the same level of compliance. Germany has two procedures known only in Germany. Most relevant in legal terms is Annex XXVII of the StVZO[125] - Annex on § 48 (2) and Annex XIV point 3.4 - in which regulations on measures against air pollution by particles of commercial vehicles and of mobile machines and devices with compression-ignition engine are laid down. The DPF certification laid down in this Regulation is designed, inter alia, for retrofitting construction machines which are allowed to be operated on public streets. The test procedure is defined in detail. DPFs are finally approved for Germany by the Kraftfahrt-Bundesamt (KBA) and get a KBA approval number. However, in contrast the Switzerland the KBA does not publish the list of approved systems. Nevertheless, it can be assumed that this certification system is less used for non-road mobile machinery than the Swiss one and only very few NRMM after-treatment systems are certified in accordance with Annex XXVII.

Moreover, in Germany the "Förderkreis Abgasnachbehandlungstechnologien für Dieselmotoren (FAD)" is of some importance[126]. FAD examines the functionality of DPF (Diesel Particulate Filter) under different application-specific conditions. In the test the filtration is checked as well as regeneration, durability, maintenance and on-board diagnostics (based on national and international standards and guidelines). Key requirements are, inter alia, NO_2 increase max. 20% compared to NO_x raw emissions (without filter) in the application specific FAD cycle, particulate reduction rates for PM> 90% and pollutant emissions of NO_x, HC and CO must not increase by more than 5%[127].

7.5 The VERT system

Most likely best known is the VERT certification system (Association for Verification of Emission Reduction Technology)[128,129,130]. The VERT consortium was formed in the mid 1990s with the aim to achieve a drastic reduction of soot emitted by machinery used in tunnel construction. VERT approvals were historically based upon testing conducted on a single Liebherr construction equipment engine in a Swiss laboratory. It was simply assumed that the results from the Liebherr engine remain representative for other applications (different engine manufacturer, different emission Stage, larger, smaller, rail, inland waterway, etc).

Nevertheless, VERT has established a widely used retrofit certification protocol for DPFs that served as one of the important examples that led to a United Nations retrofit emission control (REC) device regulation (UN Regulation Number 132[131]), see below[132].

VERT has certified more than 65 retrofit filter systems for both on-road and off-road applications[133]. VERT industry association has evolved its retrofit filter certification process over more than 20 years.

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[125] Anlage XXVII StVZO, Maßnahmen gegen die Verunreinigung der Luft durch Partikel von Nutzfahrzeugen sowie von mobilen Maschinen und Geräten mit Selbstzündungsmotor.
[126] http://www.fad-diesel.de/zertifizierte-systeme
[127] FAD Qualitätssiegel: Ein Instrument zur Qualitätssicherung bei Abgasnachbehandlungssystemen und –komponenten für Dieselmotoren.
[128] http://www.vert-certification.eu/
[129] According to VERT the certificate has recognition in/at: Switzerland: BAFU, SUVA, ASTRA | Austria: AUVA; Tyrol construction |Germany: BG Bau; UBA; TRGS 554 7 USA: MSHA; NY City | CARB partly | Netherlands: VROM | Italy: alto Adige | Canada: Mining | UK: London TFL and LEZ | Denmark: for all applications | Chile: Santiago Bus, Gensets | China: Hong Kong busses; Beijing | UNECE
[130] Please note that both the Swiss scheme and the VERT scheme share the same certification Bureau (Swiss Institute) which has a monopoly on issuing approvals in Switzerland. However, since Switzerland accepts also UNECE R 132 certifications obtained in other UNECE countries are valid in Switzerland.
[131] A driving force for the work on UNECE R 132 was that those involved in development of R132 could not agree to the "Liebherr assumption" mentioned above.
[132] It should be noted that when the Swiss introduced the OAPC they did not simply copy the VERT requirements, and nor do they require all elements of SNR 277205/277206. Rather the Swiss set a limited set of functional requirements in their regulation and only use certain elements of SNR 277206 as a test method to demonstrate that the list of requirements in the OAPC has been met. VERT, as an association of retrofit after-treatment manufacturers, continues to provide approvals on a voluntary basis that go beyond the requirements of the Swiss OAPC. This is not based upon regulation, these are all self-commitments, subject to change at any time at the choice of the association and its members.
[133] https://www.vert-dpf.eu/j3/images/pdf/article/48/VERT-Filter-Liste-Sept-2017.pdf

The current VERT certification protocol focuses only on particle filter systems with high particle reduction efficiencies and these same particle filter technologies combined with SCR NO_x reduction catalysts. VERT approved retrofit particle filter must demonstrate at least a 98 % reduction efficiency for solid particle number emissions in the 20-300 nm range before and after a 2000 hour field durability demonstration (using the Euro PMP particle measurement protocol reference; particle filtration performance up from a minimum 97 % particle reduction requirement in 2007). Particle reduction efficiency must be at least 80 % during active filter regeneration events before and after the 2000 hour field durability demonstration (up from at least 70 % reduction efficiency in 2012). The filter device is not allowed to increase European cycle-weighted regulated emissions versus the baseline engine. Catalytic conversion of NO to NO_2 within the filter system is capped at no more than 20 % over the baseline engine. The filter system must also not increase any secondary emissions versus the baseline engine (e.g., air toxics or other unregulated emissions). All filter systems must have on-board electronic monitoring of back pressure and temperature. Unidirectional designs are required to prevent reverse mounting of the filter element. Manufacturers are required to provide a minimum two year/1000 hour warranty on materials and function.

A manufacturer's quality system for production is subject to an annual audit. Filter + SCR retrofit systems may be approved with NO_x reduction levels of 55 %, 65 %, or 75 % after 1000 hours of field aging. These NO_x reduction systems must also have NH3 emissions < 25 ppm and N_2O emissions < 10 ppm (peak emissions over the applicable regulatory test cycle). Other relevant criteria are: Exhaust back pressure < 200 mbar; no negative impact on the noise and impact on fuel consumption ≤ 3 %. To retain their VERT approval a manufacturer must prove on an annual basis that the failure rate in the field of each approved filter families remains below 5 % for all filters not older than 5 years. The VERT approval system also defines a voluntary label[134] that is displayed on certified technologies[135].

In summary, with regard to the after-treatment DPF device the VERT test is carried out under the strictest conditions, for all particle sizes, for maximum space velocity and temperature as well as for extreme transients and is therefore valid for all engines and all applications.

The costs of the VERT DPF certification are standardized. The costs for the durability run are about 70000 €. If a secondary emission test has to be added (novel catalytic materials), then VSET must be made in addition costing about 75000 €. The certification includes all diesel engines and all applications. For combined DPF+SCR systems, the SCR retrofit devices are tested. The test costs approx. 40000 €. Afterwards a continuous run over 1000 operating hours takes place in customer hand and a remeasurement, which costs of approx. 25000 €. The measurement of NH_3, N_2O, secondary emissions and other unknown substances are included.

7.6 UNECE R 132

UN Regulation Number R 132[136] is the most recent one and the first one officially developed by an international organisation[137]. It was adopted by the UN's WP29 working group in Geneva, Switzerland in 2014 and subsequently revised in 2015 and 2018[138]; it unifies different procedures[139]. One of the reasons that R 132 was developed was to overcome perceived weaknesses in the Swiss and preceding VERT testing. Key among these was the fact that there is no option for Member State approval

[134] Requirements are set by the consortium of manufacturers and not set in the regulation.
[135] A concise overview of the VERT certification process including details on in-use filter compliance checks using portable nanoparticle instruments are also summarized in 2016 VERT slide presentation made at an air quality conference in Teheran, Iran available at: http://vertcertification.
eu/j3/images/pdf/AQM_Teheran_Workshop_2016/5_Inspection_and_Maintenance.
pdf.
[136] http://www.unece.org/fileadmin/DAM/ trans / main / WP29 / wp29regs / updates / R132r1e.pdf
[137] There are approximately 50 contracting parties/countries that have signed on to the UN 132 retrofit regulation including all European Union Member States, Egypt, Russia, Turkey, Malaysia, New Zealand, and South Africa.
[138] Supplement 1 to the 01 Series of amendments to UNECE Regulation No. 132 of 26.3.2018
[139] Elements of the Swiss and VERT schemes are included in UNECE R 132 In addition R 132 resolved a number of technical concerns with these certifications including that the engine to which the retrofit may be applied could be totally different and of different base emission level to that for which the retrofit was proven – prior to R132 it was simply assumed retrofit will perform the same on a different engine.

authorities to issue approvals in their own regions and obtain 'free circulation' in low emission zones in other Member States following conventional EU type-approval process and international agreements.

Use of the UNECE mutual recognition approach avoided these concerns. A UN Regulation in force binds legally all those Contracting Parties which signed the same Regulation. A Contracting Party to the 1958 Agreement can sign the UN Regulations in which it is interested, but it is not an obligation. It may even not adopt any of the UN Regulations. Furthermore, a Contracting Party can cease applying any Regulation at any time giving one year's notice. The approvals granted remain valid until their withdrawal. The mutual recognition of approval is also applicable only for the Regulations adopted by a Contracting Party. The Contracting Party which signed a Regulation may issue approvals and certifications according to that Regulation and shall recognize the approvals and certifications issued by all other Contracting Parties which signed the Regulation too. However, a Contracting Party which signed the Regulation has not to set-up an own approval system; it can stick to the recognition level.

In the light of the notification requirements laid down in UNECE R 132 it would be of advantage to establish within the EU a communication toll to be used by all Member States. It should be considered whether the IMI tool established under Regulation (EU) 2016/1628 is an appropriate option.

UNECE Regulations, which are applicable in the EU, must be translated into all official EU languages and published in the Official Journal of the European Union. This happened on 27.4.2018[140]. However, already at earlier occasions[141] the Commission took the view that "*it is not envisaged to make the REC UNECE rules legally binding for the purposes of EC type-approval. This would mean, in principle, that authorities at national, regional or local level could reinforce the requirements of the regulation with complementary or alternative national measures in order to improve the air quality in their respective areas. However, it is believed that the REC Regulation sets out a strong reference for national retrofit schemes, and expected that the latter are developed in accordance with the regulation."*

This Regulation applies to Retrofit Emission Control devices (REC) to be installed, inter alia, on CI engines having a net power higher than 18 kW but not more than 560 kW installed in non-road mobile machinery, operated under variable speed; on CI engines having a net power higher than 18 kW but not more than 560 kW installed in non-road mobile machinery, operated under constant speed and on CI engines having a net power higher than 18 kW but not more than 560 kW installed in category T vehicles.

"Non-road mobile machinery" is defined as any mobile machine, transportable industrial equipment or vehicle with or without body work, not intended for the use of passenger- or goods-transport on the road, in which an internal combustion engine is installed, e.g. IWW vessels or vehicles with rail traction (locomotives, railcars) are covered by the UNECE Regulation only in so far as an on-road engine is used for NRMM. In practical terms R 132 covers large parts of the category NRE[142] of the

[140] However, it should be noted that Regulation UNECE 132 is not part of Regulation (EU) 2016/1628. The fact that is has been published on 27.4.2018 is at the time being of no relevance for the EU Regulation.
[141] OJ C 197, 26/06/2014
[142] The following categories fall under the EU Regulation:
NRE: (a) engines for non-road mobile machinery that are not included in any other category; (b) engines having a reference power of less than 560 kW used in the place of Stage V engines of categories IWP, IWA, RLL or RLR; NRG: engines having a reference power that is greater than 560 kW, exclusively for use in generating sets; engines for generating sets other than those having those characteristics are included in the categories NRE or NRS, according to their characteristics; NRSh: hand-held spark-ignition engines having a reference power that is less than 19 kW, exclusively for use in hand-held machinery; NRS: spark-ignition engines having a reference power that is less than 56 kW and not included in category NRSh; IWP: (a) engines exclusively for use in inland waterway vessels, for their direct or indirect propulsion, or intended for their direct or indirect propulsion, having a reference power that is greater than or equal to 19 kW; (b) engines used in place of engines of category IWA; IWA: auxiliary engines exclusively for use in inland waterway vessels and having a reference power that is greater than or equal to 19 kW; RLL: engines exclusively for use in locomotives, for their propulsion or intended for their propulsion; RLR: (a) engines exclusively for use in railcars, for their propulsion or intended for their propulsion; (b) engines used in the place of Stage V engines of category RLL; SMB: spark-ignition engines exclusively for use in snowmobiles; engines for snowmobiles other than spark-ignition engines are included in the category NRE; ATS: spark-ignition engines exclusively for use in all-terrain vehicles and side-by-side vehicles; engines for

Regulation (EU) 2016/1628. However, it should be noted that the retrofitting of Pre-Stage I engines does not fall under UNECE R 132 since these engines are not defined and have unknown emissions.

UNECE R 132 requires that a type approval shall be granted by the competent authority if the REC meets the requirements of this Regulation. That means an official approval and authorisation system needs to be established by countries if the country aims at granting approvals under this Regulation.

UNECE R 132 is the only process to approve an SCR or combined SCR + DPF retrofit. This is important in context of bringing a pre-Stage IIIA engine to a level of NO_x and PM/PN similar to Stage V.

In substance UNECE R 132 requires, inter alia, that the particle mass is reduced by 90 % and the particle number by > 97 % and that the NO_x concentration is reduced by at least 60 % (Level 01). Level 01 is further divided into five Classes (I, IIA, IIB, III, IV) which apply to either PM only or NO_x only reduction system or to both (all but Class III which applies to NO_x reduction only). It contains two classes with regard to repercussions on NO_2: Class 1: no NO_2 increase[143], class 2A / B: NO_2 increase <20/30 %. Moreover, it provides for Classes III, IV and Stage V type approval equivalence matrix for retrofitting devices to be fitted to a baseline engine up to UNECE Regulation 96, category P (i.e. Stage IIIB) to achieve a PM and/or NO_x emission level up to Regulation 96, category R (i.e. Stage IV) and V (i.e. Stage V). The equivalent matrix can be used if compliance with a defined limit value Stage is desired. However, it should be recalled that the overall performance a retrofitted Stage V engine is not fully identical to a new Stage V engine.

The Level and Classes defined in UNECE R 132 are shown in Table 7-1 Levels and Classes as defined in UNECE R 132

Table 7-1 Levels and Classes as defined in UNECE R 132

Levels and Classes	PM	NO_x
Reduction level 01 Reduction efficiency	90 %	60 %
Class I	PN at least 97 % vis-a-vis baseline	No NO_2 increase via-a-vis baseline
Class IIA	PN at least 97 % vis-a-vis baseline	Max. 20 % increase NO_2 increase via-a-vis baseline without REC
Class IIB	PN at least 97 % vis-a-vis baseline	Max. 30 % increase NO_2 increase via-a-vis baseline without REC
Class III		NO_2 not above levels in Annex 6, expressed in g/kWh Ammonia max. 25 ppm
Class IV	PN at least 97 % vis-a-vis baseline	NO_2 not above levels in Annex 7, expressed in g/kWh Ammonia max. 25 ppm

UNECE R 132 also contains emissions performance testing before and after a 1000 hour durability demonstration (the durability demonstration may be done in the field or in an engine test cell with a specified aging cycle). This regulation specifies emissions measured the NRTC cycle for off-road equipment applications. Retrofit devices must meet minimum emission reduction the effects on fuel consumption should be max. 4 %. UNECE R 132 does not include any in-use testing requirements.

all-terrain vehicles and side-by-side vehicles other than spark-ignition engines are included in the category NRE

[143] See 8.4.1 of the Regulation: "For a Class I REC, there shall be no increase in NO_2 emissions above the NO_2 baseline emissions, measured as defined in Annex 5 to this Regulation."

Approved devices do have a specified emissions durability requirement of 200,000 km or 6 years for highway applications and 4,000 hours or 6 years for off-road applications[144]. In general, the retrofit device cannot increase any secondary emissions above those measured on the baseline engine that does not contain the retrofit device. NH_3 emissions for a urea-SCR retrofit cannot exceed 25 ppm over the appropriate regulatory test cycle.

The following Table 7-2 summarises the key characteristics of UNECE R 132:

Table 7-2 Key certification criteria of UNECE R 132

Levels and Classes	PM
Emission performance	PM/PN, NO_x concentration measured before and after the retrofit system; aging using NRTC
NO_2 limits	Depending on Class: Classes I to IIB 0 % or + 20 % or + 30 % versus baseline or for Classes III or IV as laid down in Annexes 6 or 7
NH_3	25 ppm
Secondary unregulated pollutants	No increase versus baseline
Durability	1000 hours in service or on dynamometer using aging protocol
Retrofit classification	According to Level 01: At least 90 % PM, at least 97 % PN for all Classes but Class III, at least 60 % NO_x reduction efficiency for all Classes
On board monitor	Filter pressure drop, exhaust temperature, urea use in case of SCR
Warranty	Retrofit durability of 4000 hours for retrofits complying with manufacturer's instructions; manufacturer must have an approved production quality system

UNECE R 132 does also deal with the retrofitting of engines which are already equipped with after-treatment devices. The general rule, as laid down under point 11, is that any modifications of engine operation parameters which might affect the engine baseline emissions must be kept within the limits specified by the original engine manufacturer[145]. Moreover, point 11 requires that the emission control

[144] The actual test requirement is considerably shorter as the retrofit manufacturer may extrapolate test results. A 1000 hour test is accepted same as for the voluntary VERT scheme.
[145] Point 11 reads: "11. Modifications to engine baseline emissions
11.1. Any modifications of engine operation parameters which might affect the engine baseline emissions must be kept within the limits specified by the original engine manufacturer (for example maximum allowable exhaust gas back pressure or limits set for impact of external devices upon the electrical or data handling systems).
11.2. In cases where additional measures with respect to emission-relevant components or system components, such as modifications to the exhaust gas recirculation (EGR) control, are necessary in order to ensure proper functioning of the engine and exhaust after treatment systems in conjunction with the REC, the applicant shall provide a detailed description of the design modification along with an explanation of how the modification will change the operation and performance of the emission control strategy. To support its claims, the applicant shall submit additional test data, engineering justification and analysis, or any other information deemed necessary by the Type Approval Authority or Technical Service to address the differences between the modified and original designs.
11.3. The emission control system of the original engine manufacturer shall not be modified, except for: (a) Modifications allowed by written permission of the original engine manufacturer; or (b) In the case of a Class I, Class IIA or Class IIB REC, replacement of an existing diesel oxidation catalyst providing that: (i) The requirements of paragraph 8.4. are met; and (ii) The retrofitted engine system meets at least the limits for the Stage to which the base engine was approved for each of the other controlled pollutants

system of the original engine manufacturer shall not be modified, except for: (a) Modifications allowed by written permission of the original engine manufacturer; or (b) In the case of a Class I, Class IIA or Class IIB REC, replacement of an existing diesel oxidation catalyst (DOC) providing that: (i) The requirements of NO_2 emissions requirements , in particular with regard for a Class I REC ("there shall be no increase in NO_2 emissions above the NO_2 baseline emissions") are met and the retrofitted engine system meets at least the limits for the Stage to which the base engine was approved for each of the other controlled pollutants relevant to that Stage; (c) the installation of temperature and/or pressure measuring probes at the entrance of the NO_x reduction REC system including the dosing unit. If these requirements are met, modifications downstream of an original after treatment system are permitted. Moreover, the performance of any On-Board Diagnostics (OBD) system and NO_x control system of the original engine system shall not be compromised by the retrofitting.

UNECE R 132 defines players like 'Manufacturer'[146] and 'Installer'[147] and lays down procedural aspects which have to be implemented by countries. However, UNECE R 132 does not regulate in-use performance testing and the nomination of a recall authority. Nevertheless, the approval can be revoked by the authority which granted the approval.

Finally, it should be mentioned that Regulation R 132 includes a labelling requirement for the retrofit to enable level of emission reduction to be identified when combined with engine emission label information.

In summary, while no certification procedure, including UNECE R 132, is in all details comparable to the tests to be carried out for new engines R 132 gets closer than any other certification procedure to the testing requirements for new engines.

The cost of REC certification is around 75000 to 150000 € for a single engine family; usually several families are needed to compete in a market[148]. This makes the test more expensive than for example VERT. Moreover, UNECE testing provides far less detailed information about the filter as such.

Since R 132 is a new regulation, few countries are actually utilizing this UN requirements and it will still take some time before a significant number of systems are certified.

Moreover, with regard to the application of UNECE R 132 as part of an EU retrofitting policy for NRMM it is a short-coming that no all engines which fall under the EU Regulation are covered by Regulation 132.

NRE engines > 560 kW could most likely be incorporated into the existing system for the power range > 560 kW and < 19 kW in order to cover the full power range addressed by Regulation (EU) 2016/1628, if necessary. The reason Regulation 132 was not yet expanded to cover < 19 kW and > 560 kW is that it is based on the principle of reducing emissions from one recognised EU emission level to another recognised EU emission level. It does not currently cover retrofit of unregulated engines (in any category) because the prior environmental performance of the engine is not known in this case. The mandate to update UNECE R 132 to include Stage V did not include a mandate to change this principle of R 132. This could yet be addressed in a future revision to Regulation 132 if deemed worthwhile and a new approach put forward to UNECE to also cover retrofit of unregulated engines.

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relevant to that Stage; (c) The installation of temperature and/or pressure measuring probes at the entrance of the NOx reduction REC system including the dosing unit.
11.4. Subject to the requirements of paragraph 11.1. of this Regulation being met, modifications downstream of an original after treatment system are permitted.
11.5. The performance of any On-Board Diagnostics (OBD) system and NOx control system of the original engine system shall not be compromised by the REC."

[146] means the person or body who is responsible to the Type Approval Authority for all aspects of the type-approval and can demonstrate that it possesses the features required and the necessary means to achieve quality assessment and conformity of production. It is not essential that the person or body be directly involved in all Stages of the construction of the vehicle, system, component or separate technical unit which is the subject of the approval process.

[147] means a person or body who is responsible for the correct and safe installation of the approved REC.

[148] TÜV NORD estimates that about 3 system families need to tested in average

Currently there are no systems certified in accordance with UNECE R 132. It can be assumed that no manufacturers have obtained Regulation 132 type-approval because, so few regulators have so far specified UNECE R 132. This is a classic chicken and egg situation. Without demand from regulators no manufacturer wants to obtain Regulation 132 type-approval, without manufacturers having type-approval few regulators ask for Regulation 132. If more regulators required Regulation 132 then demand would be created.

7.7 Rail and inland waterway

The certification of after-treatment systems used in rail and inland waterway vehicles requires special considerations most likely difficult to integrate into UNECE R 132 since the scope of Regulation 132 is constrained by the 1958 UNECE agreement and cannot include rail or inland waterways. A different forum would be required. For example, in the Panteia study (Panteia, 2013) it is said that with regards to retrofitting of existing engines conditions for appropriate after-treatment systems need to be developed, accompanied by type approvals and monitoring systems which, amongst others, keep track of consumed additives, such as urea and facilitate for reading data with respect to the operation of the installation (interface). This also includes procedures, equipment, interval and criteria. The obligation to have the relevant information available on board should be included in the legislation. Details of the systems must be entered in the ship's certificate. Panteia proposed that these requirements could be incorporated in Directive 2006/87/EC[149], since this Directive contains already provisions as regards to after-treatment systems. Furthermore, provisions must be elaborated for the availability of adequate maintenance systems with regard to the functionality of after-treatment technologies. There are on-going discussions at international level on the best way forward.

Similar problems might exist for railway vehicles since these have as well a special approval system for the vehicle. For more details see chapter "Potential problems associated with retrofitting due to the existing legislation".

7.8 Conclusions

- Certification procedures ensure that the retrofitting device as such and the retrofitted engine in total meet pre-defined requirements. Several certification procedures for retrofitting devices are available but differ in detail and only one is internationally harmonised. Moreover, most of them focus on DPF retrofitting. Most widely used in Europe have been the VERT or the Swiss certification procedures. A significant number of systems have been certified in the past and are available to the market.
- Since 2015 the certification procedure under Regulation UNECE R 132 is in place; it binds legally all those UN Contracting Parties which signed the same Regulation. It covers NRE engines and DPF and SCR retrofitting in the power range 19 to 560 kW and is most appropriate for internationally harmonised measures since it has been established at international level, involving experts from all UNECE members. This opens the option of recognition and free access of retrofitted NRMM in all EU Member States. Moreover, it can be considered as the internationally most up-dated of all certification procedures and further up-dates are possible within an internationally coordinated procedure.
- However, since UNECE R 132 is a new regulation, only few countries are actually using this procedure in practice, although it applies to all EU Member States since these are contracting parties to UNECE. It will take some time before a significant number of systems are certified.
- Although this is a drawback at the time being, the fact that only few Member States currently require retrofitting but most likely all will recognise UNECE R 132 opens the option to achieve an EU wide harmonisation in a few years. If needed, transitional provisions might be helpful for the relatively few NRMM retrofitted under the different certification procedures applied within the EU up to now in order to ensure EU wide usage of these NRMM.

[149] This Directive has been repealed by Directive (EU) 2016/1629 of the European Parliament and of the Council of 14 September 2016 laying down technical requirements for inland waterway vessels, amending Directive 2009/100/EC and repealing Directive 2006/87/EC

- The certification of NRE engines < 19 kW and > 560 kW as well as those used in rail and inland waterway vehicles are not covered by UNECE R 132. This is a shortcoming which could be solved in the coming years, if necessary. Currently off-road engines of these sub-categories are certified, if required, mainly under the VERT system.
- The costs for certification differ somewhat, depending on the procedure. Most expensive is the testing which costs – as a rule – several ten thousand € and up to about 150000,- € per system. In tendency UNECE R 132 requires the certification of well-defined after-treatment/engine combinations; this might entail additional costs compared to other certification procedures.
- Administrative costs differ substantially. Some Member States just register the certification, other European countries, e.g. Switzerland, established detailed administrative procedures which cause higher administrative costs.
- In the light of the notification requirements laid down in UNECE R 132 it would be of advantage to establish within the EU a communication tool to be used by all Member States. It should be considered whether the IMI tool established under Regulation (EU) 2016/1628 is an appropriate option.

8 Potential problems associated with retrofitting due to the existing legislation

8.1 General relevant requirements of EU legislation

Directive 98/67/EC (as amended by 2012/46/EC)[150] and Regulation (EU) 2016/1628 concern new engines for non-road mobile machinery only, and in the latter case new non-road mobile machinery in respect to engine exhaust emissions; however, they contain provisions which are indirectly of relevance for retrofitting activities.

Although Directive 97/68/EC is repealed retrofitting measures would aim mainly at engines type-approved under this Directive. Pre-Stage I engines do not have to comply with any legal obligation. A key question to answer is whether a retrofitted engine still complies with the type-approval granted since Article 12 (Non-conformity with the approved type or family) of Directive 98/67/EC requires:

"1. There shall be failure to conform to the approved type or family where deviations from the particulars in the type-approval certificate and/or the information package are found to exist and where these deviations have not been authorized, pursuant to Article 5(3), by the Member State which granted the type-approval.

2. If a Member State which has granted type-approval finds that engines accompanied by a certificate of conformity or bearing an approval mark do not conform to the type or family it has approved, it shall take the necessary measures to ensure that the engines in production again conform to the approved type or family. The approval authorities of that Member State shall advise those of the other Member States of the measures taken which may, where necessary, extend to withdrawal of type-approval."

The above Article is aimed at ensuring the engine manufacturer or importer fulfils the responsibility to place on the market an engine in conformity with its type-approval. However, the engine manufacturer has no obligations in respect to modifications made to the engine by other natural or legal persons.

Article 12 has to be seen in conjunction with Article 8 on placing on the market: *"1. Member States may not refuse the placing on the market of engines, whether or not already installed in machinery, which meet the requirements of this Directive.*"

Modifying an engine beyond the type-approval characteristics is not allowed and a new type-approval is needed. In consequence the person/body that modified the engine has to apply for a new type-approval, even if this concerns only one engine[151].

The certification systems described in chapter "Approval and testing of after-treatment devices" are designed to guarantee a certain emission reduction performance of PM or NO_x. The fact that a retrofit kit is certified does not mean automatically that the type-approval of the engine is not violated. Not all certification schemes pay attention to the conformity of the original engine, only the incremental reduction of specified pollutants.

[150]The Directive 97/68/EC is repealed with effect from January, 1st 2017. It is replaced by Regulation (EU) 2016/1628 which shall apply from the same day, setting emission limits for Stage V.

[151] Please note: in 97/68/EC the person/body that has to apply for type-approval is: "manufacturer shall mean the person or body who is responsible to the approval authority for all aspects of the type-approval process and for ensuring conformity of production. It is not essential that the person or body is directly involved in all Stages of the construction of the engine" That means it has not to be the original engine manufacturer or the OEM of the machine but also a person/body who modified an NRMM engine, e.g. ‚retrofit emission control device manufacturer�到, or ‚REC manufacturer' which would then become the manufacturer.

Continued conformity of the original engine to its type-approval can be taken as given up to Stage IIIA, e.g. a type-approved engine equipped with a certified after-treatment system[152] is considered to be still in compliance with the type-approval once granted, so long as the maximum exhaust back-pressure specified in the engine type-approval is not exceeded.

However, from IIIB onwards and in case that the type-approved engine configuration already includes an after-treatment system, it is not guaranteed that conformity of the original engine to its type-approval is maintained. The Directive specifies in its Annexes obligations to be met by the engine within the type-approval tests which are not automatically considered as to be still fulfilled by adding a "certified" after-treatment device to a Stage IIIB/IV engine. Therefore, for Stage IIIB/IV engines the engine concerned may no longer comply with the type-approval that applied when it was originally placed on the market or installed in the non-road mobile machinery. In this case, however, the type-approval has to be obtained under the new EU Regulation since the Directive is not in force anymore. This is a significant extra burden for retrofitting Stage IIIB/IV engines.

This can be avoided under UNECE R 132 if the requirements of point 11 are met[153]. In practical terms any sort of retrofitting has to avoid modifying the after-treatment systems installed by the OEM.

Alternatively, the retrofitter needs a written permission of the original engine manufacturer, though there is no obligation on that manufacturer to provide that permission. However, even then additional proof must be provided that the retrofitted engine still meets the defined exhaust gas performances. This requirement is quite stringent and might in many cases prevent retrofitting at all.

Moreover, and with regard to pre-Stage IIIB engines, while the type-approval is valid for an engine type or family, retrofitted with a certified after-treatment system, a retrofitting measure concerns an individual engine. Hence, in such a case at least the operating manual of the retrofitted engine needs to be up-dated or supplemented.

Assuming that the engine retrofitted with a certificated after-treatment system does not need new type-approval under Regulation (EU) 2016/1628 it has still to comply with EU regulations on general

[152] After-treatment means the passage of exhaust gases through a device or system whose purpose is chemically or physically to alter the gases prior to release to the atmosphere.

[153] Point 11 reads: "11. Modifications to engine baseline emissions
11.1. Any modifications of engine operation parameters which might affect the engine baseline emissions must be kept within the limits specified by the original engine manufacturer (for example maximum allowable exhaust gas back pressure or limits set for impact of external devices upon the electrical or data handling systems).
11.2. In cases where additional measures with respect to emission-relevant components or system components, such as modifications to the exhaust gas recirculation (EGR) control, are necessary in order to ensure proper functioning of the engine and exhaust after treatment systems in conjunction with the REC, the applicant shall provide a detailed description of the design modification along with an explanation of how the modification will change the operation and performance of the emission control strategy. To support its claims, the applicant shall submit additional test data, engineering justification and analysis, or any other information deemed necessary by the Type Approval Authority or Technical Service to address the differences between the modified and original designs.
11.3. The emission control system of the original engine manufacturer shall not be modified, except for:
(a) Modifications allowed by written permission of the original engine manufacturer; or (b) In the case of a Class I, Class IIA or Class IIB REC, replacement of an existing diesel oxidation catalyst providing that: (i) The requirements of paragraph 8.4. are met; and (ii) The retrofitted engine system meets at least the limits for the Stage to which the base engine was approved for each of the other controlled pollutants relevant to that Stage; (c) The installation of temperature and/or pressure measuring probes at the entrance of the NOx reduction REC system including the dosing unit.
11.4. Subject to the requirements of paragraph 11.1. of this Regulation being met, modifications downstream of an original after treatment system are permitted.
11.5. The performance of any On-Board Diagnostics (OBD) system and NOx control system of the original engine system shall not be compromised by the REC."

product safety[154] and on machinery[155]. These Directives would be violated if the retrofitting causes a significant change to the non-road mobile machinery. The original machine placed on the market by the OEM complies with these two Directives and so must be the retrofitted one.

Moreover, if there is a significant change due to retrofitting the owner of the machine - as the customer of the retrofitter - becomes the manufacturer of the machine and must comply with the manufacturer's obligations in accordance with the Product Safety Act and the Machinery Directive.

The owner, of course, wants to avoid this and obliges the retrofitter to take the necessary steps. Since the owner is unlikely to have the skill or knowledge to check that the retrofitter has fulfilled the necessary requirements it is best to involve third parties. In the best of all cases the retrofitter should inform the designated Technical Service appointed by the national competent authority and which was also involved in the approval process of the NRMM in order to clarify whether the machine is still in compliance with the Product Safety Act, the Machinery Directive and corresponding national legislation[156] and report back to the owner.

Of particular importance in this respect are the impacts the retrofit might have on safety of the machine. As a rule, no significant change to the machine can be assumed if the after-treatment equipment is located inside the machine covers, usually in place of the original silencer. However, additional protection on surface temperatures is also important if retrofit is installed inside machine covers as elevated temperatures and the amount of heat radiating from the retrofit can lead to fire risk if not properly addressed.

A substantial change of the machine is given, for example, if after an exhaust system the after-treatment system causes a visual restriction. This might happen if the after-treatment system cannot be incorporated in the machine body. In such a case additional measures have to be taken. As a rule, visual restrictions can be overcome with technical measures such as special mirrors or cameras. Heat protection and insulation is another relevant issue. The surface temperature of the housing of after-treatment devices might be significantly higher than the systems without such equipment. In such cases additional heat protection must be installed.

In any case, the changes to the machine and the installation of the after-treatment device should be documented in form of an acceptance protocol between the owner of the machine and the retrofitter and the necessary documents must be added to the machine papers. Again, cooperation between the OEM, the retrofitter, the technical service and the owner of the machine is the best way forward. In cases of legal doubt, it might be necessary to contact in addition the national competent authority which granted the type-approval in first place.

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[154] DIRECTIVE 2001/95/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 3 December 2001 on general product safety. The scope of the Directive on general product safety is to ensure that products placed on the market are safe. It applies if the retrofitted engine or the retrofitted machine is considered as a product, as defined in the Directive *("'product' shall mean any product — including in the context of providing a service — which is intended for consumers or likely, under reasonably foreseeable conditions, to be used by consumers even if not intended for them, and is supplied or made available, whether for consideration or not, in the course of a commercial activity, and whether new, used or reconditioned. This definition shall not apply to second-hand products supplied as antiques or as products to be repaired or reconditioned prior to being used, provided that the supplier clearly informs the person to whom he supplies the product to that effect*").

[155] Directive 2006/42/EC: The purpose of the machinery Directive is to ensure that machines have an inherently safe design and construction and a proper installation and maintenance. It aims at ensuring that persons, in particular workers and consumers and, where appropriate, domestic animals and goods, are protected in relation to the risks arising out of the use of machinery. It does not apply to agricultural and forestry tractors for the risks covered by Directive 2003/37/EC, with the exclusion of machinery mounted on these vehicles and to means of transport by air, on water and on rail networks with the exclusion of machinery mounted on these means of transport. It covers the 'placing on the market' (that means making available for the first time in the Community machinery or partly completed machinery with a view to distribution or use, whether for reward or free of charge) and the 'putting into service' (that means the first use, for its intended purpose, in the Community, of machinery covered by this Directive).

[156] It remains unclear whether this is done so in all Member States since NRMM - as a rule - do not have a type-approval, unlike road vehicles, e.g. national authorities or Technical Services are not automatically informed about retrofitting activities.

In Switzerland the whole retrofitting procedure is regulated in detail, including documentation requirements, and the obligations of the players involved are laid down in official documents. This is not the case in the same detail in other countries so that the owner of the machine who initiates the whole process has to take care that the responsibilities of the player involved are clearly defined.

There is another aspect of Regulation 2016/1628 which should be mentioned: 'replacement engine'. Replacement engines are engines that are exclusively used to replace an engine already placed on the market and installed in non-road mobile machinery. Such engines comply with an emission Stage which is lower than that for an engine to be installed in a new machine as applicable on the date of the engine's replacement. For a given period of time after the introduction of Stage V limit values machines equipped with an engine approved under Directive 96/68/EC can be equipped with replacement engines in case of engine break-down. For example for NRE engines a period of 20 years *"... starting from the applicable dates for the placing on the market of Stage V engines set out in Annex III, provided that the engines: (a) belong to category NRE with a reference power no less than 19 kW and no greater than 560 kW, and comply with an emission Stage that expired not more than 20 years before the placing on the market of those engines and that is at least as stringent as the emission limits that the engine to be replaced had to meet when it was placed on the market originally".* Retrofitting requirements would also include such replacement engines. Obviously, in case of a far-reaching general EU wide retrofitting requirement, e.g. all machines must be retrofitted to mention an extreme; the replacement engine regulation would lose sense. However, even less far reaching regulations there might be significant repercussions on the replacement engine regulation.

8.2 Inland waterway and railways

Special requirements have to be met by inland waterway vessels and railway vehicles. While certification of retrofitting systems can be obtained just like for NRE engines, e.g. VERT[157], additional requirements have to be met concerning the vehicles as such. Many of these requirements concern the save operation of the vessel or railway vehicle which must be ensured in case of a retrofitted engine as it was before retrofitting happened. European requirements and procedures apply and, as a rule, designated competent authorities must inspect the retrofitted vessel or railway vehicle for this purpose.

As far as inland water way vessels are concerned there is legislation which provides some guideline (European Commission, 2009d; European Commission, 2016a). In order to operate on European inland waterways vessels must have a European Vessel Identification Number (ENI) and a Union Inland Navigation Certificate (UINC). To receive the UINC requires that a survey the on the vessel has been completed, in line with the EU requirements. After retrofitting it must be checked whether the requirements are still met. Moreover, for vessels operating on the river Rhine additional detailed rules apply[158], e.g. ES-TRIN 2017 chapter 9 article 9.09 published by CESNI, which became legally binding via the Directive (EU) 2016/1629 (and Delegated Act 2018/970 and the RheinSchUO) on 6.10.2018[159]. CESNI committees will also look into the issue of retrofitting under the current work programme (the European Commission is represented by DG-MOVE). In addition, national legislation might apply, e.g. as part of national financial support programmes[160].

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[157] Not all certification systems cover engines used for inland waterway vessels or railway vehicles, e.g. UNECE R 132.
[158] Rheinschiffsuntersuchungsordnung (RheinSchUO)
[159] Source: https://www.cesni.eu/en/documents/
[160] See as far as Germany is concerned:
1. https://www.elwis.de/DE/Service/Foerderprogramme/Nachhaltige-Modernisierung-von-Binnenschiffen/Nachhaltige-Modernisierung-von-Binnenschiffen-node.html
2. https://www.elwis.de/DE/Service/Foerderprogramme/Nachhaltige-Modernisierung-von-Binnenschiffen/Zuszubestimmungen-ANS.pdf?__blob=publicationFile&v=3
3. https://www.elwis.de/DE/Service/Foerderprogramme/Nachhaltige-Modernisierung-von-Binnenschiffen/Zusatzbestimmungen-KWE.pdf?__blob=publicationFile&v=3.

As far as railway vehicles are concerned EU legislation also provides some guidance[161], including essential requirements, technical specifications for interoperability (TSIs) and checking procedures to be carried out by a Notified Body (NoBo). More specifically, Member States must verify that the safety of the rail system into which the subsystems will be integrated will be maintained. That means it must be checked whether the requirements laid down in the EU Directives or the additional national legislation is still met after retrofitting. If verification of the safe integration of the subsystem is not possible the TSI must be identified by means of an explicit risk assessment. Even though the harmonisation of rail systems in the EU made good progress in recent years, there are still certain differences among Member States. Any open issues that might persist in the relevant TSI must be assessed at national level. Assessment Bodies must verify the suitability systems, like the propulsion engine, that have undergone significant changes with respect to safety requirements. In case of a significant change, for example retrofitting of an engine, it must be ensured that the change will not adversely affect the safety of the system as a whole. Following completion of the assessment, the Assessment Body issues a safety assessment report. Assessment Bodies must be accredited or designated by a Member State of the European Union. According to European directives and regulations, the Member States must notify the EU Commission of any differences in national requirements which are relevant for the safe integration of subsystems into the rail systems of the individual Member States. However, no national or international activity is known which addresses specifically the question of retrofitting.

8.3 Conclusions

- Care must be taken to not violate the type-approval of a NRMM engine when retrofitting this engine. There might be cases in which the type-approval needs to be repeated. This holds in particular for engines which are already equipped with after-treatment systems in fits place.
- Certification in accordance with UNECE R 132 – as a rule – avoids the need to obtain a new type-approval since it requires the approval of the original engine manufacturer. This means on the other hand that some engines might not be retrofitting due to the lack of the OEM permission.
- NRMM have also to comply with the EU machine Directive and with EU safety regulations; retrofitting might violate these regulations. Therefore, in addition to a certification system the technical service has to check whether such violations are avoided in case of retrofitting.
- In many cases, this can be managed for retrofitted non-road mobile machinery engines in the sub-sectors construction works and agriculture. For inland waterways vessels and rail vehicles this might be more difficult since additional requirements apply. As a rule, special investigations have to be carried out after retrofitting in order to keep the operation certificate for a retrofitted vehicle;
- Engines that already include an after-treatment system as part of the type-approved configuration are much more difficult to retrofit with additional devices. Since after-treatment was introduced from 2011 in certain categories used in construction and agriculture the number of engines still operating without after-treatment in these sectors which could be easily retrofitted is declining.

[161] The 4th Railway Package is a set of 6 legislative texts designed to complete the single market for Rail services (Single European Railway Area). It comprises two 'pillars' which have been negotiated largely in parallel: The technical pillar and the market pillar. The 'technical pillar', which was adopted by the European Parliament and the Council in April 2016, includes:

- Regulation (EU) 2016/796 on the European Union Agency for Railways and repealing Regulation (EC) n° 881/2004
- Directive (EU) 2016/797 on the interoperability of the rail system within the European Union (Recast of Directive 2008/57/EC)
- Directive (EU) 2016/798 on railway safety (Recast of Directive 2004/49/EC)

9 Implementing retrofitting measures

9.1 Literature review

Retrofitted engines - as well as new engines equipped with after-treatment devices - are new to many operators of mobile machinery, but partly as well to the official institutions responsible for the implementation of legislation.

Moreover, it cannot be assumed the NRMM owner understands the retrofitter might make changes that affect product safety, nor can it be assumed that the retrofit installer - which could, if not regulated, be a local garage or mechanic with no knowledge of legislation - will work in conjunction with technical services[162].

Several studies on operational problems experienced with retrofitted non-road mobile machines have been carried out, for example UMTEC (2005), FSKB (Fachverband der Schweizerischen Kies- und Betonindustrie, 2003), BUWAL (2005) and Wagner (2013) which studied the in-use experiences with particle filters or publications of Mayer et al. (2004).

Retrofitted engines - as a rule - have higher operational costs than engines without after-treatment. Moreover, failures might lead to engine shut-downs. Reasons for failures are for example local temperature peaks during regeneration, ash plugging of filter cells, material failures of the filter media, filter breakthroughs due to filter overload, cementing failures with segmented filters, mechanical shocks during transport or installation, insufficient vibration decoupling, usage of wrong fuels, high lubrication oil consumption, non-respected backpressure alarms not respected, unprofessional ash cleaning, careless, engine maintenance etc.

All this could be a motivation for the operator of a mobile machinery to take-off or by-pass after-treatment equipment[163]. In fact, EUROMOT mentioned as well for new engines and machines concerns regarding tampering after-treatment and electronic control units[164].

Therefore, for retrofitted engines maintenance and periodic checks are very important. Hence, in addition to the certification of after-treatment devices countries or regions or cities which introduced a retrofitting programme identified the need to accompany such programmes with measures which ensure proper implementation.

A simple measure is the publication of guidance mainly designed to inform engine owners, but which might also of help to inspectors, e.g. as published in Switzerland (Arbeitsgruppe Baumaschinen, 2010; BAFU, 2009; Federal Department of the Environment, 2010b), in London (Crossrail, 2012; Crossrail, 2013a; Greater London Authority, 2017), by VERT (2016) and in Berlin (Senat Berlin, 2015). As a rule, the guidance informs about general aspects of retrofitting measures and on the processes and procedures that should be in place on all relevant construction sites, including the recommended practices, documentation, considerations and planning conditions.

In Switzerland long-term experiences are available, see for example Hallauer (2014). The implementation of the Swiss legislation is complex and involves 6 Federal institutions and 26 Cantons. There is great interest that the implementation is harmonised and follows common rules. Experience in Switzerland shows that intensive communication with those affected by retrofitting measures

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[162] This is ensured by the Swiss system and UNECE regulation since R132 sets out installation responsibilities linked to the type-approval.

[163] In 2012 in Switzerland 1398 inspections of construction works were carried out and 68 violations identified.

[164] EUROMOT statement of 14.12.2017. It should be mentioned that Article 18(4) of Regulation 2016/1628 in conjunction with more detailed requirements laid down in the Delegated Regulation 2017/654 and the Implementing Regulation 2017/656 aims at preventing tampering. However, EUROMOT drew attention to commercial tampering services which aim at saving end-user's money by defeating emission reduction systems and gave reference to Article 8(2) of Regulation 2016/1628 which provides a legal basis for Member States to intervene against such practices.

strengthens acceptance and helps with implementation difficulties. Therefore, the central government established a number of rules to apply and is aiming at providing further guidance (BAFU, 2016b).

As far as existing guidance is concerned FOEN (Federal Department of the Environment, 2010a) - for example - published a document which deals with the conformity procedure, according to the Ordinance on Air Pollution Control (OAPC). It is designed for OEM's who supply machines fitted with diesel engines for use on construction sites in Switzerland but also for engine manufacturers who provide type-approved (according to Directive 97/68/EC) engine and filter systems for factory installation by construction machine OEM's.

Moreover, seeing that construction works are the main focus in Swiss legislation, Bundesamt für Umwelt (BAFU, 2016a) published in 2016 a guide on "Air Pollution Control at Construction Sites" in order to provide a guideline on how construction sites are categorised in the framework of the approval procedures. This guideline, inter alia, describes the periodic inspection with the appropriate measuring procedures of construction machines in operation.

More specific for construction work machinery is the publication of an expert group[165] in which good practice for performing exhaust gas maintenance and control on construction machinery and equipment is described. The guidance aims at facilitating uniform enforcement by the authorities and cantons and serves as a basis for operators to monitor engine emissions and the efficiency of exhaust after-treatment systems, such as particulate filter[166].

Finally, Member States should consider taking legal action against commercial tampering services.

9.2 Conclusions

- Retrofitting measures need to be accompanied by guidance and the actual implementation needs to be verified by inspection teams;
- Surveillance is needed, seeing that NRMM operators might have economic advantages not applying the after-treatment systems properly;
- Member States should consider taking legal action against commercial tampering services;
- The costs for Member States associated with the establishment of guidance and surveillance cannot be estimated. As a rule, however, Member States have already now established institutions for similar purposes so that costs are most likely negligible.

[165] Expert Group 2010: Abgaswartung und Kontrolle von Maschinen und Geräten auf Baustellen. Technische Anleitung zur Umsetzung der Luftreinhalteverordnung LRV

[166] Although the Swiss regulational scheme is quite comprehensive, it does not include installation responsibilities other than certification for environmental performance, e.g. it does not set responsibilities for safe installation.

10 The EU after-treatment market

10.1 Literature review

There are no official statistics on the EU retrofitting market available.

Most of the may be 20 to 40 firms, including manufacturers and installers, offering currently after-treatment solutions for NRMM in the EU belong to the group of small or medium size companies with an annual turn-over in the range of the one to two-digits millions. Their fields of business activities include also on-road vehicles which make up, as a rule, the larger part of their turnover. Moreover, some OEMs offer retrofitting services.

In terms of turnover, looking at business report of some retrofitting firms, the EU retrofitting market is relatively small with an economic volume in the one to two-digit million range.

The NRMM retrofit market is mainly a DPF market. The number of applications of retrofit urea-SCR systems is relatively small compared to retrofit DPFs. SCR retrofits in the non-road sector have largely focused on stationary diesel engines. There could be some very limited applications on non-road construction equipment, although there are no statistics available[167].

In general, there are indications that the retrofitting market declines on cost of deliveries to OEMs for new engines. In fact, the retrofitters speak of a "dead" retrofit market. The reasons for the decline might be that with the introduction of Stages IIIB and IV NRMM with exhaust gas after-treatment became available. This offered the option to NRMM equipment users to purchase a machine which meets national or local requirements, in particular with regard to DPF. As explained in the chapter "Measures taken by Member States, States and local level", apart from the non-EU country Switzerland, there is no regulation in the EU which actually forces retro-fitting without giving an alternative[168]. As a rule, the alternative is to use NRMM equipment complying with about the latest Stages of the EU limit values.

An increasing number of end-users decide in favour of new NRMM. In particular retrofitting old and low power equipment is in economic terms often not cost efficient since their economic value is lower than the retrofitting cost.

Moreover, leasing equipment which meets the requested specific requirements is another option for firms. This applies in particular to construction works where equipment leasing is common practice[169,170,171,172] in particular for time-limited works.

Finally, larger construction firms with a machine pool have the option to shift after-treatment equipped NRMM to those works where specific environmental performances are required.

In informal contacts representatives of the retrofitting industry confirm these views.

The total retrofitting capacity of the market adapts to the demand, but could be also relatively quickly enlarged, if necessary. In so far, at least for the NRE sector there seems to be no capacity problem if retrofitting of a large number of NRMM within a couple of years would be required.

It is more critical to require that retrofitting system must comply with UNECE R 132. Currently there is most likely no system available which is certified under R 132 since the certification is very expensive (costs are estimated by retrofitting firms to be in the range of 100000,- € to 200000,- € per engine family) and no firm takes the risk in the light of the market situation to launch a certification without having an order for the equipment. Moreover, UNECE R 132 limits in comparison to other certification

[167] Notable that in case operator chooses retrofit as method to comply with London LEZ requirements for construction equipment (www.nrmm.london) it is necessary to retrofit for both PM and NOx.
[168] Please note: Switzerland does not mandate retrofit in case the machine complies with PN limit (e.g. already fitted with DPF).
[169] Leaseurop 2017: The European leasing market
[170] Bundesverband Deutscher Leasing Unternehmen: Jahresberichte
[171] Städler 2017: Leasing-Quoten nach Leasingnehmer-Bereichen
[172] Städler 2017: Leasing-Quoten nach Gütergruppen

systems the scope of the certificate to well-defined engine/after-treatment combinations. In consequence more, certificates are needed in order to cover the market. Since the retrofitting costs have to be included in the price for the equipment a significant number of orders would be needed before such a step is taken. Moreover, certification takes quite long due to the durability requirements.

In consequence, if short term measures were required a transition period would make sense within which existing certifications were accepted[173].

10.2Conclusions

- The EU after-treatment market for NRMM is small; it could grow if the demand increased;
- The market is currently practically inactive since nowhere within the EU retrofitting is mandatory and a large number of new machinery equipped with after-treatment devices are available on the market. If specific additional NRMM emission reduction provisions are required there are always other options allowed;
- In the light of the very weak NRMM after-treatment market and the potentially high cost for testing there is currently no after-treatment system certified under UNECE R 132.

[173] This would correspond to arrangements made for the retrofitting of buses which allows VERT certification for a transition period.

11 External costs

11.1 Introduction

The starting point of all external costs' considerations are exposure-receptor relationships, e.g. a unity of a concentration or a load increase an effect with a certain probability in a definite response of the receptor. Due to variations in ambient air concentrations/loads, which are, inter alia, a function of emission height, receptor characteristics and exposure, receptor/population density, meteorological and geographical conditions etc. external costs are a function of space and time. As an example, external cost estimates for PM are shown as a function of emission height and population density, see Figure 11-1.

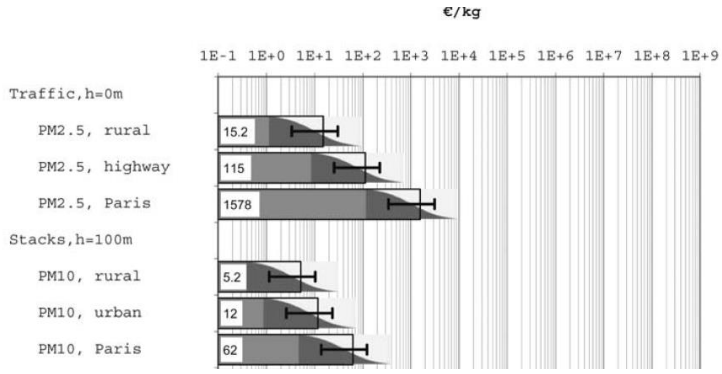

Figure 11-1 Example of PM external cost estimates as a function of emission height and population density (Rabl et al., 2005)

On top external costs are a function of time, as some of the parameters listed change over time.

Depending on the case, external costs include a number of different cost categories, e.g. accidents, air pollution, climate change, noise, loss of nature and landscape, loss of biodiversity, soil and water pollution, etc.

Complex models are therefore needed to calculate external costs. However, this study does not envisage the use of such models. This study applies a much simpler approach based on average external costs per mass of pollutants emitted.

Air pollution costs include, as a rule, health costs, years of human life lost, crop losses, building damages, costs for nature and biosphere. In this study health costs due to air pollution are of greatest importance. The air pollutants considered under the category air pollution are exposure data to PM, NO_x, CO_2 and BC.

11.2Literature review

A number of studies on external costs have carried out related to costs of transport or energy production in recent years, see UIC (2018), e.g. NEEDS (2007), 2008 Handbook, UIC (2011), Ricardo/AEA (2014).

The Commission, based on CE Delft, estimates that the prevented damage costs are in average 5,2 €/kg for NO_x and 130 €/kg for $PM_{2.5}$ (European Commission, 2014a; Van Essen et al., 2008)[174].

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[174] The relevant text in the Impact assessment reads: "*As it proved difficult to determine the exact location of the emissions considered, cost-benefit calculations under Option 3 were systematically carried out on the basis of two damage cost values for $PM_{2.5}$ emissions according to the following scenario assumptions:*

- *'Low': $PM_{2.5}$ emission damage costs of 35 000 €/t*
- *'Medium': $PM_{2.5}$ emission damage costs of 130 000 €/t*

The low damage cost value corresponds to the very lowest estimate for an average EU-25 value referred to in this study, whereas the medium damage cost has been determined as a typical EU-25 average value which is representative for urban areas, indexed to 2015 prices respectively. The study mentions, in addition, significantly higher cost damage values for urban-metropolitan areas which were however not been used in the current calculations."

Van Essen et al. (2008) reported for $PM_{2.5}$ under inner city conditions and taking year 2000 prices a range of 50 to 500 €/kg, under urban conditions a range of 15 - 290 €/kg and under rural conditions a range of 12 - 125 €/kg. For NO_2 the range is in average 1,5 - 19,3 €/kg. CE Delft external cost estimates have also been used in the recent publication of the JRC on public procurement[175].

Kasper reported in 2013 for Switzerland for PM_{10} health related costs of 460 CHF/kg.

UIC (2011) found in 2011 for $PM_{2.5}$ 430 €/kg in metropolitan areas, 138 €/kg for urban areas and 83 €/kg for non-urban areas.

In the NEEDS (Preiss and Klotz, 2007) project the following figures can be found for 2005/7: $PM_{2.5}$/rural 28,1 €/kg, suburban 70,3 €/kg and urban 270,1 €/kg and for NO_2 10,6 €/kg. For CO_2 the range is between 20 - 70 €/t[176].

Van Zeebroeck (2009) used in the 2009 impact assessment study values of Van Essen et al. (2008) and indexed them to 2008. They estimated values for PM of about 30,6 €/kg and for NO_x of about 5,2 €/kg. These external costs take into account a valuation of health impacts (and air quality), crop damage, material damage and negative consequences for biodiversity. Valuations of health impacts are based on scientific studies evaluating extra mortality, cardiopulmonary morbidity, (cerebrovascular hospital admissions, congestive heart failure, chronic bronchitis, and chronic cough in children, lower respiratory symptoms, and cough in asthmatics[177].

In Directive 2009/33/EC (European Commission, 2009c) the following external costs for road vehicles are given: 87 € /kg PM_{10}, 4,4 € /kg NO_x and 0,03-0.04 €/kg CO_2.

In a more recent Danish study of Brandt et al. (2011) estimated external costs for the sector non-road mobile sources of 43,8 €/kg for $PM_{2.5}$ and 6,37 €/kg NO_x. In the study Brandt et al. conclude that the following sectors contribute significantly to health-related external costs in Europe are: agriculture (43%), road traffic (18%), major power plants (10%), domestic heating (wood stows; 9%) and other mobile sources (8%).

The German Umweltbundesamt published in 2014 estimates of external costs for various sources, including road transport (Umweltbundesamt, 2014). For CO_2 it proposed 0,080 $€_{2010}$/kg CO_2 for 2010 and 0,145 $€_{2010}$/kg CO_2 for 2030. For PM_{10} it proposed 8,5 to 36,3 $€_{2010}$/kg for extra-urban area and urban area, respectively. The corresponding values for $PM_{2.5}$ are 81 and 393 $€_{2010}$/kg and for NO_x 10,3 $€_{2010}$/kg irrespective of the point of emissions. Recently, these estimates have been up-dated (Bünger and Matthey, 2018). For CO_2 the external cost values proposed increased to (€/kg) 0,180 (in 2016) 0,205 (2030) and 0,240 (2050). For PM and NO_x the following estimates are proposed for road traffic, see Table 11-1:

Table 11-1 External cost estimates of the German Umweltbundesamt for road traffic (Bünger and Matthey, 2018)

All figures in $€_{2016}$/kg	Rural	Urban area
PM_{10}	6.8	28.5
$PM_{2.5}$	59.7	242.5
NO_2	15	15

[175] JCR 20019: Revision of the EU Green Public Procurement Criteria for Transport
[176] This corresponds more or less to the range given in the US document "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 (May 2013, Revised August 2016)" in which costs between 11 to 101 $\$_{2007}$ are estimated for 2015.
[177] Following elements have not been considered as impacts on these elements are minor or not existent: Water quality and resources, soil quality and resources, renewable or non-renewable resources Biodiversity, flora, fauna and landscapes, land use, waste production/generation/recycling. The likelihood or scale of environmental risks, the environmental consequences of firms' activities.

Shindell (2015) studied social costs of atmospheric releases and estimates these costs to about 67 US $$_{2007}$/kg for NO_x, 27 to 150 US $$_{2007}$/t for CO_2 and 210 to 310 US $$_{2007}$/kg for BC in total, including climate change, and 62 US $$_{2007}$/kg for health effects only.

The UK Department of Environment, Food and Rural Affairs (DEFRA, 2015) estimated the NO_2 human health damage costs for "average transport" to be about 23 €/kg NO_x.

In California, for the in-use off-road diesel vehicle Regulation, cost-effectiveness values of 4,74 US $ per lb[178] for NO_x and 83,87 US $ per lb for PM were used[179].

IPCC[180] recommended in 2014 an external cost values of 0,1735 €$_{2016}$/kg CO_2 which is close to the values proposed by the German Umweltbundesamt.

11.3 Proposal for cost benefit calculations

Averaged external cost estimates are associated with large of assumptions and simplification and therefore with uncertainties. ExtremE, for example, highlighted this aspect by showing the development of costs estimates within the project, see Figure 11-2.

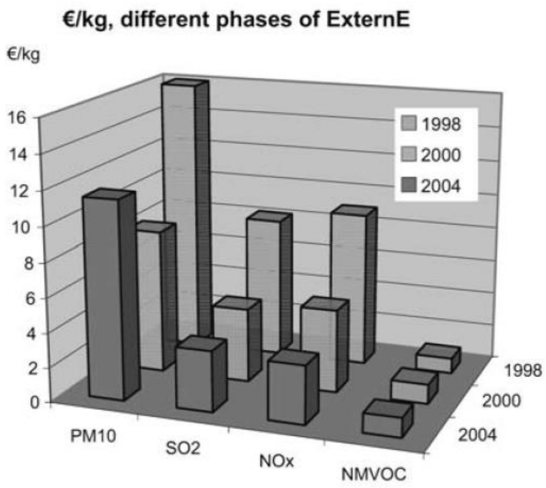


Figure 11-2 Development of external cost estimates for Life Cycle Analysis in EU-15 at different Stages of the ExtremE project (Bickel et al., 2005)

Despite these shortcomings, this study has to provide estimates of external costs to be included in the cost-benefit analysis. This study uses the general average external costs for the EU. In addition, another set of data is used for urban areas/cities, as the external costs vary widely according to population density. These are all estimates in orders of magnitude.

Taking the literature values into account, corrected for exchange rates and inflation, the following averaged estimates for external costs are used in the assessments carried out in this report, see Table 11-2:

[178] 1lb = 0,45359237kg

[179] CARB 2017: PUBLIC HEARING TO CONSIDER THE PROPOSED AMENDMENTS TO THE AIRBORNE TOXIC CONTROL MEASURE FOR DIESEL PARTICULATE MATTER FROM PORTABLE ENGINES RATED AT 50 HORSEPOWER AND GREATER, AND TO THE STATEWIDE PORTABLE EQUIPMENT REGISTRATION PROGRAM REGULATION. STAFF REPORT: INITIAL STATEMENT OF REASONS

[180] IPCC 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and sectoral aspects. Working Group II contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press.

Table 11-2 Estimated external costs used in this study

All figures in €/kg	General	Urban area
PM_{10}	10	50
$PM_{2.5}$	75	250
NO_2	10	20
CO_2	0.15	
BC	200	

These are order of magnitude estimates, to be used in simplified assessments only. In tendency they are at the high end of external costs reported in literature.

11.4 Conclusions

- The estimation of external costs requires sophisticated investigation which is outside the scope of this study.
- Simplified approaches, using averaged external cost figures can be provided and used for the cost/benefit studies to be carried out within this study. Cost figures are expressed in €/kg or €/t of emissions.
- External cost estimates for PM_{10}, $PM_{2.5}$, NO_2, CO_2 and BC are provided.

12 Cost-benefit analysis

12.1 Methodology

A cost-benefit analysis (CBA) model has been developed to enable assessment of the different retrofitting options. The main objective of the CBA model is to deliver an analysis of the associated trade-offs between costs and benefits, and hence to assess how the environmental, health and other benefits expected compare to the respective technology costs. The key outputs delivered by the CBA model for each of the examined metrics and scenarios are summarized below:

- Environmental benefits (emissions savings) per pollutant, machinery category and year;
- Total (monetised) benefits, total costs and net benefits per machinery category and year;
- Cost-effectiveness results per pollutant and per machinery category (i.e. costs required per tonne of pollutant emissions saved).

The main methodological components of the CBA model are:

- Calculation of costs (in €) for the implementation of appropriate retrofit systems;
- Calculation of environmental benefits (emission savings for NO_x and PM);
- Calculation of benefits (in €) for each NRMM category and pollutant;
- Calculation of cost-benefit (in €) and cost-effectiveness (in €/kg).

Cost Analysis

The cost analysis model directly involves the total societal cost incurred for the implementation of each retrofitting option. The costs considered in this study include:

- Investment costs;
- Operation Costs;
- Costs incurred from fuel penalty due to the installation of a retrofitting device.

The investment costs are calculated by multiplying the basic investment cost for implementing the retrofitting system for each engine with the retrofitted fleet for each year (Eq. 1). The operation costs refer to all retrofitted engines, namely to those retrofitted each year, as well as the ones surviving every consecutive year. Thus, operations costs are calculated by multiplying the total retrofitted fleet with the operation cost of each retrofitting system per engine (Eq. 2). Finally, the costs incurred from fuel penalty are again calculated for all retrofitted engines, based on Eq. 3. The correction factor refers to a correction used to account for the decreasing operating hours of the engines as a function of the engine age. This is applicable only for the sub-sector agriculture/construction. In the following equations (Eq. 1, Eq. 2 and Eq. 3), i refers to the number of years examined as retrofitting period.

$$Investment\ Costs = \sum_{i}^{n} retrofitted\ fleet_i * investment\ cost\ per\ engine \qquad \textbf{Eq. 1}$$

$$Operating\ Costs = \sum_{i}^{n} (retrofitted\ fleet_i + remaining\ retrofitted\ fleet_i) * operating\ cost\ per\ engine \qquad \textbf{Eq. 2}$$

$$Fuel\ Penalty\ Costs = \sum_{i}^{n} \frac{(retrofitted\ fleet_i + remaining\ retrofitted\ fleet_i) * fuel\ penalty * fuel\ consumption * fuel\ cost * engine\ power * annual\ hours * load\ factor * correction\ factor}{fuel\ density} \qquad \textbf{Eq. 3}$$

Benefits

This methodological component of the CBA model combines the different parameters from the examined scenario to calculate the emission savings for each pollutant. In order to calculate the monetised benefit (in €) derived from the emission savings, the latter are multiplied with the external marginal (damage) costs per tonne of pollutant emitted. These external costs, once saved from the implementation of a retrofitting technology, correspond to the monetised environmental benefit. Specifically, the benefit calculation is as follows:

$$\boldsymbol{total\ benefit}\ [\boldsymbol{M}€] = \left(\frac{\boldsymbol{M}€}{\text{kt}}\,emissions\ saved\right) * (kt\ of\ emissions\ saved)$$

The benefit is calculated per retrofitting technology, per machinery category and per year.

Cost-benefit and cost-effectiveness analysis

The CBA uses as input the results of the previous tools, i.e. the cost analysis tool and the benefits tools. The CBA is built for each machinery category and is presented schematically in Figure 12-1.

The equivalent monetised total benefit coming from the pollutants saved is calculated by multiplying the emission savings, with the external marginal costs, for each of the examined pollutant. The net benefit is then calculated by subtracting the total cost from the pollutants benefit. The cost-effectiveness analysis provides the cost per unit of mass of pollutants saved. This is derived by dividing the implementation costs over the emission savings for each pollutant.

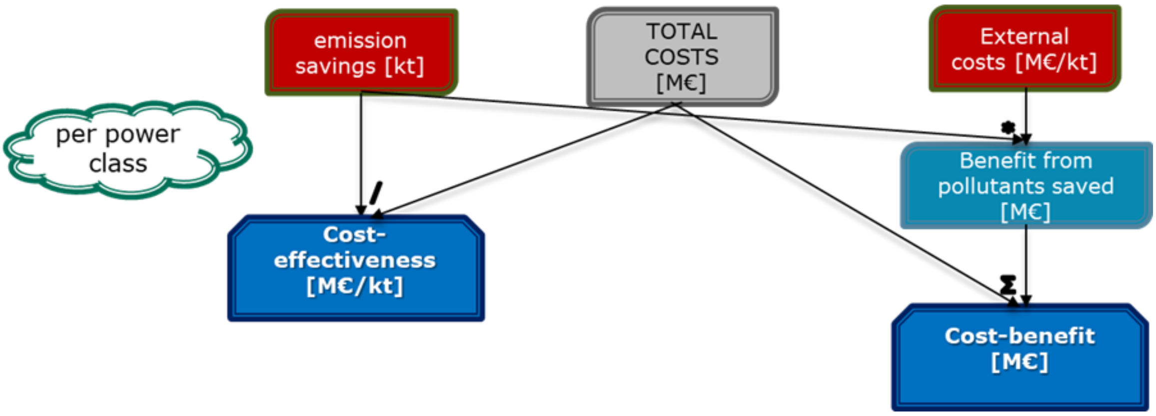


Figure 12-1 Cost-benefit analysis block diagram

Basic parameters

The parameters provided as input to the CBA model are described in the following:

- Fleet data: The fleet turnover simulation has been presented in detail in chapter 4.2.1 and covers the time period 2020-2050. In the subsequent calculations the year 2020 has been assumed as first year of retrofitting but other implementation years are also possible. An excerpt of fleet evolution for the agricultural and construction category for the power class 37-56 kW is presented in Table 12-1. In this table **no Stage V machinery is included as these are considered not to be subject to retrofitting**. Only very few unregulated machinery exist in 2020 hence retrofitting does not make much sense for such old machinery. Also, there is very few remaining Stage I machinery, which is phased out quickly as they have limited lifetime left.

Table 12-1 Fleet evolution for the agricultural and construction category, power class 56-75 kW

Year	Unregulated	Stage I	Stage II	Stage IIIA	Stage IIIB	Stage IV	Total
2020	10,104	114,605	432,943	560,938	466,204	901,389	2,486,183
2025	235	9,869	114,605	316,709	382,100	934,859	1,758,377
2030	0	235	9869	72,485	169,452	732,995	985,036
2035	0	0	235	5056	26,453	332,164	353,908
2040	0	0	0	93	1148	57,031	58,272
2045	0	0	0	0	11	3,267	3,278
2050	0	0	0	0	0	50	50

- Emissions data: PM and NO_x emissions for the time considered (2020-2050) were calculated based on the analysis provided in section 4.2.2.
- Retrofitting costs: values for retrofitting costs for all categories are provided in Table 6-8, Table 6-9, Table 6-10, Table 6-15 and Table 6-16. For these costs a ±20% uncertainty has been considered. A fuel consumption penalty equal to 3% has been considered, as explained in section 6.6.1.
- Reduction efficiencies: low and high values for the reduction efficiencies of the retrofitting technologies are taken from the corresponding analysis of chapter 6 and are summarized in Table 12-2.

Table 12-2 Reduction efficiencies per retrofitting technology and pollutant

SCR – NO_x emissions		DPF – PM emissions		DPF+SCR – NO_x emissions		DPF+SCR - PM emissions	
Low	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
60%	90 %	90 %	99 %	85 %	90 %	95 %	99 %

- External costs: values for the external costs for the two pollutants (PM and NO_x) are taken from Table 11-2. For these costs a ±20% uncertainty has been considered. Since the external costs are much higher in urban areas than in rural areas, the spatial distribution of machinery has an important impact on calculations. To this aim, Table 12-3 shows the split into agricultural and construction machinery for the different power classes and Table 12-3 shows the assumed allocation of machinery into general and urban area.

Table 12-3 Split of total machinery stock into agricultural and construction machinery by power class*

Category	<19 kW	19-37 kW	37-56 kW	56-75 kW	75-130 kW	130-560 kW	> 560 kW
Agriculture	39 %	21 %	60 %	49%	76 %	79 %	54 %
Construction	61 %	79 %	40 %	51 %	24 %	21 %	46 %

* For computing the above shares, generator sets were equally distributed to agricultural and construction machinery

Table 12-4 Use of equipment (general scenario)

General Scenario	Agriculture	Construction	Inland Waterways	Railcars	Locomotives	Shunting Locomotives
General	100 %	50 %	90 %	30 %	98 %	98 %
Urban Area	0 %	50 %	10 %	70 %	2 %	2 %

In order to assess the impact of NRMM operation in urban areas only, an urban scenario has been also considered, as shown in Table 12-5. Evidently, this will result in greater benefits, since the external costs for urban areas are higher than those of the general case.

Table 12-5 Use of equipment (urban scenario)

Urban Scenario	Agriculture	Construction	Inland Waterways	Railcars	Locomotives	Shunting Locomotives
General	0 %	0 %	70 %	10 %	95 %	95 %
Urban Area	100 %	100 %	30 %	90 %	5 %	5 %

The year 2020 is assumed as first year of introduction of the retrofitting technologies. The total net benefits for the time period 2020-2050 for DPF, SCR and DPF+SCR, for the various power classes and emission Stages have been calculated. A parametric analysis has been also performed by assigning low and high values for the different parameters considered in the analysis as shown in Table 12-6.

Table 12-6 Values for the parameters

Parameters	Baseline Scenario	Minimum Scenario	Maximum Scenario
Retrofitting Costs	Moderate	Low	High
Reduction Efficiency	High	High	Low
External Costs	Moderate	High	Low

12.2Results

12.2.1 Agriculture and Construction machinery

Power Class <19 kW

For the power class <19kW only unregulated machinery are subject to retrofitting since there is no other emission Stage until the introduction of Stage V in January 2019. The retrofitting of DPF displays only losses, as displayed in Table 12-7. The values in the following tables represent the net benefits in M€, whereas the high and low values correspond to the parametric analysis as described above (Table 12-6). Even though the investment and operating costs for this power class are the lowest across all power classes, the environmental benefits in monetary terms are relatively low, resulting in losses (in monetary terms).

Table 12-7 Net benefit [M€] for DPF retrofitting of the power class <19 kW for the two scenarios

Power class	Emissions stage	General Scenario	Urban Scenario
< 19 kW	Unregulated	-2200^{+740}_{-796}	-1753^{+830}_{-918}

No SCR retrofitting has been considered for this class, due to the small size of the machinery as explained previously.

Power Class 19-37 kW

For DPF retrofitting, both the general and the urban scenarios display losses, since the environmental benefits are much lower than retrofitting costs (Table 12-8).

Table 12-8 Net benefit [M€] for DPF retrofitting of the power class 19-37 kW for the two scenarios

Power class	Emissions stage	General Scenario	Urban Scenario
19-37 kW	Stage IIIA	-1814^{+659}_{-716}	-1443^{+734}_{-818}
	Stage II	-7^{+2}_{-2}	-7^{+2}_{-2}

Table 12-9 displays the net benefits for SCR retrofitting, which shows negative benefits (losses) for all emission Stages. Compared to DPF, the investment costs of SCR are higher, thus resulting to higher costs. The emission savings using SCR, which are converted to monetised environmental benefits, are much lower than the corresponding costs.

Table 12-9 Net benefit [M€] for SCR retrofitting of the power class 19-37 kW for the two scenarios

Power class	Emissions stage	General Scenario	Urban Scenario
19-37 kW	Stage IIIA	-3880^{+981}_{-1129}	-3639^{+1029}_{-1241}
	Stage II	-15^{+3}_{-3}	-14^{+3}_{-4}

For the combined system (DPF+SCR), again negative benefits are observed for all cases (Table 12-10). These losses are similar to the SCR only, but higher when compared to DPF only.

Table 12-10 Net benefit [M€] for DPF and SCR retrofitting of the power class 19-37 kW for the two scenarios

Power class	Emissions stage	General Scenario	Urban Scenario
19-37 kW	Stage IIIA	-3879^{+1294}_{-1344}	-3266^{+1418}_{-1490}
	Stage II	-16^{+4}_{-4}	-15^{+4}_{-4}

Power Class 37-56 kW

This class shows losses for DPF retrofitting for all cases (Table 12-11). Based on these results, lower losses are observed for unregulated machinery, and higher for Stage IIIB machinery. As discussed previously, Stage IIIB is mostly equipped with DPF and hence their emissions level is already very low. Evidently there is no point in DPF retrofitting and the results are for comparison only.

Table 12-11 Net benefit [M€] for DPF retrofitting of the power class 37-56 kW for the two scenarios

Power class	Emissions stage	General Scenario	Urban Scenario
37-56 kW	Stage IIIB	-5229^{+1020}_{-1028}	-5146^{+1037}_{-1050}
	Stage IIIA	-1589^{+499}_{-535}	-1222^{+573}_{-635}
	Stage II	-713^{+200}_{-211}	-598^{+223}_{-243}
	Stage I	-124^{+45}_{-49}	-86^{+53}_{-59}
	Unregulated	-10^{+3}_{-4}	-7^{+4}_{-4}

SCR retrofitting results in damages for all emission Stages for both scenarios (Table 12-12). SCR retrofit losses are higher than DPF, since SCR investment costs are higher than for DPF, whereas the emission savings are lower compared to the emission savings from DPF retrofitting.

Table 12-12 Net benefit [M€] for SCR retrofitting of the power class 37-56 kW for the two scenarios

Power class	Emissions stage	General Scenario	Urban Scenario
37-56 kW	Stage IIIB	-4536^{+1322}_{-1646}	-3726^{+1484}_{-2025}
	Stage IIIA	-2206^{+558}_{-647}	-1982^{+602}_{-752}
	Stage II	-993^{+256}_{-298}	-888^{+277}_{-347}
	Stage I	-215^{+55}_{-64}	-193^{+60}_{-74}
	Unregulated	-16^{+4}_{-5}	-14^{+5}_{-6}

DPF+SCR shows losses for both scenarios, which are higher compared to only DPF retrofitting. The losses for DPF+SCR for the urban scenario for Stage IIIA, Stage I and unregulated machinery are lower compared to those using only SCR retrofitting technology (Table 12-13).

Table 12-13 Net benefit [M€] for DPF and SCR retrofitting of the power class 37-56 kW for the two scenarios

Power class	Emissions stage	General Scenario	Urban Scenario
37-56 kW	Stage IIIB	-6756^{+1811}_{-1869}	-5863^{+1990}_{-2086}
	Stage IIIA	-2579^{+831}_{-862}	-1989^{+950}_{-1002}
	Stage II	-1184^{+357}_{-369}	-964^{+401}_{-421}
	Stage I	-231^{+79}_{-82}	-172^{+91}_{-96}
	Unregulated	-17^{+6}_{-6}	-13^{+7}_{-8}

Power Class 56-130 kW

For this power class losses are observed for all Stages and all retrofitting technologies (and combinations). Results are summarised in Table 12-14, Table 12-15 and Table 12-16. Some marginal benefits are only observed for Stage I and unregulated machinery for the combined system (DPF+SCR) in the urban scenario and for low retrofitting costs and high reduction efficiency and external costs.

Table 12-14 Net benefit [M€] for DPF retrofitting of the power class 56-130 kW for the two scenarios

Power class	Emissions stage	General Scenario	Urban Scenario
56-130 kW	Stage IIIB	-6781^{+1324}_{-1338}	-6637^{+1353}_{-1377}
	Stage IIIA	-4216^{+1596}_{-1746}	-2648^{+1909}_{-2174}
	Stage II	-2089^{+693}_{-747}	-1520^{+807}_{-903}
	Stage I	-276^{+148}_{-165}	-96^{+184}_{-214}
	Unregulated	-26^{+12}_{-13}	-14^{+14}_{-17}

Table 12-15 Net benefit [M€] for SCR retrofitting of the power class 56-130 kW for the two scenarios

Power class	Emissions stage	General Scenario	Urban Scenario
56-130 kW	Stage IIIB	-4404^{+1348}_{-1731}	-3420^{+1545}_{-2190}
	Stage IIIA	-4270^{+1368}_{-1761}	-3261^{+1570}_{-2232}
	Stage II	-2065^{+702}_{-912}	-1527^{+810}_{-1163}
	Stage I	-401^{+140}_{-182}	-294^{+161}_{-231}
	Unregulated	-31^{+13}_{-19}	-18^{+16}_{-24}

Table 12-16 Net benefit [M€] for DPF and SCR retrofitting of the power class 56-130 kW for the two scenarios

Power class	Emissions stage	General Scenario	Urban Scenario
56-130 kW	Stage IIIB	-7623^{+2068}_{-2138}	-6496^{+2293}_{-2412}
	Stage IIIA	-5226^{+2387}_{-2520}	-2649^{+2903}_{-3131}
	Stage II	-2646^{+1119}_{-1178}	-1539^{+1340}_{-1442}
	Stage I	-401^{+253}_{-250}	-114^{+292}_{-318}
	Unregulated	-34^{+21}_{-22}	-8^{+26}_{-28}

Power Class 130-560kW

For this power class marginal benefits are observed for Stage I machinery and for the urban scenario only, as presented in Table 12-17.

Table 12-17 Net benefit [M€] for DPF retrofitting of the power class 130-560 kW for the two scenarios

Power class	Emissions stage	General Scenario	Urban Scenario
130-560 kW	Stage IIIB	-3786^{+699}_{-712}	-3630^{+731}_{-755}
	Stage IIIA	-2378^{+806}_{-881}	-1433^{+995}_{-1139}
	Stage II	-739^{+229}_{-247}	-514^{+274}_{-308}

	Stage I	-44^{+33}_{-38}	13^{+45}_{-54}
	Unregulated	-12^{+7}_{-7}	-2^{+9}_{-10}

SCR retrofitting is cost-beneficial for the urban scenario and for Stage I (only for low retrofitting costs and high reduction efficiency and external costs). Very small benefits are also observed for unregulated machinery, as shown in Table 12-18.

Table 12-18 Net benefit [M€] for SCR retrofitting of the power class 130-560 kW for the two scenarios

Power class	Emissions stage	General Scenario	Urban Scenario
130-560 kW	Stage IIIB	-2842^{+760}_{-973}	-2194^{+890}_{-1275}
	Stage IIIA	-2242^{+845}_{-166}	-1260^{+1041}_{-1625}
	Stage II	-687^{+292}_{-407}	-336^{+362}_{-570}
	Stage I	-71^{+38}_{-55}	-20^{+48}_{-79}
	Unregulated	-11^{+9}_{-14}	3^{+12}_{-21}

The benefits are further improved for the combined system (DPF+SCR), as demonstrated in Table 12-19. For the urban scenario clear benefits are observed for Stage I and somewhat lower for unregulated machinery. In case of low retrofitting costs and high reduction efficiency and external costs, benefits are also observed for Stage IIIA and Stage II machinery for the urban scenario and for Stage I and unregulated machinery for the general scenario.

Table 12-19 Net benefit [M€] for DPF and SCR retrofitting of the power class 130-560 kW for the two scenarios

Power class	Emissions stage	General Scenario	Urban Scenario
130-560 kW	Stage IIIB	-4308^{+1122}_{-1163}	-3505^{+1283}_{-1358}
	Stage IIIA	-2615^{+1336}_{-1423}	-689^{+1721}_{-1882}
	Stage II	-839^{+421}_{-448}	-263^{+536}_{-586}
	Stage I	-56^{+60}_{-64}	57^{+81}_{-90}
	Unregulated	-9^{+13}_{-14}	15^{+18}_{-20}

Power Class >560 kW

The power class >560 kW shows benefits for almost all retrofitting options, as presented in Table 12-20, Table 12-21 and Table 12-22. This is explained by the fact that the total fleet, and hence also the associated costs, of this power class is small (about 1% of the agriculture and construction machinery fleet) relative to other power classes, whereas the emission savings are high since all vehicles are unregulated and hence high emitters. However, it should be noted that the results for the "urban" scenario are more theoretical because mobile machinery with such powerful engines is practically not used in urban areas. These machines are more likely to be found in quarries and mining.

Table 12-20 Net benefit [M€] for DPF retrofitting of the power class >560 kW for both scenarios

Power class	Emissions stage	General Scenario	Urban Scenario
>560 kW	Unregulated	40^{+921}_{-1103}	1757^{+1265}_{-1571}

Table 12-21 Net benefit [M€] for SCR retrofitting of the power class >560 kW for both scenarios

Power class	Emissions stage	General Scenario	Urban Scenario
>560 kW	Unregulated	482^{+1023}_{-1815}	2336^{+1393}_{-2680}

Table 12-22 Net benefit [M€] for DPF and SCR retrofitting of the power class >560 kW for both scenarios

Power class	Emissions stage	General Scenario	Urban Scenario
>560 kW	Unregulated	5007^{+1116}_{-1329}	8577^{+1830}_{-2181}

Apart from the results for each power class, weighted costs and weighted benefits were calculated for the whole sector agriculture/construction. The weighted costs and benefits were calculated as the weighted average cost and benefit value taking into account all the power classes, based on Eq. 4 and Eq. 5 respectively, where i is the number of the power classes.

$$Weighted\ Costs = \frac{\sum_i^6 costs_i * total\ retrofitted\ fleet_i}{\sum_i^6 total\ retrofitted\ fleet_i} \qquad \textbf{Eq. 4}$$

$$Weighted\ Benefits = \frac{\sum_i^6 benefits_i * total\ retrofitted\ fleet_i}{\sum_i^6 total\ retrofitted\ fleet_i} \qquad \textbf{Eq. 5}$$

In the following tables (Table 12-23, Table 12-24 and Table 12-25) these weighted costs and weighted benefits are presented, which were calculated for each emissions Stage and for both scenarios (general and urban). The weighted costs are the same for both scenarios, whereas the benefits differ between the two scenarios, with the benefits being higher in the urban scenario.

Table 12-23 Weighted costs and weighted benefits [M€] for DPF retrofitting of the agriculture/construction sector

Emissions Stage	Weighted Costs	Weighted Benefits (general scenario)	Weighted Benefits (urban scenario)
Stage IIIB	6022^{+563}_{-563}	182^{+36}_{-50}	324^{+65}_{-88}
Stage IIIA	4149^{+393}_{-393}	1287^{+257}_{-351}	2208^{+442}_{-602}
Stage II	2164^{+207}_{-207}	538^{+108}_{-147}	949^{+190}_{-259}
Stage I	393^{+38}_{-38}	171^{+34}_{-47}	301^{+60}_{-82}
Unregulated	2914^{+288}_{-288}	873^{+175}_{-238}	1402^{+280}_{-382}

Table 12-24 Weighted costs and weighted benefits [M€] for SCR retrofitting of the agriculture/construction sector

Emissions Stage	Weighted Costs	Weighted Benefits (general scenario)	Weighted Benefits (urban scenario)
Stage IIIB	5655^{+528}_{-528}	1457^{+291}_{-680}	2462^{+492}_{-1149}
Stage IIIA	4613^{+439}_{-439}	970^{+194}_{-453}	1608^{+322}_{-751}
Stage II	2258^{+216}_{-216}	583^{+117}_{-272}	988^{+198}_{-461}
Stage I	443^{+43}_{-43}	113^{+23}_{-53}	191^{+38}_{-89}
Unregulated	178^{+16}_{-16}	483^{+97}_{-225}	760^{+152}_{-355}

Table 12-25 Weighted costs and weighted benefits [M€] for DPF and SCR retrofitting of the agriculture/construction sector

Emissions Stage	Weighted Costs	Weighted Benefits (general scenario)	Weighted Benefits (urban scenario)
Stage IIIB	8376^{+799}_{-799}	1639^{+328}_{-398}	2785^{+557}_{-677}
Stage IIIA	6351^{+613}_{-613}	2257^{+451}_{-536}	3817^{+763}_{-906}
Stage II	3218^{+312}_{-312}	1121^{+224}_{-267}	1937^{+387}_{-462}
Stage I	617^{+61}_{-61}	284^{+57}_{-67}	492^{+98}_{-117}
Unregulated	40^{+2}_{-2}	1356^{+271}_{-321}	2162^{+432}_{-511}

Additionally, figures on the total costs by power class for each retrofitting technology are included in Annex IV. These are the total costs required for retrofitting vehicles in each power class, taking into account the parametric analysis for high and low retrofitting costs.

For the above scenarios the emission reductions that will be achieved using the various retrofitting systems were calculated as a share of the total emissions of the sub-sector agriculture/construction and they are presented in Table 12-26. Based on these results, DPF retrofitting system shows the highest emission reductions, followed by the combined system (DPF+SCR).

Table 12-26 Emission reductions from agriculture/construction machinery for high and low reduction values, 2020-2050

Retrofitting System	Emissions reductions for high reduction efficiency	Emissions reductions for low reduction efficiency
SCR	11 % of NO_x emissions	8 % of NO_x emissions
DPF	24 % of PM emissions	22 % of PM emissions
DPF+SCR	12 % of NO_x and PM emissions	10 % of NO_x and PM emissions

Figure 12-2, Figure 12-3 and Figure 12-4 present the evolution of emissions using the various retrofitting systems, for high and low reduction efficiency values, as well as the evolution of emissions in case no retrofit takes place.

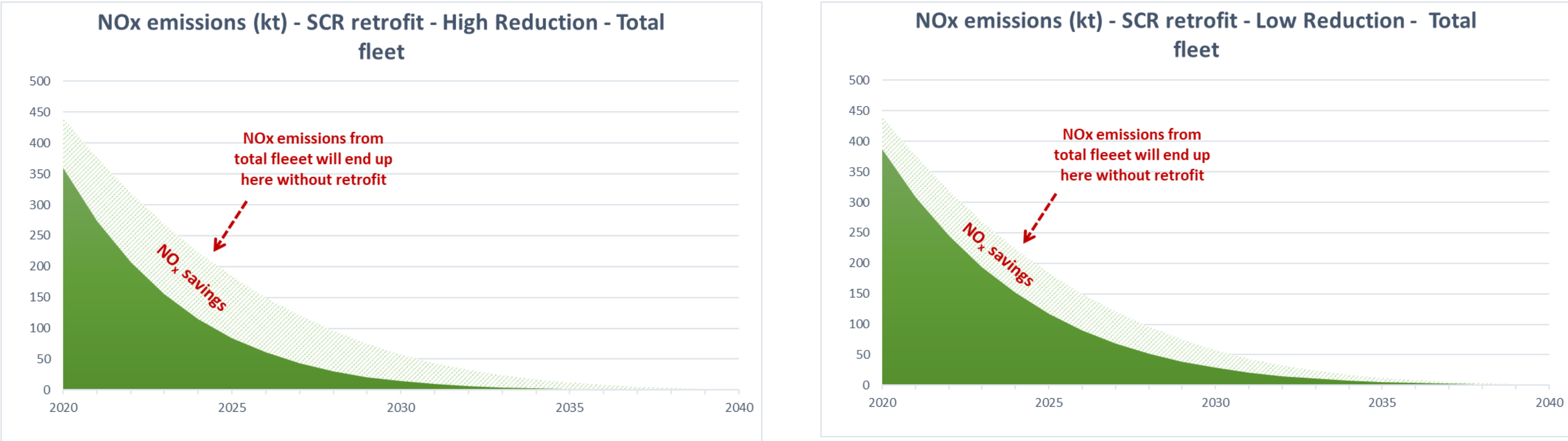


Figure 12-2 Evolution of NO_x emissions from agriculture/construction machinery with/without SCR retrofit, 2020-2040

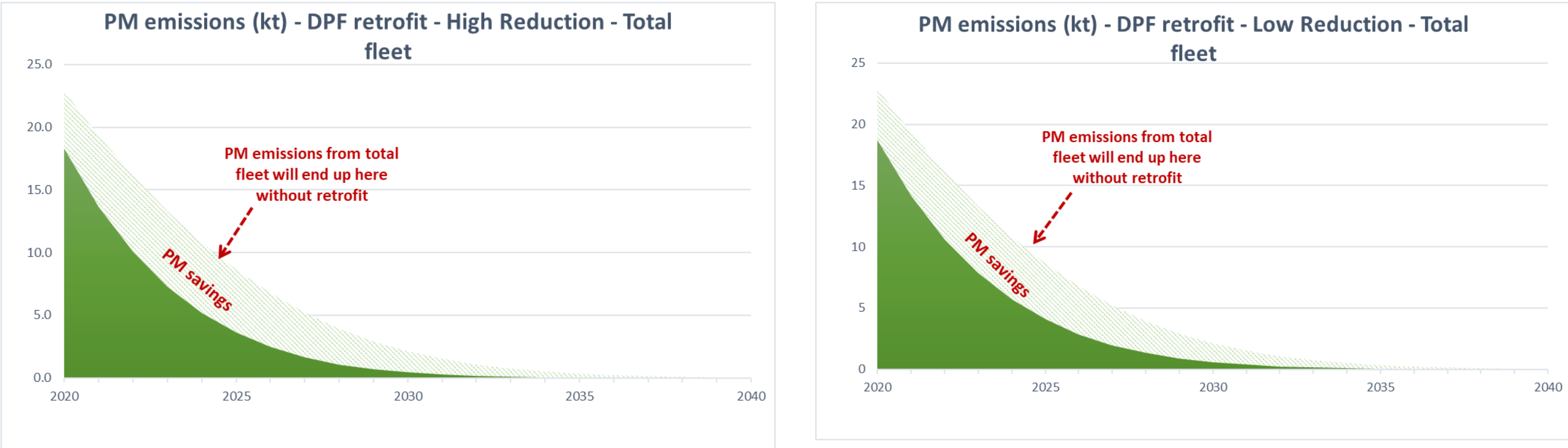


Figure 12-3 Evolution of PM emissions from agriculture/construction machinery with/without DPF retrofit, 2020-2040

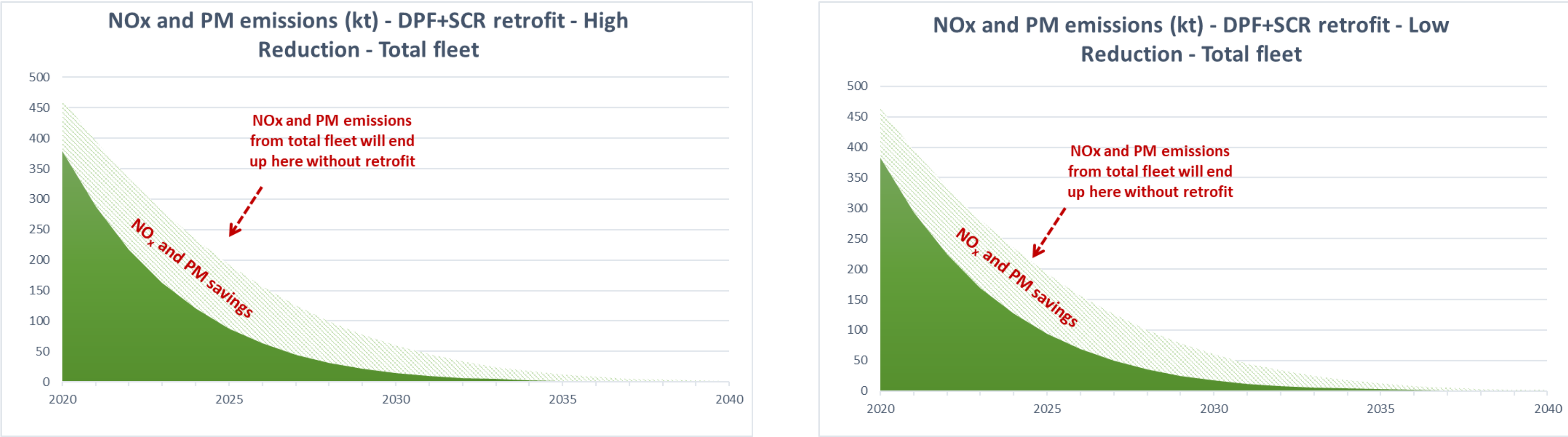


Figure 12-4 Evolution of NO_x and PM emissions from agriculture/construction machinery with/without DPF+SCR retrofit, 2020-2040

Figures on the cost-effectiveness (i.e. costs required per kilogram of pollutant emissions saved) are included in Annex V for all retrofitting systems.

In the above analysis, the year 2020 has been considered as the first year of retrofitting. This results in the highest possible benefits as the emissions are reducing every year due to normal fleet turnover. Evidently, benefits (if any) are reducing with the year of implementation and may result in losses (negative benefits) after a certain point in time. In order to investigate what is the time-window for which retrofitting remains beneficial, a parametric analysis was performed. The analysis follows the same principles with the cost-benefit calculations presented previously.

In the following figures (Figure 12-5 and Figure 12-6) dark green cells denote the cases where benefits are observed for the baseline scenario (i.e. moderate retrofitting costs, moderate external costs and high reduction efficiency values), the patterned green cells denote the cases of high retrofitting costs and low reduction efficiency and external costs, and light green cells show the cases of low retrofitting costs and high reduction efficiency values and external costs for which benefits are observed. Red cells show the years for which retrofitting becomes not beneficial. Finally, grey cells represent cases where retrofitting is not applicable as the specific emissions Stage is phased out of the fleet.

In general, for the lower power classes (<560 kW) retrofitting will only deliver benefits if introduced within the next 4-5 years, i.e. until 2024-2025. The only exceptions are for the 130-560 kW power class (i) Stage I machinery for DPF retrofitting, and (ii) Stage I and unregulated machinery for combined DPR and SCR, for which retrofitting is still beneficial if introduced around 2030. Evidently, the benefits of retrofitting are reducing with the year of introduction.

For the >560 kW class there are still substantial benefits that can be delivered with a later introduction. For both DPF and SCR retrofitting the time-window extends to about 2040 for the urban scenario, whereas for the combined DPF+SCR there will always be benefits, even after 2040. In the general scenario benefits can only be expected if retrofitting starts before 2028 (for DPF) or 2030 (for SCR). For the combined system the time-window extends beyond 2040.

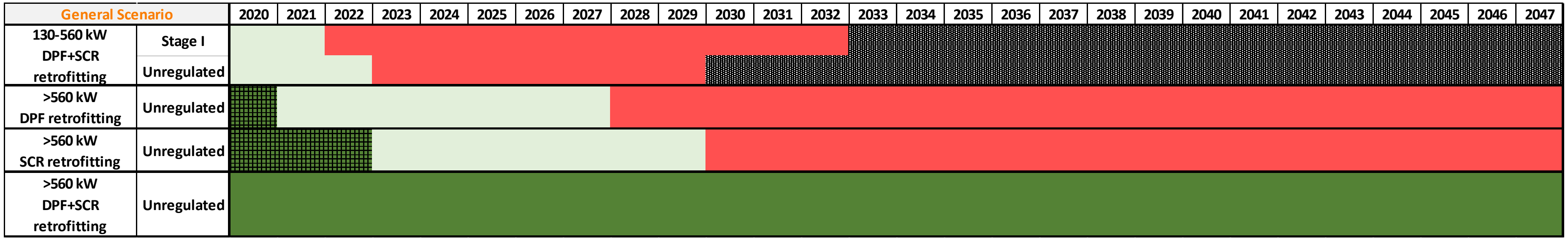


Figure 12-5 Benefits of retrofitting for agriculture/construction machinery as a function of introduction year for the general scenario

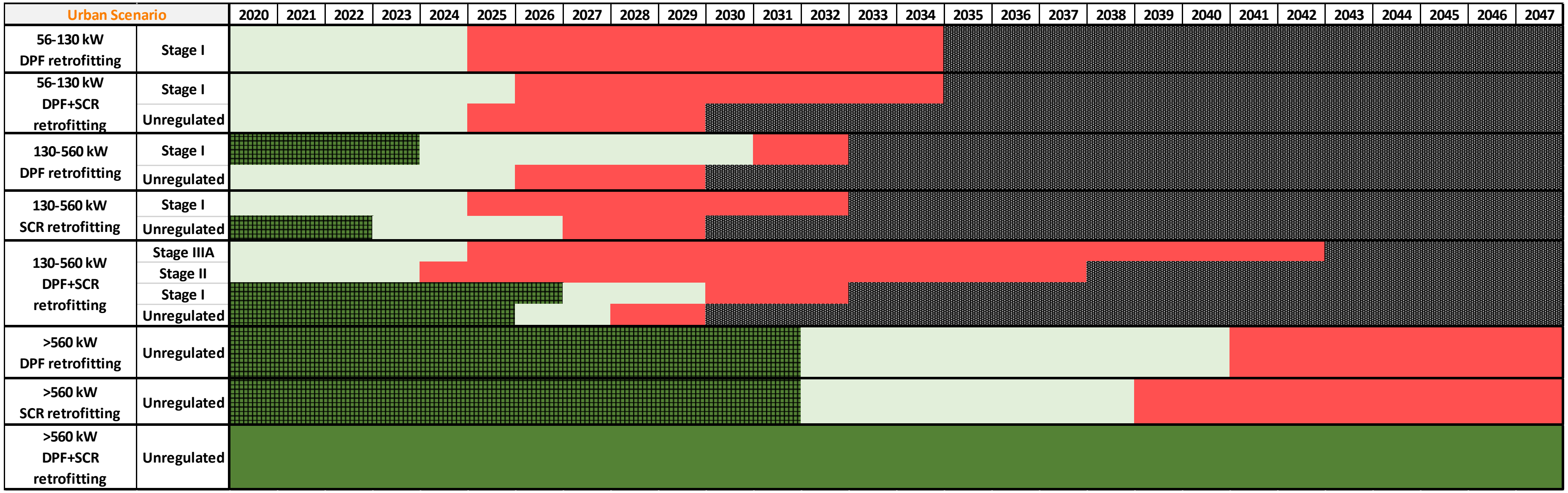


Figure 12-6 Benefits of retrofitting for agriculture/construction machinery as a function of introduction year for the urban scenario

12.2.2 Inland waterway and railways

Inland Waterways

For inland waterways, only Stage IIIA and unregulated vessels are subject to retrofitting, since there is no other emission Stage until the introduction of Stage V in January 2020. For all retrofitting systems, namely DPF, SCR and the combined system (DPF+SCR), only benefits are observed for both scenarios, as shown in Table 12-27, Table 12-28 and Table 12-29. Benefits are higher for unregulated vessels, due to the higher emission savings these vessels present. Comparing the various retrofitting technologies, it is obvious that greater benefits are observed in case of the combined system, since emission reductions for both pollutants are achieved.

Table 12-27 Net benefit [M€] for SCR retrofitting of IWW for the two scenarios

Category	Emissions stage	General Scenario	Urban Scenario
IWW	Stage IIIA	1157^{+518}_{-1050}	1520^{+590}_{-1219}
	Unregulated	8048^{+2394}_{-5145}	9924^{+2769}_{-6020}

Table 12-28 Net benefit [M€] for DPF retrofitting of IWW for the two scenarios

Category	Emissions stage	General Scenario	Urban Scenario
IWW	Stage IIIA	1370^{+463}_{-607}	1769^{+544}_{-715}
	Unregulated	4681^{+1482}_{-1945}	5971^{+1740}_{-2296}

Table 12-29 Net benefit [M€] for DPF and SCR retrofitting of IWW for the two scenarios

Category	Emissions stage	General Scenario	Urban Scenario
IWW	Stage IIIA	3055^{+925}_{-1077}	3817^{+1077}_{-1258}
	Unregulated	14189^{+3708}_{-4372}	17355^{+4341}_{-5130}

Railcars

Stage IIIB, Stage IIIA and unregulated railcars are subject to retrofitting. For SCR retrofitting, benefits are observed for almost all Stages, except for few cases for Stage IIIB railcars (Table 12-30). The benefits are further improved for the combined system (DPF+SCR), as demonstrated in Table 12-32. For DPF retrofitting, Stage IIIB railcars present losses (Table 12-31), mainly because very small emission reductions are observed.

Table 12-30 Net benefit [M€] for SCR retrofitting of Railcars for the two scenarios

Category	Emissions stage	General Scenario	Urban Scenario
Railcars	Stage IIIB	356^{+729}_{-1372}	639^{+786}_{-1504}
	Stage IIIA	1046^{+483}_{-988}	1269^{+528}_{-1091}
	Unregulated	562^{+195}_{-407}	656^{+213}_{-451}

Table 12-31 Net benefit [M€] for DPF retrofitting of Railcars for the two scenarios

Category	Emissions stage	General Scenario	Urban Scenario
Railcars	Stage IIIB	-1160^{+284}_{-324}	-1092^{+298}_{-342}
	Stage IIIA	1003^{+414}_{-538}	1217^{+457}_{-596}
	Unregulated	100^{+82}_{-103}	137^{+89}_{-113}

Table 12-32 Net benefit [M€] for DPF and SCR retrofitting of Railcars for the two scenarios

Category	Emissions stage	General Scenario	Urban Scenario
Railcars	Stage IIIB	474^{+922}_{-1046}	825^{+992}_{-1131}
	Stage IIIA	2568^{+858}_{-997}	3004^{+946}_{-1101}
	Unregulated	794^{+263}_{-308}	924^{+288}_{-339}

Locomotives

For locomotives, Stage IIIB, Stage IIIA and unregulated locomotives are subject to retrofitting. SCR retrofitting is cost-beneficial for unregulated locomotives. Benefits are also observed for Stage IIIA locomotives for almost all cases, whereas for Stage IIIB benefits are only observed in cases of low retrofitting costs and high reduction efficiency and external costs, as demonstrated in Table 12-33.

Table 12-33 Net benefit [M€] for SCR retrofitting of Locomotives for the two scenarios

Category	Emissions stage	General Scenario	Urban Scenario
Locomotives	Stage IIIB	-225^{+709}_{-1242}	-166^{+720}_{-1270}
	Stage IIIA	194^{+296}_{-549}	222^{+301}_{-562}
	Unregulated	1467^{+618}_{-1255}	1537^{+632}_{-1288}

DPF retrofitting is cost-beneficial only for Stage IIIA and unregulated locomotives in cases of low retrofitting costs and high reduction efficiency and external costs, as presented in Table 12-34. Stage IIIA and unregulated locomotives show also benefits for the combined system (DPF+SCR retrofitting), whereas Stage IIIB show marginal benefits for the cases of low retrofitting costs and high reduction efficiency and external costs (Table 12-35).

Table 12-34 Net benefit [M€] for DPF retrofitting of Locomotives for the two scenarios

Category	Emissions stage	General Scenario	Urban Scenario
Locomotives	Stage IIIB	-1614^{+273}_{-288}	-1607^{+274}_{-290}
	Stage IIIA	-99^{+183}_{-221}	-82^{+186}_{-225}
	Unregulated	-143^{+229}_{-273}	-123^{+233}_{-279}

Table 12-35 Net benefit [M€] for DPF and SCR retrofitting of Locomotives for the two scenarios

Category	Emissions stage	General Scenario	Urban Scenario
Locomotives	Stage IIIB	-505^{+851}_{-946}	-4391^{+864}_{-962}
	Stage IIIA	550^{+434}_{-493}	595^{+443}_{-504}
	Unregulated	1818^{+792}_{-918}	1908^{+810}_{-940}

Shunting Locomotives

SCR retrofitting is cost-beneficial for all Stages for shunting locomotives except for the cases of high retrofitting costs and low reduction efficiency and external costs for Stage IIIB shunting locomotives (Table 12-36). A similar situation is observed for the combined (DPF+SCR) retrofitting, where the benefits are further improved (Table 12-38). For DPF retrofitting, as demonstrated in Table 12-37, Stage IIIB shunting locomotives show losses for all cases, whereas Stage IIIA and unregulated shunting locomotives show benefits, with few exceptions for Stage IIIA shunting locomotives (cases of low retrofitting costs and high reduction efficiency and external costs).

Table 12-36 Net benefit [M€] for SCR retrofitting of Shunting Locomotives for the two scenarios

Category	Emissions stage	General Scenario	Urban Scenario
Shunting Locomotives	Stage IIIB	733^{+500}_{-1006}	789^{+511}_{-1032}
	Stage IIIA	325^{+162}_{-333}	344^{+165}_{-342}
	Unregulated	732^{+235}_{-504}	762^{+241}_{-517}

Table 12-37 Net benefit [M€] for DPF retrofitting of Shunting Locomotives for the two scenarios

Category	Emissions stage	General Scenario	Urban Scenario
Shunting Locomotives	Stage IIIB	-994^{+166}_{-181}	-987^{+168}_{-183}
	Stage IIIA	26^{+105}_{-131}	38^{+107}_{-134}
	Unregulated	123^{+110}_{-139}	136^{+113}_{-143}

Table 12-38 Net benefit [M€] for DPF and SCR retrofitting of Shunting Locomotives for the two scenarios

Category	Emissions stage	General Scenario	Urban Scenario
Shunting Locomotives	Stage IIIB	635^{+600}_{-691}	698^{+613}_{-707}
	Stage IIIA	595^{+249}_{-289}	626^{+255}_{-296}
	Unregulated	1030^{+332}_{-389}	1073^{+340}_{-399}

Additionally, figures on the total costs for each retrofitting technology are included in Annex IV. These are the total costs required for retrofitting engines in each category, taking into account the parametric analysis for high and low retrofitting costs.

For the above scenarios the emission reductions achieved using the various retrofitting systems were calculated as a share of the total emissions of the sub-sectors inland waterways and railways and they are presented in Table 12-39.

Table 12-39 Emission reductions from inland waterways for high and low reduction values, 2020-2050

	Retrofit System	Emissions reductions for high reduction efficiency	Emissions reductions for low reduction efficiency
Inland waterways	SCR	58 % of NO_x emissions	38 % of NO_x emissions
	DPF	65 % of PM emissions	59 % of PM emissions
	DPF+SCR	56 % of NO_x and PM emissions	53 % of NO_x and PM emissions
Railways	SCR	38 % of NO_x emissions	25 % of NO_x emissions
	DPF	52 % of PM emissions	46 % of PM emissions
	DPF+SCR	38 % of NO_x and PM emissions	36 % of NO_x and PM emissions

Figure 12-7, Figure 12-8, Figure 12-9, Figure 12-10, Figure 12-11 and Figure 12-12 present the evolution of emissions using the various retrofitting systems, for high and low reduction efficiency values, as well as the evolution of emissions in case no retrofit takes place.

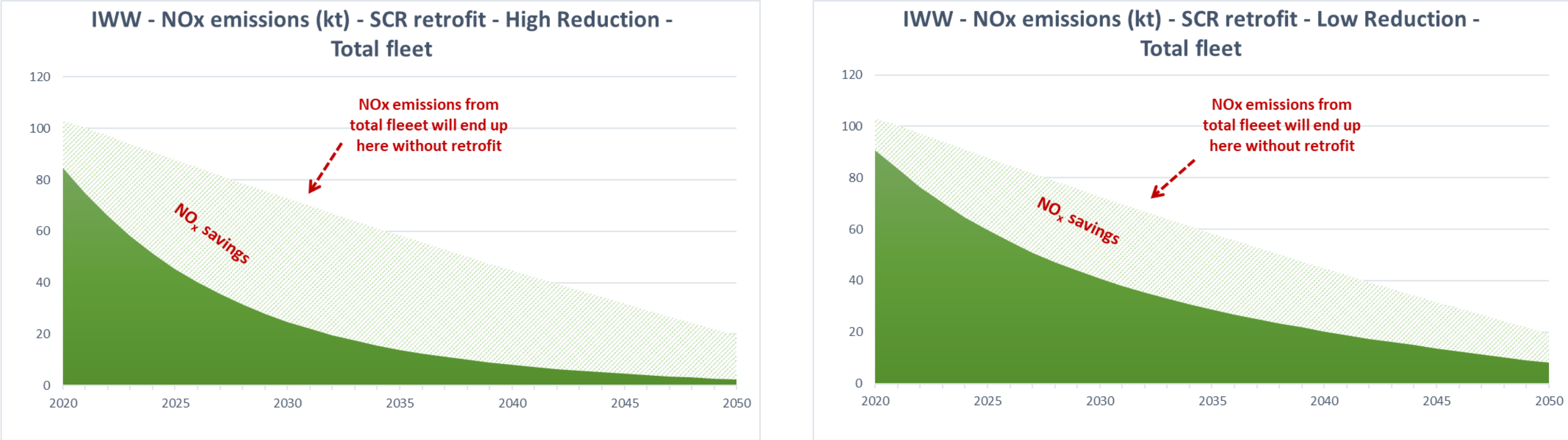


Figure 12-7 Evolution of NO_x emissions from inland waterways with/without SCR retrofit, 2020-2050

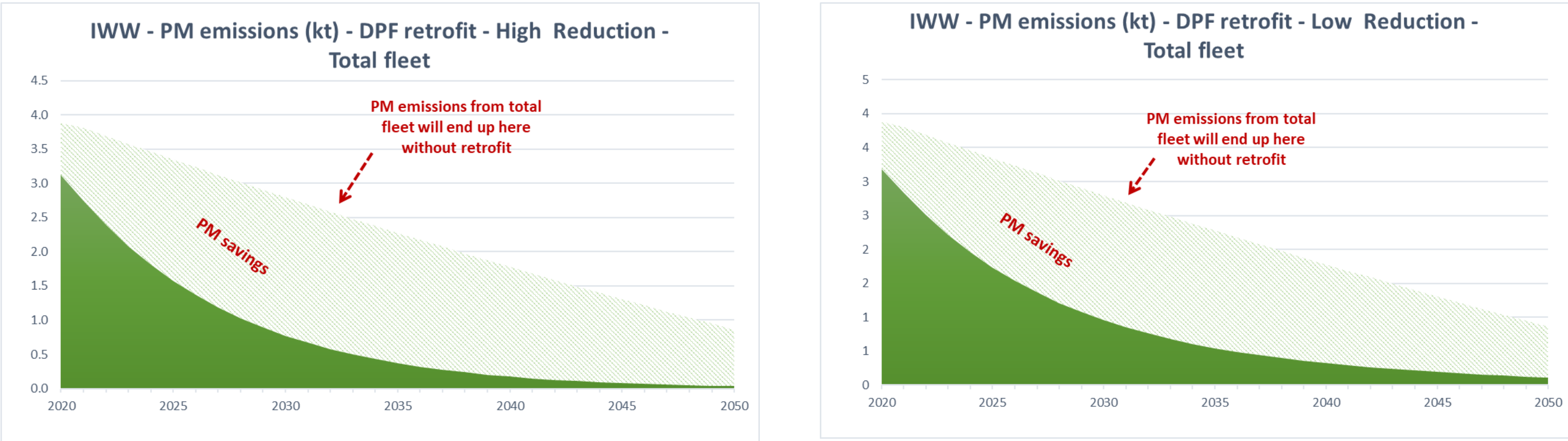


Figure 12-8 Evolution of PM emissions from inland waterways with/without DPF retrofit, 2020-2050

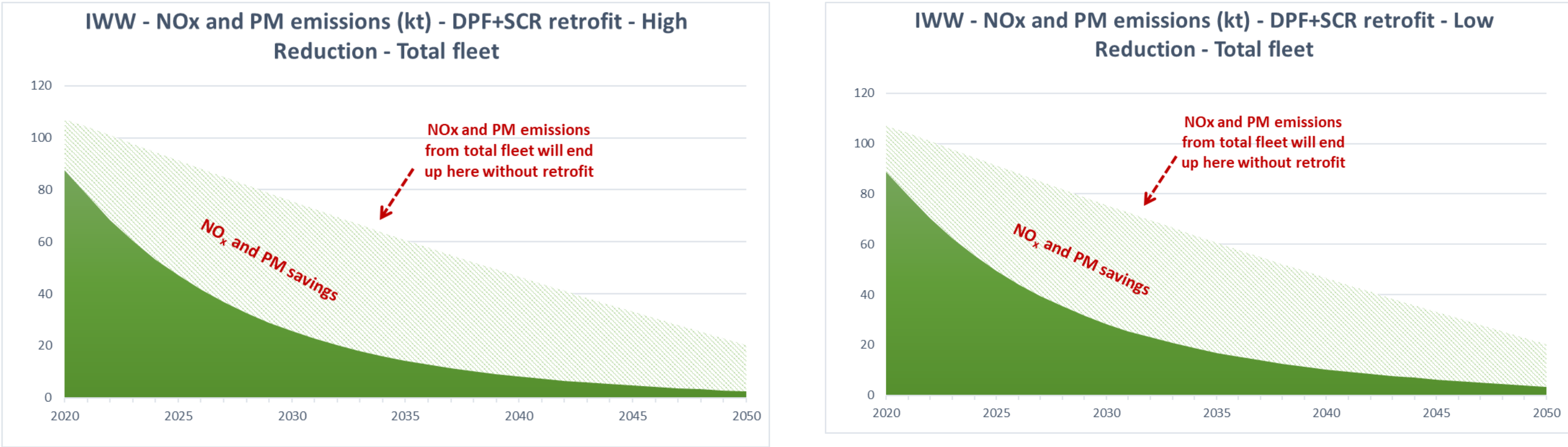


Figure 12-9 Evolution of NO_x and PM emissions from inland waterways with/without DPF+SCR retrofit, 2020-2050

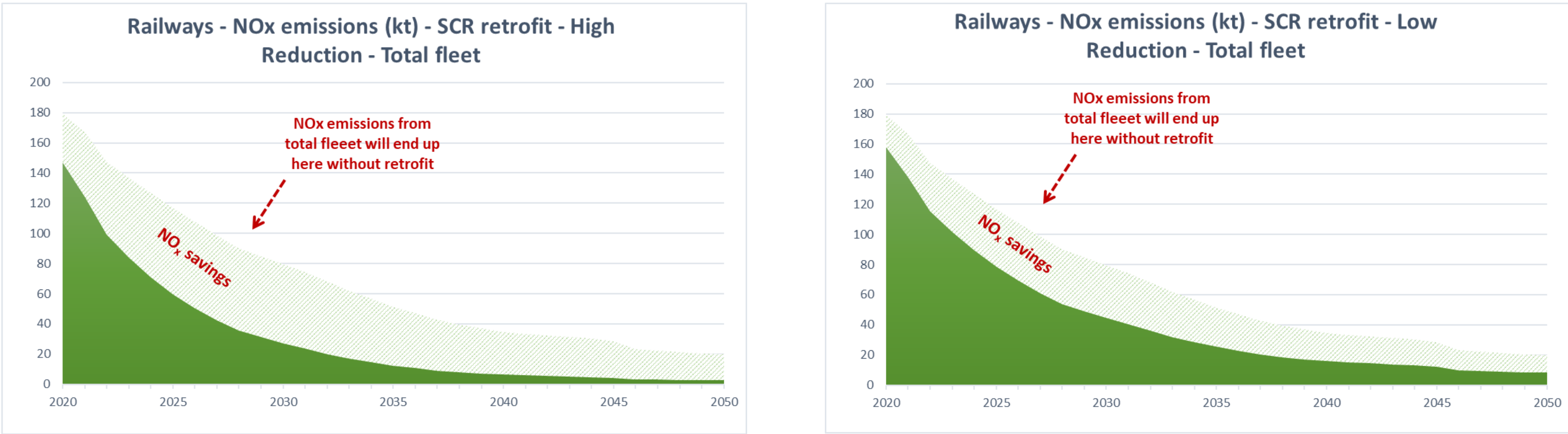
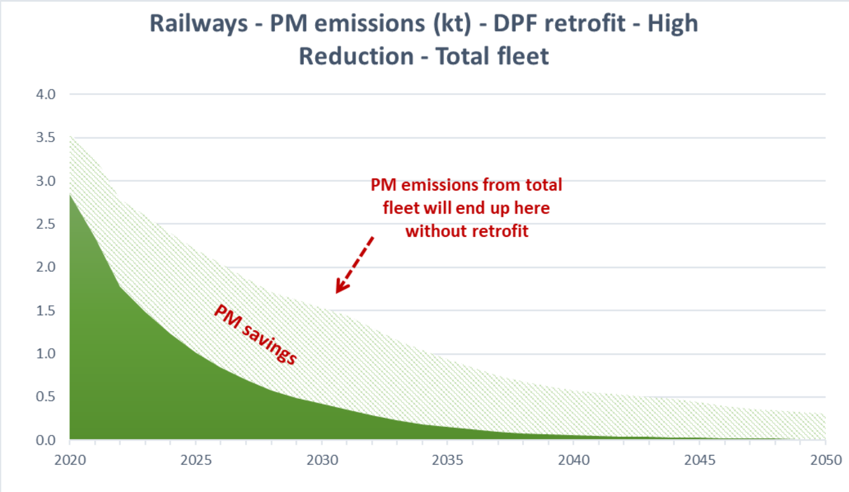


Figure 12-10 Evolution of NO_x emissions from railways with/without SCR retrofit, 2020-2050



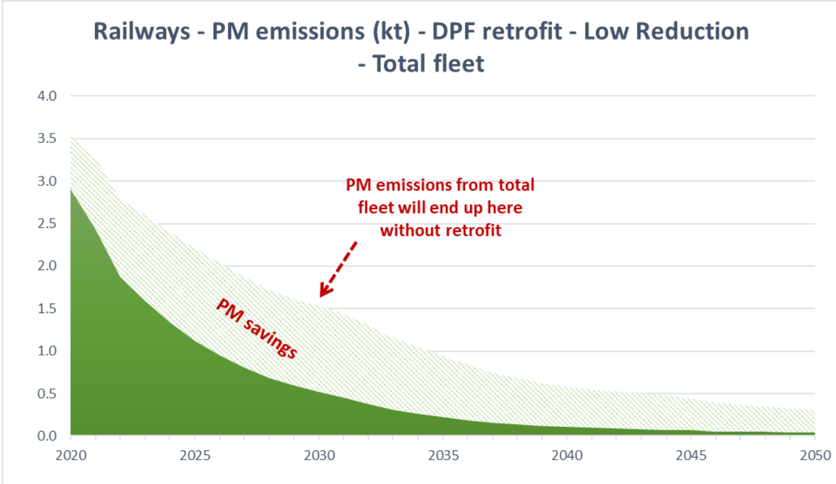
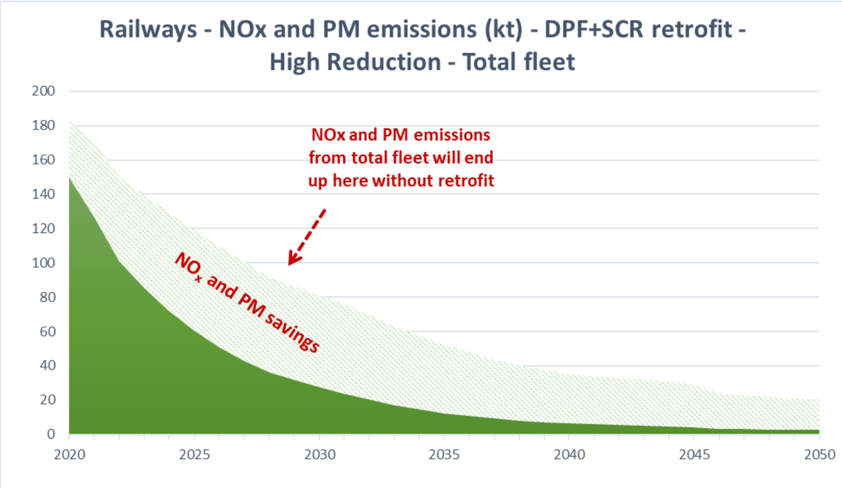


Figure 12-11 Evolution of PM emissions from railways with/without DPF retrofit, 2020-2050



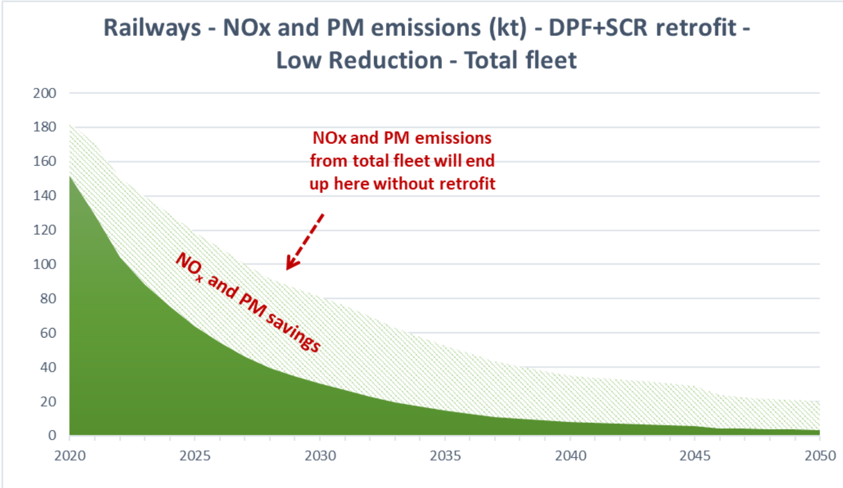


Figure 12-12 Evolution of NO_x and PM emissions from railways with/without DPF+SCR retrofit, 2020-2050

Figures on the cost-effectiveness (i.e. costs required per kilogram of pollutant emissions saved) are included in Annex V for all retrofitting systems.

In the above analysis, the year 2020 has been considered as the first year of retrofitting. This results in the highest possible benefits as the emissions are reducing every year due to normal fleet turnover. Evidently, benefits (if any) are reducing with the year of implementation and may result in losses (negative benefits) after a certain point in time. In order to investigate what is the time-window for which retrofitting remains beneficial, a parametric analysis was performed. The analysis follows the same principles with the cost-benefit calculations presented previously.

In the following figures (Figure 12-13, Figure 12-14, Figure 12-15, Figure 12-16, Figure 12-17, Figure 12-18, Figure 12-19 and Figure 12-20) dark green cells denote the cases where benefits are observed for the baseline scenario (i.e. moderate retrofitting costs, moderate external costs and high reduction efficiency values), the patterned green cells denote the cases of high retrofitting costs and low reduction efficiency and external costs, and light green cells show the cases of low retrofitting costs and high reduction efficiency values and external costs for which benefits are observed. Red cells show the years for which retrofitting becomes not beneficial. Finally, grey cells represent cases where retrofitting is not applicable as the specific emissions Stage is phased out of the fleet.

For inland waterways, there are benefits delivered even for later introduction. The benefits are diminished only close to 2050.

A similar situation is observed for railcars, for which retrofitting remains beneficial for the entire period examined (i.e. until 2050), with the exception of Stage IIIB engines, for which the time-window is limited to about 2045.

For locomotives, retrofitting will deliver benefits if introduced until 2035-2036, with the exception of (i) DPF retrofitting for unregulated engines, for which it should be introduced before 2026, and (ii) the combined system for Stage IIIB engines for which retrofitting is beneficial only if applied before 2031-2032.

For shunting locomotives, the various retrofitting technologies will deliver benefits even if introduced in 2040 or later for all cases.

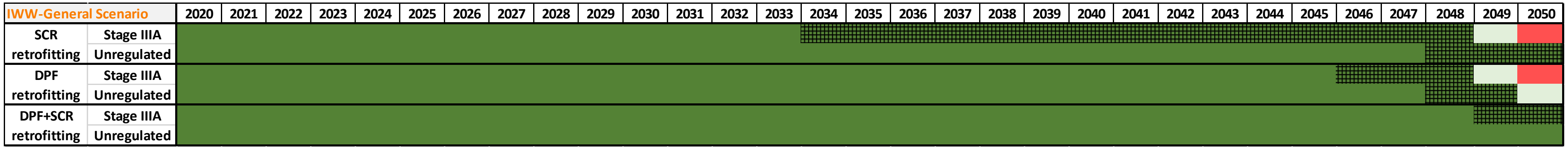


Figure 12-13 Benefits of retrofitting for inland waterways as a function of introduction year for the general scenario

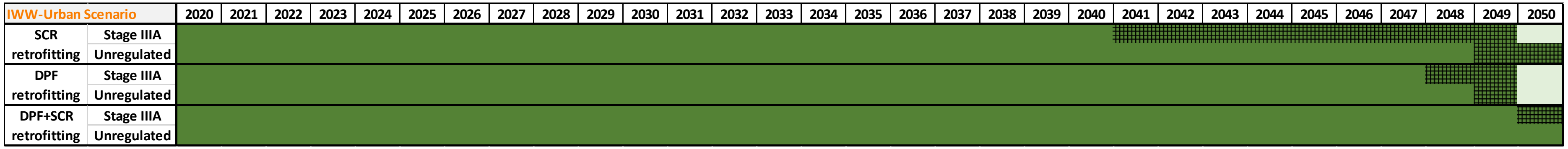


Figure 12-14 Benefits of retrofitting for inland waterways as a function of introduction year for the urban scenario

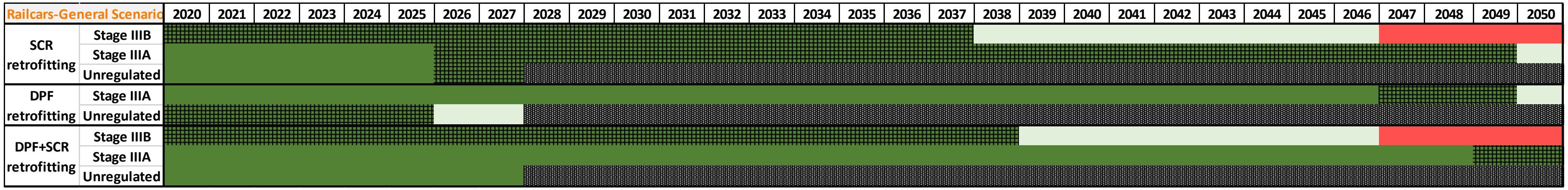


Figure 12-15 Benefits of retrofitting for railcars as a function of introduction year for the general scenario

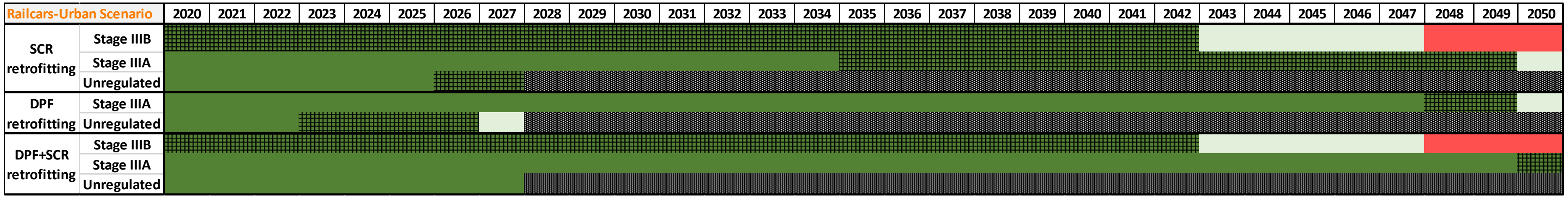


Figure 12-16 Benefits of retrofitting for railcars as a function of introduction year for the urban scenario

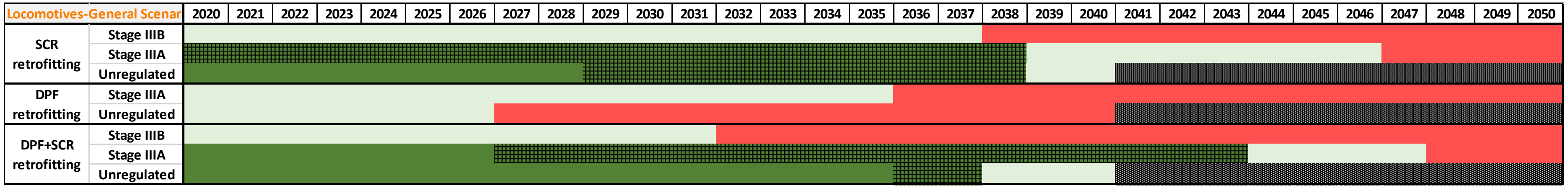


Figure 12-17 Benefits of retrofitting for locomotives as a function of introduction year for the general scenario

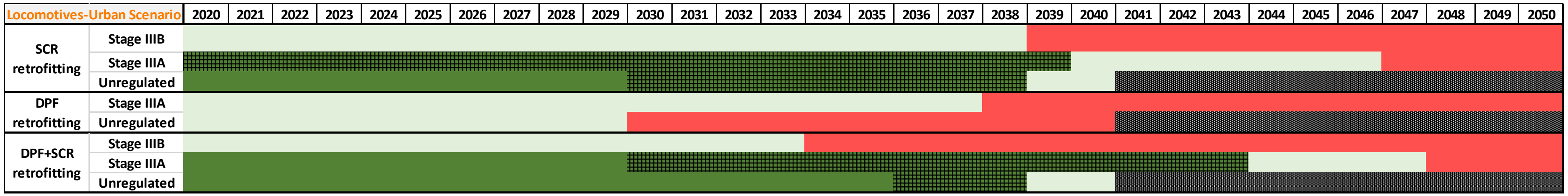


Figure 12-18 Benefits of retrofitting for locomotives as a function of introduction year for the urban scenario

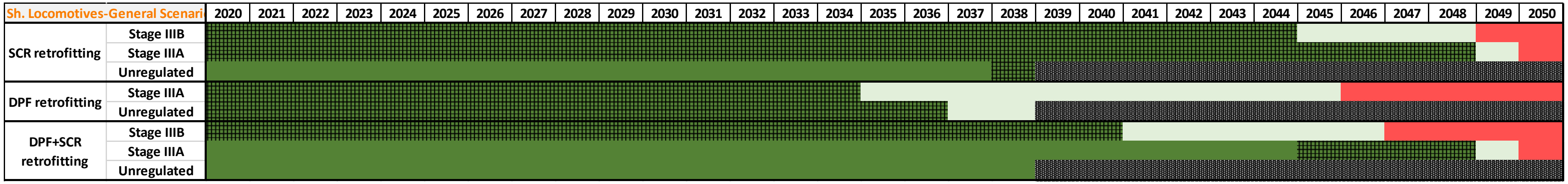


Figure 12-19 Benefits of retrofitting for shunting locomotives as a function of introduction year for the general scenario

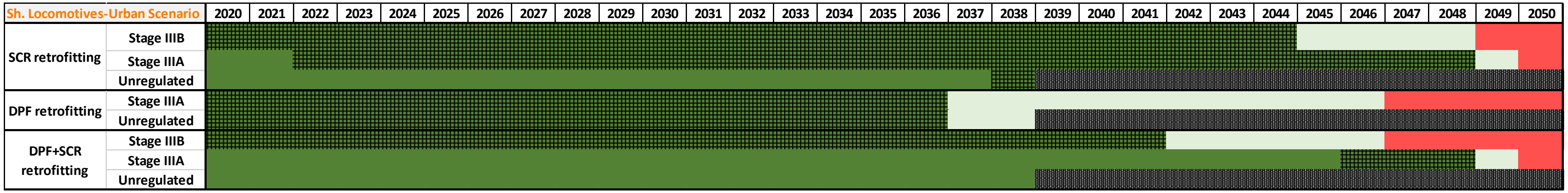


Figure 12-20 Benefits of retrofitting for shunting locomotives as a function of introduction year for the urban scenario

12.3 Conclusions

General

- The results of the analysis presented in this chapter demonstrate the cases for which retrofitting is cost beneficial from the point of view of the society. From the owner's perspective the decision on whether to retrofit may depend on other criteria as well, mainly financial. The cost of retrofitting compared to the cost of a new engine and/or a new NRMM is presented and discussed in Annex VI.

Agriculture and Construction

- The cost-benefit analysis shows negative benefits (losses) for the small to medium range power classes up to 130 kW and for all emission Stages and all retrofitting technologies examined in this study (DPF, SCR, and the combined system).
- Some very few exceptions exist for Stage I machinery for the urban scenario only and for low retrofitting costs and high reduction efficiency and external costs.
- Retrofitting is cost beneficial for the 130-560 kW class for Stage I machinery and for urban conditions only. The benefits however are rather small.
- Clear benefits are only observed for the most powerful machinery (>560 kW) for non-urban conditions. As this class was largely unregulated (before the introduction of Stage V) with high emission levels because of the high power, big emission savings have been calculated for all retrofitting options examined.
- The emission reductions for all retrofitting systems are in the range of 10-24 %, with DPF showing the highest benefits.
- The time-window for which retrofitting remains beneficial is limited for almost all power classes, except for the >560kW class for which it extends to about 2040.

Inland Waterways and Railways

- The cost-benefit analysis shows clear benefits for all Stages for inland waterways. The benefits are greater for unregulated vessels and for the combined (DPF+SCR) system.
- For railcars, retrofitting is cost-beneficial for DPF and DPF+SCR for almost all Stages. Stage IIIB present losses for SCR retrofitting, whereas Stage IIIA and unregulated engines show benefits for the same technology.
- SCR retrofitting is beneficial for locomotives only in few cases for Stage IIIA and unregulated engines, whereas DPF and the combined system shows clears benefits for all Stages but Stage IIIB.
- DPF and the combined system is cost-beneficial for almost all Stages for shunting locomotives, with few exceptions for Stage IIIB engines, whereas SCR shows benefits for unregulated and Stage IIIA engines, but not for Stage IIIB engines.
- The emission reduction for both sub-sectors (inland waterways and railways) are in the range of 25-65 % for all retrofitting systems, with DPF showing the highest benefits.
- For inland waterways, railcars and shunting locomotives, the time-window for which retrofitting remains beneficial is for most cases until 2048, whereas for locomotives retrofitting is considerably limited.

13 Position of industrial associations and NGOs with regard to retrofitting

A couple of NGOs and industrial organisations have expressed positions with regard to retrofitting measures. A few are listed in the following.

The NGO Transport & Environment (T&E) expressed its view at several occasions. In summary T&E is of the opinion that *"NRMM engines, and especially the larger ones that emit a lot of pollutant emissions, have long lifecycles, operating for more than 30 years in many cases. The engine fleet takes a long time to be replaced, and so taking action only on new engines further delays the urgent emission reductions that are required to improve air quality* "and concludes "*Even though the mandate of the European Commission stops once the engine is placed on the market, a proper retrofit strategy should be considered."*

Several German and international NGOs[181] have combined efforts in the campaigns "Soot free for the Climate" and "Clean Air". In simple words these campaigns require either to ban diesel engines or at least to equip them all with DPFs, including retrofitting of existing fleets.

The construction industries or individual firms are quite critical with regard to retrofitting, see for example Sick[182] who fears collateral damage for the NRMM sector due to the flood of EU directives and uncoordinated additional local measures.

The Committee for European Construction Equipment (CECE) published a position paper in 2017 and called upon Member States, regional and municipal authorities intending to set a LEZ affecting construction equipment to:

> *• Encourage the use of the latest technologies through initiatives such as financial incentive schemes and green procurement to boost the renewal of the equipment. New machines not only offer better emission performance but also improved safety, enhanced operator comfort, lower noise and higher efficiency.*
>
> *• Promote harmonisation of LEZ schemes to avoid the creation of multiple unique requirements with similar aims.*
>
> *• Adopt an approach on strictly technology neutral emission limits from the perspective of engine technology and fuel choice as per Directive 97/68/EC and Regulation (EU) 2016/1628.*
>
> *• Set criteria that align with published EU engine emission limits.*
>
> *• Always permit the use of construction equipment that complies with the latest applicable EU emission Stage."*

CECE recognised that it is important that users are able to continue to operate machines with installed engines complying with a previous EU emission Stage, and therefore suitable modifications (retrofit) could be permitted in order to achieve the goals of the LEZ. Such modifications should respect the following:

- Only products and technologies that have been type-approved to UN ECE Regulation R 132 and demonstrated to be effective for the application should be permitted.
- The installation of retrofit devices shall not affect the conformity of the machine with other applicable legislation in force at the date of its first placing on EU market, in particular the Machinery Directive which sets out essential health and safety requirements that are mandatory for the placing on the EU market of the machine.

[181] Key players are: Deutsche Umwelthilfe e.V. , Bund für Umwelt und Naturschutz Deutschland e.V. , Naturschutzbund Deutschland e.V., Verkehrsclub Deutschland e.V., European Environmental Bureau.

[182] Sick 2013: Nachrüstung der Baumaschinen zur Verringerung der Feinstaubbelastung in Innenstädten. Vortrag auf dem 42. VDBUM-Seminar, 26.2.–1.3.2013 in Braunlage

- The compliance of the engine or the combination of engine and retrofit device to the PM or NO_X emission limits or PM and NO_X emission limits required by LEZ can be demonstrated via the engine type-approval number or both engine and retrofit type-approval numbers.
- It should be recognised that a retrofitted engine cannot achieve the same environmental performance as an engine specifically built to meet a more demanding emission Stage defined in EU legislation which delivers improvements for a range of pollutants.

The European Association of Internal Combustion Engine Manufacturers (EUROMOT) has not published a position paper but it supported in the past the CECE position. In addition, EUROMOT warns that retrofitting measures might have negative repercussions on the markets for new and second-hand equipment.

The German Verband Deutscher Maschinen-und Anlagenbau (VDMA) published several position papers. In 2009 it explained that while there are cases in which retrofitting is feasible, there are many others in which retrofitting is technically not feasible. In case retrofitting were legally required it would be necessary to obtain the approval of the engine manufacturer, the OEM of the non-road mobile machinery and to harmonise the legal framework at EU level. Moreover, it needed fiscal incentives for the implementation of such a measure. In a paper published in 2012 it highlighted the legal difficulties associated with retrofitting, giving reference to Directive 2006/42/EC[183] and 2007/104/EC[184], but also to national legislation like the German StVZO. It concluded that retrofitting is neither technically nor legally trivial and that non-harmonised local retrofitting requirements might lead to an extended responsibility of the machine owner. In 2014 VDMA issued another position paper in which concrete proposals for legal text was published in case legal action is taken. The general approach preferred is that either Stages IIIA or IIIB are met or retrofitting with a particle filter in accordance with UNECE Regulation should be required. However, there must be exemptions in case that no certified retrofitting system is offered on the market.

The FÉDÉRATION EUROPÉENNE DE LA MANUTENTION Product Group Cranes and Lifting Equipment expressed it views in a statement on 24.02.2013. The association explained in the paper that "*The possibility of retrofitting diesel engines with particulate filters is limited by technical reasons as each filter in the exhaust system affects the combustion process and as such the engine will lose the certification according to 97/68/EC. The diesel engine manufacturer will exclude warranty for changes not permitted."* and concluded that *"Any change affecting the system consisting of Diesel engine end exhaust bears the risk of losing: certificates, especially the emission certificate and warranties."*

There are no specific position papers on retrofitting of NRMM published by retrofitters, e.g. organised in ERECA[185] or CLEPA[186]. AECC[187] has no specific position paper but published a number of more general papers on retrofitting on-road and off-road engines which call for taking action.

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[183] Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC
[184] Directive 2009/104/EC of the European Parliament and of the Council of 16 September 2009 concerning the minimum safety and health requirements for the use of work equipment by workers at work (second individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)
[185] Exhaust Retrofit Emission Control Alliance, ERECA is an initiative of European companies, who manufacture and supply retrofit emission control systems.
[186] CLEPA is the association of European automotive suppliers. It brings together well over 100 of the world's most prominent suppliers for car parts, systems and modules and more than 20 national trade associations and European sector associations.
[187] AECC is the Association for Emission Control by Catalyst.

14 Policy Option for the Commission

14.1 Introduction

This chapter considers policy options for the Commission applying to the EU. The EU Treaties define several types of legal acts. Some are binding, others are not. Some apply to all EU countries, others to just a few:

- Regulations: A binding legislative act. It must be applied in its entirety across the EU.
- Directives: A legislative act that sets out a goal that all EU countries must achieve. However, it is up to the individual countries to devise their own laws on how to reach these goals.
- Decisions: Is binding on those to whom it is addressed (e.g. an EU country or an individual company) and is directly applicable.
- Recommendations: Enables the Commission (or the Council) to establish non-binding rules for the Member States or, in certain cases, Union citizens.
- Opinions: An instrument that allows the institutions to make a statement in a non-binding fashion, in other words without imposing any legal obligation on those to whom it is addressed. An opinion is not binding.

Moreover, the Commission can publish guidelines which are supposed to help Member States to apply Community law correctly.

Suitable for retrofitting measures are Regulations, Directives and Recommendations. An opinion as an answer to a request laid down in an EU Regulation seems to be less suitable and a Guideline would not fit since the EU Regulation on new NRMM does not need any guidance with regard to retrofitting existing NRMM.

In any case if legislation is considered a separate legal act should be drafted. It seems to make no sense incorporating measures on existing NRMM in the existing legation on new NRMM since the retrofitting measures on existing NRMM are of temporary character.

Legal acts - and Commission measures and proposals in general - have to be justified. Key questions to be answered for legal acts are:

I. Why? What is the problem being addressed?
II. What is this initiative expected to achieve?
III. What is the value added of action at the EU level?
IV. What legislative and non-legislative policy options have been considered? Is there a preferred choice or not? Why?
V. Who supports which option?
VI. What are the benefits of the preferred option (if any, otherwise main ones)?
VII. What are the costs of the preferred option (if any, otherwise main ones)?
VIII. Will there be significant impacts on national budgets and administrations? How will businesses, SMEs and micro-enterprises be affected?
IX. Will there be other significant impacts?
X. When will the policy be reviewed?

In order to identify the appropriate measure answers have to be given to these questions and combined with the most appropiate instrument.

14.2 Specific requests of Regulation (EU) 2016/1628

With regard to question I. the relevant text of Regulation (EU) 2016/1628 should be recalled:

Recital (23) "*Given the long lifetime of non-road mobile machinery, it is appropriate to consider the retrofitting of engines already in service. Such retrofitting should, in particular, target densely populated urban areas as a means of helping Member States to comply with Union air quality legislation. To ensure a comparable and ambitious level of retrofitting, Member States should take into account the principles of UNECE Regulation No. 132.*"

and

Article 60: *"By 31 December 2018, the Commission shall submit a report to the European Parliament and to the Council regarding the assessment of the possibility of laying down harmonised measures for the installation of retrofit emission control devices in engines in non-road mobile machinery that has already been placed on the Union market. That report shall also address technical measures and financial incentive schemes as a means of helping Member States to comply with Union air quality legislation, by assessing possible action against air pollution in densely populated areas, and with due respect for the Union rules on state aid."*

The text suggests that two objectives are of particular importance:

- To improve air quality in urban areas by retrofitting engines already in service[188]
- To harmonise retrofitting measures giving reference to UNECE Regulation 132

Moreover, financial incentive schemes are highlighted as a possible policy instrument. This aspect is addressed in chapter 15.

14.3 Limitations of the assessment

Retrofitting of NRMM is one possible measure in a long list of potential measures capable to reduce PM and NO_x emissions, e.g. emission limits for all sorts of combustion engines (EURO standards or standards for non-road mobile machinery), fuel standards, energy efficiency standards, the industrial and combustion installation emissions standards as well as measures like the deployment of alternative fuels infrastructure. The EU has taken measures in this respect and more could be done at EU or national level.

Moreover, the EU could develop regulations on black carbon or on nano-particles, improve further regulation on real-world driving emission, tackle the negative effects of tampering practices (i.e. removal of catalyst systems), regulate on brake, clutch and tyre wear, regulate ammonia (NH3) volatilization from manure application, regulate space heating and power, regulate emissions from construction sites or emissions to air from biomass heating etc.

In addition, non-regulatory instruments, like funding mechanisms and knowledge transfer have been taken in the past and could be enhanced, e.g. improve coherence of cities' implementation approaches of Low Emission Zones (LEZs) within the Partnership on Air Quality.

Therefore, the measure 'retrofitting of NRMM' must theoretically prove that it has advantages over other possible measures.

This is usually depending on the local situation when the air quality of PM and NO_2 are concerned. With regard to critical loads, the issue has a national character. Both, the local and the national situation show a large variability and o general conclusion can be drawn.

[188] This is also supported by the original amendment 32 proposed by the EP which highlights the urban areas not complying with the air quality limit values: *"Article 5 – paragraph 1 a (new)*
Amendment 1a. In urban areas not complying with the limit values as laid down in Directive 2008/50/EC, Member States shall, as part of the development of air quality plans under Article 23 of that Directive, assess the need to take measures, not entailing disproportionate costs, to ensure retrofitting with the latest emission abatement technology of existing engines installed in non-road mobile machinery. Such retrofitting shall be done with a view to achieving Stage V requirements." EP report A8-9999/2015 of 30.9.2015

However, it is important to note that it is not part of this study to assess alternative options to NRMM retrofitting in a more general framework of emission reduction measures covering multiple sources. The study deals exclusively with the NRMM retrofitting measure. Nor is it possible within the framework of this study to examine in more detail the measures taken or discussed at local or regional level, such as the establishment of environmental zones, the switch to low-emission modes of transport, speed limits or on-road parking management.

For BC the situation is somewhat different since it concerns climate change. Although the impact of BC emissions depends on the location of the emission BC reduction it is of more general nature so that the effectiveness of measures for different sectors can be compared. This has been done, for example, by Hansson who compared BC reduction cost for different sectors, see Figure 14-1 (Hansson et al., 2011).

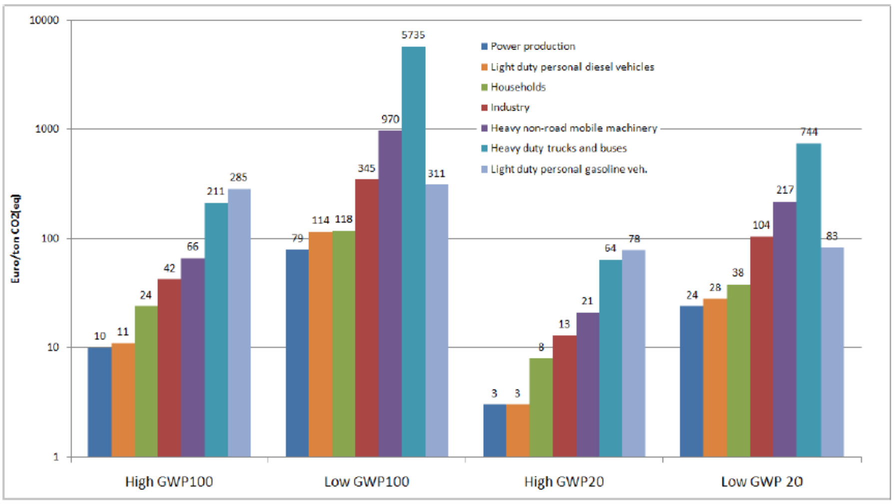

Figure 14-1 Estimated costs of measures for BC reduction in different sectors, differentiated for high and low GWP estimates and a 20 or 100 years' time span

As indicated above, measures in the sector "heavy non-road mobile machinery" are not the most cost-efficient according to these calculations. Moreover, BC reduction is currently not part of the EU climate change policy. In addition, BC reduction is a long-term target as part of the climate change policy. In the long-term, however, the introduction of NRMM Stage V limit values will reduce BC emissions significantly as shown in the chapter on air pollution. Therefore, it is difficult to justify general NRMM retrofitting measures due to black carbon pollution.

In summary, it is important to note that the discussion on policy options below is limited to NRMM measures and does not consider alternative options covering all possible sources.

14.4 Key results to be taken into account

In order to identify the most appropriate policy option the results of the analysis presented in the previous chapters has to be considered. The following table summarises the key findings:

Table 14-1 Key findings of the analysis of retrofitting measures

Chapter: Air pollution problems and the potential contribution of emissions from non-road mobile machinery
• NO_x and PM emissions still cause major environmental problems, including breaches of air quality limit and target values and critical loads; BC emissions are also of concern, in particular for the Arctic region; violations of the air quality limit values laid down for NO_2 and PM occur in cities and highly populated regions.

- Emissions of NO_x and PM in total as well as the contribution of the sub-source NRMM vary at national, regional and local level. In some cases, NRMM emissions are a significant source of NO_x, often as well of PM and BC.
- This variability in terms of sectoral impact, even within a single country, calls for targeting NRMM retrofitting measures, if desired, at improving air quality at regional or city level.

Chapter: Measures taken at Member State, State or local level

- Measures on NRMM do not play a major role in national, regional or local air pollution abatement plans. The only country in Europe which has taken severe measures, including obligatory retrofitting of existing NRMM with DPF, is Switzerland; from EU countries only Austria has taken nationwide measures which include existing NRMM. Most of the specific measures have been taken in cities.
- Currently all measures concentrate at DPF retrofitting; SCR retrofitting is not required at all in any European country.
- I general, the regulatory systems established require that NRMM used in defined zones have to meet specific emission limit Stages or have to be retrofitted. Nowhere in the EU retrofitting of existing NRMM is an unavoidable obligatory measure.

Chapter: Emission estimates

- A total of 536 kt NO_x emitted in EU 28 in 2019 was calculated. The highest contribution comes from the power class of 19-560 kW, with a share of 84 %. A similar situation is observed for PM emissions, with 28 kt PM emitted in 2019 in EU 28. The power class 19-560 kW contributes with a share of 85 % to the total PM emission.
- Stages I to IIIA machinery is responsible for 56 % of the total NO_x emissions and 67 % of the total PM emissions in 2019.
- For inland waterways total NO_x emissions for 2019 amount to 107 kt and PM emissions to 4 kt. Unregulated engines are responsible for about 90 % of these emissions.
- NO_x emissions in the railways sector were estimated in 2019 for EU 28 to be equal to 187 kt and PM emissions equal to 4 kt. Unregulated and Stage IIIA engines contribute the highest to these emissions with a share of 87 % for NO_x emissions and 92 % for PM emissions.

Chapter: Technologies of new NRMM engines complying with the different limit value Stages

- The technical potential of retrofitting depends, inter alia, on the technology used for new engines.
- New NRE engines between of Stages IIIB/IV in the power class 56 – 560 kW together with some Stage IIIB engines for locomotives and railcars above 130 kW use already after-treatment systems, e.g. either SCR or DPF or both. In these cases, retrofitting is more complex and close co-operation with OEMs is recommended.

Chapter: Retrofitting technologies and costs

- DPF and SCR retrofitting technologies are available for all subsectors and all power classes considered in this study. Best suited for after-treatment are Stage I to Stage IIIA engines and those well-maintained engines which had to comply with no limit values (< 19 kW) although there are additional constraints for very small engines including low cost/value of machine to be retrofitted and more severe use/vibration/handling and safe installation requirements.
- Within a simplified approach ranges for costs for well-maintained engines have been identified for all sub-sectors which can be used in the cost/benefit analysis.
- For sectors like IWW vessels and railways with individual retrofitting cases the retrofitting potential, including the number of NRMM which could actually be retrofitted, might need further investigations.

Chapter: Approval and testing of retrofitting technologies

- A number of certification procedures are available for off-road engines in Europe, mainly for engines used in the NRE class. As a rule, they differ somewhat in detail with regard to the requirements to be met for obtaining a certification. Many of these are only recognised in one Member State.
- Most appropriate for EU measures is the UNECE Regulation 132 which covers the power range 19 to 560 kW since it has been established at international level, involving experts

from all UNECE members. This opens the option of recognition and free access of retrofitted NRMM in all EU Member States. Further up-dates are possible within an internationally coordinated procedure. • However, since UNECE R 132 is a new regulation, only few countries are actually using this procedure in practice, although it applies to all EU Member States since these are contracting parties to UNECE. It will take some time before a significant number of systems are certified. • The certification of NRE engines < 19 kW and >560 kW as well as those used in rail and inland waterway vehicles are not covered by UNECE R 132. This is a shortcoming which could be solved in the coming years. Currently off-road engines of these sub-categories are certified, if required, mainly under the VERT system.
Chapter: Potential problems associated with retrofitting due to existing legislation
• NRMM have to comply with the EU machine Directive and with EU safety regulations. • Retrofitting might violate these regulations. Therefore, in addition to the certification of after-treatment systems the technical service has to check whether such violations are avoided in case of retrofitting NRMM.
Chapter: Implementing retrofitting measures
• Retrofitting measures need to be accompanied by guidance and the actual implementation needs to be verified by inspection teams. • Surveillance is needed, seeing that NRMM operators might have economic advantages not applying the after-treatment systems properly.
Chapter: The after-treatment market
• The EU after-treatment market for NRMM is small; currently the market is practically inactive since nowhere within the EU retrofitting is mandatory. • In the light of the very weak NRMM after-treatment market and the potentially high cost for testing there is currently no after-treatment system certified under UNECE R 132.
Chapter: External costs
• A simplified approach, using averaged external cost figures is used for the cost/benefit study carried out within this study. Cost figures are expressed in €/kg or €/t of emissions. • Averaged external cost estimates for PM_{10}, $PM_{2.5}$, NO_2, CO_2 and BC are provided.
Chapter: Cost/benefit calculations
• The cost/benefit calculations cover EU 28, not individual Member States or regions or the local level. The cost/benefit calculations suffer under uncertainties. Most relevant is the lifetime of the equipment. This parameter might differ among Member States, e.g. in the South of the EU equipment might be used longer than in the North. • Another source of uncertainty are the technology costs and the external costs. These have been taken into account by error margins. • Owners of the NRMM might take decision which deviate from the general cost/benefit calculations and prefer the purchase of a new NRMM instead of retrofitting an old one. This aspect has not been studied. • The cost-benefit analysis for the sub-sector agriculture/construction for the EU shows negative benefits (losses) for the small to medium range power classes up to 130 kW and for all emission Stages and all retrofitting technologies examined in this study (DPF, SCR, and the combined system). • Some very few exceptions exist for Stage I and unregulated machinery for the urban scenario only and for low retrofitting costs and high reduction efficiency and external costs. • Retrofitting is cost beneficial for the 130-560 kW class for Stage I and unregulated machinery and for urban conditions only. The benefits however are rather small. • For the EU clear benefits are only observed for the most powerful machinery (> 560 kW) for non-urban conditions. As this class was largely unregulated (before the introduction of Stage V) with high emission levels because of the high power, big emission savings have been calculated for all retrofitting options examined. • For inland waterways clear benefits are observed for all Stages, which are greater for unregulated vessels and for the combined system (DPF+SCR). For railcars, retrofitting is cost-beneficial for DPF and DPF+SCR for almost all Stages. SCR retrofitting is beneficial

for locomotives only in few cases for Stage IIIA and unregulated engines, whereas DPF and the combined system shows clears benefits for all Stages but Stage IIIB. DPF and the combined system is cost-beneficial for almost all Stages for shunting locomotives, with few exceptions for Stage IIIB engines, whereas SCR shows benefits for unregulated and Stage IIIA engines, but not for Stage IIIB engines.

14.5 Other general aspects to be considered

In order to identify appropriate policy options, the key findings have to be linked to the objectives and assessment questions listed in chapter 14.1. With regard to objective 1 (to improve air quality in urban areas by retrofitting engines already in service), there is no doubt that PM and NO_2 emissions still causes problems in the EU and emission reductions from the NRMM sector will help reducing pollution.

Since almost three quarters of Europeans live in cities, cities remain the best suited level of intervention. This level also shows the best cost/benefit results.

However, air quality and climate protection are complex issues. As shown in chapter "EU air quality problems related to NRMM" many sources contribute to air pollution and climate change. Moreover, an effective policy requires coordinated efforts at national, regional and local level. The air pollution problems analysis showed also that the contribution of NRMM to local air pollution differs from city to city and that no general conclusion can be drawn, e.g. indicating that retrofitting is in any case a cost-efficient measure. This is also underlined by the fact that only very few Member States actually take measures which support retrofitting and none of these measures is forcing retrofitting; there are always other options allowed instead.

Therefore, a forcing retrofitting measure proposed by the Commission would raise the question of subsidiarity. It is difficult to see how the Commission could argue that it knows better what to do at local level than Member States or regional or local authorities.

In policy terms, the measure "retrofitting of NRMM" has also to be assessed against measures taken for the on-road sector since these two sectors corresponds to each other to a certain extent. In the past, measures on NRMM followed with some delay those taken for the on-road sector. Taking measures like mandatory retrofitting or providing economic incentives which have not been taken for road vehicles at EU level would raise questions like why now for NRMM but not in the past for on-road or why have such measures not been taken at the point of time when these would have been helpful for the on-road sector.

Moreover, measures should not be in contrast to those just agreed upon as part of Regulation (EU) 2016/1628. Existing NRMM are indirectly addressed by the rules on replacement engines. Just to recall: *"replacement engine' means an engine that: (a) is exclusively used to replace an engine already placed on the market and installed in non-road mobile machinery; and (b) complies with an emission Stage which is lower than that applicable on the date of the engine's replacement."* In practical terms instead of obliging to use Stage V engines or retrofitted replacement engines the Regulation allows for certain categories and a certain period of time to use the same engine as the one originally installed[189,190]. This exemption applies to the categories RLL, RLR, NRE >19 kW and NRE < 560 kW

[189] *"Article 34 (7): Notwithstanding Articles 5(3) and 18(2), in relation to engines of categories RLL or RLR and placed on the Union market on or before 31 December 2011, Member States may authorise the placing on the market of replacement engines if the approval authority, upon examination, recognises and concludes that the installation of an engine that complies with the applicable emission limits set out in Tables II-7 and II-8 of Annex II will involve significant technical difficulties. In such a case, the replacement engines shall either comply with the emission limits that they would have needed to meet in order to be placed on the Union market on 31 December 2011, or shall comply with more stringent emission limits. In respect of engines in categories RLL and RLR that were placed on the Union market after 31 December 2011, Member States may authorise the placing on the market of replacement engines complying with the emission limits that the engines to be replaced had to meet when they were originally placed on the Union market."*

[190] *Article 58 (10): Notwithstanding Articles 5(3) and 18(2), Member States shall authorise the placing on the market of replacement engines, for a period not longer than 15 years, starting from the applicable*

and NRE >560 kW. For RLL and RLR a special economic assessment is required. To require wide-spread retrofitting would be in conflict with the replacement rules.

In the new EU Regulation, no PN limit value has been laid down for the categories RLL, NRE < 19 kW and NRE > 560 kW. One could argue that retrofitting these categories requires more stringent measures than for new engines, although the retrofitting of NRE > 560 kW turned out to be always cost efficient[191]. Therefore, it seems to be justified to exclude categories which do not have to comply with a PN limit values under Stage V from retrofitting considerations.

The emission calculation (see chapter IV) show that NO_x emissions will be reduced by about 48 % from 2019 to 2050, whereas PM emissions will be reduced more drastically, by about 88 % over the same period. With regard to emissions the effect of retrofitting measures is limited in time since the turn-over of the market will lead to significant emission reduction anyway.

As shown in the chapter on emissions only between about 2021 to about 2035 the emission reduction could be accelerated due to retrofitting.

Finally, in order to identify appropriate NRMM retrofitting measures, or alternative options, it is also necessary to look at the possible timeline of action since some measures might turn out as senseless since they would come too late anyway. Table 14-2 displays the timelines of relevant events and of selected potential policy measures.

Table 14-2 Timetable of relevant events and of selected potential policy measures

Year	Implementation of Regulation 2016/1268 other kW classes	Implementation of Regulation 2016/1268 56 – 560 kW and rail	Commission Action required under 2016/1268	Legally binding retrofitting measures	Financial incentives
1.1.2019	Application of Stage V For CI < 19 kW CI 19-56 CI 130-560 CI > 560 kW IWW 19-300 kW		Report on retrofitting	Internal Commission procedures	Internal Commissi on procedure s on budget and rules
1.1.2020		Application of Stage V CI 56-130 IWW > 300 kW		Proposal and negotiations	Application within budgetary limits
1.1.2021	End of transitional period	Application of Stage V for rail	Assessment of additional measures	Application of EU Regulation	
1.1.2022		End of transitional period for all but rail			

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dates for the placing on the market of Stage V engines set out in Annex III, provided that the engines belong to a category equivalent to NRS with a reference power no less than 19 kW, or belong to a category equivalent to NRG, where the replacement engine and the original engine belong to an engine category or power range that was not subject to type-approval at Union level on 31 December 2016.
Article 58 (11): Notwithstanding Articles 5(3) and 18(2), Member States shall authorise the placing on the market of replacement engines, for a period not longer than 20 years, starting from the applicable dates for the placing on the market of Stage V engines set out in Annex III, provided that the engines:
(a) belong to category NRE with a reference power no less than 19 kW and no greater than 560 kW, and comply with an emission stage that expired not more than 20 years before the placing on the market of those engines and that is at least as stringent as the emission limits that the engine to be replaced had to meet when it was placed on the market originally;
(b) belong to a category equivalent to NRE and with a reference power greater than 560 kW, where the replacement engine and the original engine belong to an engine category or power range that was not subject to type-approval at Union level on 31 December 2016.

[191] One reason for this discrepancy could lay in the differences between the calculations carried out in the Impact Assessment and in this study.

1.1.2023		End of transitional period for rail		Application of EU Directive	
1.1.2024					
1.1.2015					
1.1.2026			Considerations on in-use testing and real-world emissions		

Obviously, legal retrofitting measures in form of a Directive would take some time and could hardly be applied before 1.1.2023. This is just the point of time of the end of the transitional period, i.e. full application of Stage V. This is a helpful coincidence since to require retrofitting of the existing fleet with DPF would make some sense in theory at this point of time since this would bring new and (some relevant) old engines at the same emission level. Announcing it early would, moreover, put pressure on the NRMM market to move to Stage V and would not hamper the Stage V introduction.

A Regulation would go somewhat faster, generating the same effect. However, a Regulation would require that the Commission also lays down the detailed framework for implementation, e.g. publishing guidelines and inserting retrofitting information into IMI. A Regulation would most likely also require laying down detailed surveillance instructions (see chapter Implementing retrofitting measurers), an obligation not required for new Stage V engines.

14.6 Assessment of individual policy options

In the following three policy options are assessed:

- Mandatory retrofitting of all NRMM of the subcategory NRE with a Stage V PN limit value
- Non-binding retrofitting of all NRMM of the subcategory NRE with a Stage V PN limit value used in polluted zones
- Do nothing

For the sub-sectors IWW and rail the first two scenarios are not appropriate since they are of special character and would need to be studied in greater detail[192]. Moreover, these two sub- sectors do not fall under UNECE R 132 so that different EU wide applicable certification procedures for IWW vessels and locomotives are needed. There are other, more specific studies available and statements already published by the Commission[193,194]. Moreover, I particular for IWW the discussion on policy action takes place in other fora to which this study can little contribute. In these fora financial support is a key issue. Therefore, aspects of policy options are discussed in some detail in chapter 15.

In addition, to limit the assessment to NRE classes for which Stage V limit values have been laid down is justified by the fact that it can hardly be justified to retrofit engines which even if newly designed do not require after-treatment devices.

14.6.1 Mandatory retrofitting of all NRMM of the subcategory NRE with a Stage V PN limit value

A pro/con assessment on the option "All NRMM of the subcategory NRE with a Stage V PN limit in all Member States must be retrofitted" is shown in Table 14-3.

[192] This includes taking into account the ongoing discussion in the IWW sector in which the study team is not involved.
[193] European Commission 2013: SWD(2013) 324 final
[194] Zoetermeer 2011: Medium and Long Term Perspectives of IWT in the European Union

Table 14-3 Pro/Con assessment of EU legislation requiring all NRMM to be retrofitted

Criterion/Measure	Regulation or Directive requiring retrofitting	
	All NRMM of the subcategory NRE with a Stage V PN limit in all Member States must be retrofitted	
	Pro	Con
Why? What is the problem being addressed?	Reduction of PM, NO_2 and BC emissions. Largest possible emission reduction, very positive in particular for BC, but also for compliance with critical loads and air quality limit values	Subsidiarity problem since PM and NO_2 air pollution problems are mainly of local character; no comparable measure for road; conflict with rules for NRMM replacement engines. No certified retrofitting system under UNECE R 132 available at short term.
What is this initiative expected to achieve?	Accelerated reduction of emissions in order to support air quality and climate protection measures of Member States.	Reduction will happen anyway due to Stage IIIB/IV and Stage V limits and the turnover of existing fleets.
What is the value added of action at the EU level?	Helps to comply with air quality limit values and critical loads; harmonises retrofitting activities.	General EU harmonisation is currently not needed since there are nearly no retrofitting activities in Member States. PM and in particular NO_2 compliance measures of Member States concentrate on road transport. Forced measures would help harmonisation but currently harmonisation seems not to be needed since national, regional and local authorities are aware of UNECE R 132 and willing to take them into account.
What legislative and non-legislative policy options have been considered? Is there a preferred choice or not? Why?	Regulation and Directive. A Regulation would be faster and allows a more detailed harmonisation. A Directive could pass some details to Member States.	Establishment of additional administrative EU framework required.
Who supports which option?	Parts of the EP.	Parts of the EP. However, most likely a large majority of Member States would express reservations.
What are the benefits of the preferred option (if any, otherwise main ones)?	Less pollution with beneficial effects for human health and the environment.	Cost/benefit analysis showed in nearly all cases that costs are higher than benefits in the "general" EU 28 scenario. Exceptions are retrofitting measures in the power class > 560 kW. Measures in another sector might be more beneficial.
What are the costs of the preferred option (if any,	To be estimated	Retrofitting all NRMM in the sub-sectors agriculture and construction works would be a multibillion exercise. Even if

otherwise main ones)?		distributed over several years and limited to defined power classes total costs are high. Repercussions on NRMM markets for new and second-hand NRMM have not been studied but might be significant.
Will there be significant impacts on national budgets and administrations? How will businesses, SMEs and micro-enterprises be affected?	No significant impact on national budgets. National administration needed for certification and surveillance. Most businesses concerned are SME. SME's would have to bear costs in first place and pass it to customers. Market prices for services offered by SME's would increase. Retrofitting firms are also SME's. They would benefit from retrofitting.	Field surveillance of proper functioning necessary although currently not established for new engines. Safety aspects (visibility/heat) to be checked by technical services.
Will there be other significant impacts?	Harmonisation of retrofitting activities in the EU.	In the long run a harmonisation would most likely take place without EU intervention. Possible repercussions on NRMM approval under EU machine and safety regulations, no OEM warranty for retrofitted engines.
When will the policy be reviewed?	Not discussed in the report. But in about 5 to 10 years after adoption a review would make sense since at that point of time most NRMM would have been retrofitted and Stage V would be fully implemented. Moreover, results of the other reporting obligations laid down in the EU Regulation would be available.	

In summary, mandatory retrofitting measures, be it in form of an EU Regulation or a Directive, can hardly be justified. Only very weak justifications could be given in relation to the questions listed above. The measure seems not to be cost-efficient, although these calculations are valid for EU only and suffer from great uncertainties. This is supported by the weighted costs and benefits, calculated based on Eq. 4 and Eq. 5 and presented in Table 14-4, Table 14-5 and Table 14-6. For all emissions Stages the various retrofitting system do not present benefits, based on the cost-benefit analysis performed in Chapter 12. Most positive, of course, is the general reduction of emissions, supported by the results included in Table 14-7. However, the violation of the subsidiarity principle as well as the needed complexity of a legally binding regulation speaks against such a step.

Table 14-4 Weighted costs and weighted benefits [M€] for DPF retrofitting (policy option all NRMM > 19 kW and < 560 kW to be retrofitted)

Emissions Stage	Weighted Costs	Weighted Benefits (general scenario)	Weighted Benefits (urban scenario)
Stage IIIB	8737^{+816}_{-816}	276^{+55}_{-75}	490^{+98}_{-134}
Stage IIIA	6126^{+582}_{-582}	1865^{+373}_{-509}	3203^{+641}_{-873}
Stage II	2901^{+279}_{-279}	692^{+138}_{-189}	1220^{+244}_{-333}
Stage I	412^{+40}_{-40}	167^{+33}_{-46}	294^{+59}_{-80}
Unregulated	24^{+2}_{-2}	9^{+2}_{-2}	15^{+3}_{-4}

Table 14-5 Weighted costs and weighted benefits [M€] for SCR retrofitting (policy option all NRMM > 19 kW and < 560 kW to be retrofitted)

Emissions Stage	Weighted Costs	Weighted Benefits (general scenario)	Weighted Benefits (urban scenario)
Stage IIIB	8015^{+744}_{-744}	2176^{+435}_{-1015}	3679^{+736}_{-1717}
Stage IIIA	6850^{+655}_{-655}	1403^{+281}_{-655}	2328^{+466}_{-1086}
Stage II	3082^{+297}_{-297}	745^{+149}_{-348}	1262^{+252}_{-589}
Stage I	471^{+46}_{-46}	110^{+22}_{-52}	186^{+37}_{-87}
Unregulated	28^{+3}_{-3}	10^{+2}_{-5}	17^{+3}_{-8}

Table 14-6 Weighted costs and weighted benefits [M€] for DPF and SCR retrofitting (policy option all NRMM > 19 kW and < 560 kW to be retrofitted)

Emissions Stage	Weighted Costs	Weighted Benefits (general scenario)	Weighted Benefits (urban scenario)
Stage IIIB	11990^{+1142}_{-1142}	2451^{+490}_{-596}	4168^{+834}_{-1013}
Stage IIIA	9428^{+913}_{-913}	3267^{+653}_{-776}	5530^{+1106}_{-1313}
Stage II	4373^{+426}_{-426}	1437^{+287}_{-343}	2482^{+496}_{-592}
Stage I	653^{+64}_{-64}	278^{+56}_{-66}	480^{+96}_{-114}
Unregulated	39^{+4}_{-4}	19^{+4}_{-4}	32^{+6}_{-8}

Table 14-7 Emission reductions for high and low reduction values, 2022-2030 (policy option all NRMM > 19 kW and < 560 kW to be retrofitted)

Retrofitting System	Emissions reductions for high reduction efficiency	Emissions reductions for low reduction efficiency
SCR	70 % of NO_x emissions	46 % of NO_x emissions
DPF	67 % of PM emissions	61 % of PM emissions
DPF+SCR	70 % of NO_x and PM emissions	65 % of NO_x and PM emissions

The second objective mentioned in the Regulation is harmonisation of existing retrofitting activities. To certain extent a formal harmonisation has been already realised due to the adoption of the UNECE Regulation which in principle applies to all EU Member States. Recent German regional legislation in Bayern and Baden-Württemberg, for example, require certifying after-treatment devices in accordance with the UNECE Regulation. However, since the regional regulations offer more cost-efficient alternatives to retrofitting no system has been certified in accordance with UNECE R 132 yet. The question to be answered is, whether additional EU measures are needed in order to support the harmonisation of the certification system. This question is also linked to the question of the need of a transitional period. If no transition period is allowed, e.g. accepting for one or two years that retrofitting systems certified on the basis of other procedures can be used, a further time delay would be imposed since it will take some time before UNECE certified system appear on the market.

In general, political acceptance of compulsory retrofitting measures would increase if only some selected NRMM sectors are covered. A lead candidate would be the construction sector, like in Switzerland, since most air pollution problems are located in cities, e.g. agricultural tractors would not fall under such a measure. However, even in this case the arguments given in Table 14-3 would be valid to a large extend, in particular the subsidiary principle - since retrofitting measure would not be needed in all cities within the EU - and the high costs involved.

Another option is a mandatory retrofitting of all NRMM of the subcategory NRE with a Stage V PN limit value used in polluted zones. The EU 28 cost/benefit calculation shows that such a measure is somewhat more beneficial, although costs are still higher than benefits in most of the cases. However, limiting such a mandatory measure to cities in which the air quality limit value(s) is/are violated might create an even larger opposition of Member States since such a measure would be considered as an attempt of air pollution micro management by the Commission. It would also be in conflict with the principle laid down in the EU air quality legislation since this legislation leaves measures in the hands of Member States.

In summary: General mandatory retrofitting measures at EU level seems not to be an option to be recommended.

14.6.2 Non-binding policy options

More appropriate seems to be a Commission Recommendation on NRMM retrofitting. A recommendation allows the Commissions to make its views on NRMM known and to suggest a line of action without imposing any legal obligation on those to whom it is addressed. Therefore, in contrast to legally binding measures it is not in conflict with the subsidiary principle. A Commission Recommendation leaves all options to Member States.

With regard to the two objectives mentioned above, it is obvious that a Recommendation will not directly contribute in a foreseeable manner to the first objective (To improve air quality in urban areas by retrofitting engines already in service). However, indirectly it would support measures designed at national, regional or local level. Moreover, a Recommendation would result in cost savings with regards to the development and certification of exhaust after-treatment system and would improve the planning security for NRMM end-users.

With regard to the second objective (To harmonise retrofitting measures giving reference to UNECE Regulation 132) it should be recalled that Regulation UNECE 132 is not part of Regulation (EU) 2016/1628. However, UNECE R 132 is mandatory for members of the UNECE convention which include the European Union and its Member States. Its publication in the Official Journal on 27.4.2018 in all official EU languages is helpful but legally of no practical relevance. A Commission Recommendation indicating that the Commission proposes to Member States to apply UNECE R 132 for NRMM retrofitting measures would strengthen the actual application of the Regulation.

Another aspect is the certification of already retrofitted existing engines. These have been certified applying different certification procedures. However, it would be obviously disproportionate to require any sort of re-certification or to deny certification already granted. Therefore, existing certifications should be accepted without further prove.

Moreover, in a Commission Recommendation general guideline could be given for authorities considering retrofitting measures. This includes recommending sub-sectors on the basis of the assessment of the ambient air situation and the cost benefit calculations carried out in this report. The assessment of ambient air quality situation carried out in this report shows that construction machinery used in urban areas cause potentially the greatest risk to human health. Therefore, it makes sense to limit the retrofitting measure to this sub-category and this sub-area.

To be more specific: It is, as a rule, not necessary requiring retrofitting for all urban areas since only in a few zones violations of the ambient air limit values happen. Directive 2008/50/EC defines zones identified by Member States as a part of the territory of a Member State where air quality assessment and management takes place. These zones are by definition the most polluted areas and it makes sense to limit the Recommendation to these zones[195].

In some of these zones restrictions with regard to the operation of on-road vehicles are in place. In these zones a decision on other polluting engines has to be taken anyway since it is difficult to explain to the general public that it is not allowed to enter the zone with certain types of on-road vehicles but to allow polluting machinery to be operated in these zones.

In the Recommendation relevant retrofitting criteria should be defined: What pollutants should be covered; what circumstances must be met in order to require retrofitting and what kind existing NRMM should be retrofitted. The investigations carried out in this study allow defining the required details.

With regard to the pollutants nearly all measures focused so far that on PM. However, it is also obvious that NO_2 pollution causes problems, currently more than PM pollution. Moreover, SCR retrofitting turned out to be more or less equally cost efficient as DPF retrofitting. Finally, in a number of zones the ambient air quality situation requires taking all possible measures in order to meet the limit values, irrespective of costs benefit aspects. Therefore, PM and NO_x retrofitting should be part of the Recommendation.

The question what kind of machinery should be retrofitted is also important. As already mentioned, construction machinery is the target, but should it be all existing construction machinery? The assessments on retrofitting technology as well as on technologies applied for new engines showed that it is difficult to retrofit existing engines already equipped with exhaust after-treatment systems. Moreover, there is a risk that a new type-approval is required. As a rule, this concerns relatively new machinery complying with Stages IIIB and IV, e.g. engines with quite low emissions. Moreover, retrofitting these categories turned out to be not cost-efficient. In summary it makes sense to exclude such machinery from (further) retrofitting measures.

[195] This does not mean that Member States might apply the Recommendation to other areas as well.

Instead Stage IIIB /IV - and as soon as available, Stage V - NRMM should be considered as the option allowed to be used in polluted zones as an alternative for retrofitting. This holds for variable speed engines.

Moreover, not all construction machinery should be included in retrofitting programmes since the power class < 19 kW and > 560 kW had no emission limits in the past and are not covered by UNECE R 132. Neither do the Stage V limits require meeting a PN limit.

Based on the cost/benefit calculations this measure is not cost-beneficial as presented in Table 14-8, Table 14-9 and Table 14-10, whereas the corresponding emission reductions are significant (Table 14-11) . However, the calculation suffers under uncertainties and covers the EU in total. The cost/benefit situation might differ among Member States and even within Member States. Since a Recommendation is not binding Member States or regional or local authorities can check the cost/benefit situation for their specific case and might come to the conclusion that retrofitting makes sense and is beneficial under the given circumstances.

Table 14-8 Weighted costs and weighted benefits [M€] for DPF retrofitting (policy option construction NRMM in urban zones to be retrofitted)

Emissions Stage	Weighted Costs (general scenario)	Weighted Benefits (general scenario)	Weighted Costs (urban scenario)	Weighted Benefits (urban scenario)
Stage IIIB	1760^{+165}_{-165}	16^{+3}_{-4}	3520^{+330}_{-330}	65^{+13}_{-18}
Stage IIIA	1477^{+142}_{-142}	195^{+39}_{-53}	2954^{+284}_{-284}	780^{+156}_{-213}
Stage II	645^{+62}_{-62}	51^{+10}_{-14}	1291^{+124}_{-124}	203^{+41}_{-55}
Stage I	95^{+9}_{-9}	13^{+3}_{-3}	190^{+19}_{-19}	51^{+10}_{-14}
Unregulated	$5^{+0.5}_{-0.5}$	$1^{+0.1}_{-0.2}$	10^{+1}_{-1}	2^{+1}_{-1}

Table 14-9 Weighted costs and weighted benefits [M€] for SCR retrofitting (policy option construction NRMM in urban zones to be retrofitted)

Emissions Stage	Weighted Costs (general scenario)	Weighted Benefits (general scenario)	Weighted Costs (urban scenario)	Weighted Benefits (urban scenario)
Stage IIIB	1608^{+150}_{-150}	132^{+26}_{-62}	3215^{+300}_{-300}	530^{+106}_{-247}
Stage IIIA	1988^{+193}_{-193}	133^{+27}_{-62}	3975^{+386}_{-386}	637^{+106}_{-248}
Stage II	679^{+65}_{-65}	50^{+10}_{-23}	1357^{+131}_{-131}	200^{+40}_{-93}
Stage I	108^{+11}_{-11}	8^{+2}_{-4}	216^{+21}_{-21}	31^{+6}_{-15}
Unregulated	6^{+1}_{-1}	$1^{+0.1}_{-0.3}$	12^{+1}_{-1}	$2^{+0.4}_{-1}$

Table 14-10 Weighted costs and weighted benefits [M€] for DPF and SCR retrofitting (policy option construction NRMM in urban zones to be retrofitted)

Emissions Stage	Weighted Costs (general scenario)	Weighted Benefits (general scenario)	Weighted Costs (urban scenario)	Weighted Benefits (urban scenario)
Stage IIIB	2418^{+231}_{-231}	149^{+30}_{-36}	4837^{+462}_{-462}	594^{+119}_{-145}
Stage IIIA	2541^{+248}_{-248}	328^{+66}_{-78}	5082^{+497}_{-497}	1312^{+262}_{-311}
Stage II	968^{+94}_{-94}	101^{+20}_{-24}	1937^{+189}_{-189}	402^{+80}_{-96}
Stage I	150^{+15}_{-15}	20^{+4}_{-5}	300^{+30}_{-30}	82^{+16}_{-19}
Unregulated	8^{+1}_{-1}	$1^{+0.2}_{-0.3}$	16^{+2}_{-2}	4^{+1}_{-1}

Table 14-11 Emission reductions for high and low reduction values, 2022-2030 (general scenario for the policy option construction NRMM in urban zones to be retrofitted)

Retrofitting System	Emissions reductions for high reduction efficiency	Emissions reductions for low reduction efficiency
SCR	75 % of NO_x emissions	50 % of NO_x emissions
DPF	80 % of PM emissions	70 % of PM emissions
DPF+SCR	74 % of NO_x and PM emissions	70 % of NO_x and PM emissions

The power class most suitable to be covered by a Recommendation seems to be 19 to 560 kW. The power class 19 kW to 560 kW is responsible for the large majority of PM and NO_x emissions. All types of CI engines (variable speed & constant speed engines) should be included since there is no reason to treat these differently.

However, constant speed engines and variable speed engines in the power range 19 – 37 kW have to comply under Directive 97/68/EC with Stage IIIA at the maximum. This can be achieved without after-treatment devices. After-treatment, however, is necessary for Stage V since there are no different limit value sets anymore in place for constant speed and variable speed engines, as it is the case under Directive 97/68/EC. Moreover, most constant speed NRE engines are used in mobile generator sets which run at very low load for extended periods. This leads to a cold exhaust that does not facilitate the necessary regeneration of a DPF and may be too cold for the SCR to operate effectively. Consequently, some more time should be given before requiring retrofitting, e.g. no retrofitting requirement before 2023. NRMM equipped with variable speed engines in the power class 19 to 37 kW should get one extra year for retrofitting since there are no or only very few Stage IIIB/IV engines on the market.

The power class > 560 kW should be excluded for the reasons mentioned above, although it is cost-efficient to retrofit these engines. However, NRMM with such high engine power is rarely, if at all, used in urban areas. The already scheduled next review of the Regulation could considerer these aspects.

The Pre-Stage I NRMM contributes significantly to the total NRMM emissions of PM and NO_x as well. However, the retrofitting of Pre-Stage I engines does not fall under UNECE R 132 as these engines are not defined and have unknown emissions. In addition, engines with a lifetime of more than 20 years often cannot be retrofitted due to poor maintenance. It is therefore also difficult to precisely define the requirements for retrofitted Pre-Stage I engines. Consequently, it is not possible to achieve harmonisation of certification if these engines were included in the Recommendation.

In summary, Stage IIIB and IV engines (variable speed) of the range 19 to 560 kW (equal to UNECE emission standard categories L to P and Q and R) should not be retrofitted and can operate in zones without restrictions. The Stages I to IIIA have to be retrofitted if operated in these zones (equal to UNECE emission standard categories A to C , E to D (> 19 kW) and H to K). The subgroups covered account for the large majority of the PM and NO_x emissions of NRMM operated in zones.

There are a number of other aspects to be considered in a Recommendation:

- It must be clearly spelt out that the Commission recommends that future certification of the retrofit devices should only take place in accordance with UNECE Regulation No. 132.
- It is proposed that a specific NRMM equipped with an exhaust after-treatment system which has already been certificated by a technical service and installed on that specific non-road mobile machine before the date of publication of this Recommendation can be used without further restrictions. Moreover, an exemption can be claimed until one year after the date of application of this Recommendation at national, State or local level, if a proof is submitted by a technical service which shows that the retrofitting of the construction machine in question is not possible for technical reasons[196].
- Documentation is needed: National authorities of Member States must insert defined data on retrofit Emission Control device (REC) certified in accordance with UNECE R 132 into the IMI data bank mentioned in Article 44 of Regulation (EU) 2016/1628. Moreover, for construction machinery used on construction sites in defined zones the documentation of the conformity of the exhaust after-treatment system must be available at the construction site.
- It should be recommended that Member States, States and/or local authorities publish guidance in which the measures are explained as well as the administrative and legal repercussions and consequences for the end-user of NRMM construction machinery.
- Member States, States or local authorities should lay down, if necessary, legal provision on the use of construction machinery in defined zones in order to ensure legal clarity. Moreover, Member States, States or local authorities should establish, if not already done, the institutions necessary for the administrative implementation and enforcement of the legal provisions. It should be recommended to publish guidance for the surveillance. Member States, States or local authorities should ensure surveillance of the application of the legal provisions. Moreover, it should be recommended that Member States, States or local authorities lay down, if needed, legal provisions on penalties associated with non-compliance with the legal provisions.
- The Recommendation should give a hint on incentives which are complying with EU legislation in order to accelerate the introduction of NRMM equipped with exhaust after-treatment systems.

With regard to the timing it should be recommended that Member States, States and/or local authorities should ensure a minimum of 1 year between the announcing of zones and the application of these Recommendations. This allows end-users to take the necessary action in order to comply with the requirements. This should allow the construction industry to prepare the required change of machinery, e.g. by exchanging older machines with those complying with the requirements. In cases where no replacement machine can be found or where retrofitting proves to be technically impossible, temporary exemptions should be granted. A period of 2 years should be sufficient to solve the identified and proven cases. The number of exemptions should be kept as small as possible. Applications for exemptions should be forwarded within the one-year period between the announcement of the zone and the application of the Recommendation.

However, in the period between the publication of the Recommendation and its application it should be recommended that Member States, States or local authorities encourage end-users which plan to

[196] Not mentioned in the draft Recommendation is the option that exemptions for specific NRMM types could be integrated since it is not possible within the scope of this study to carry out individual NRMM assessments.

retrofit construction machinery should apply exclusively the provisions of UNECE R 132 for the certification process.

Finally, the application of the Recommendation should take place 2 years after its publication at the latest This timing allows to identify and announce new zones but also to adapt zones for which retrofitting requirements have already been laid down to the proposed Recommendations.

In summary, the overall timing looks as shown in the following Figure:

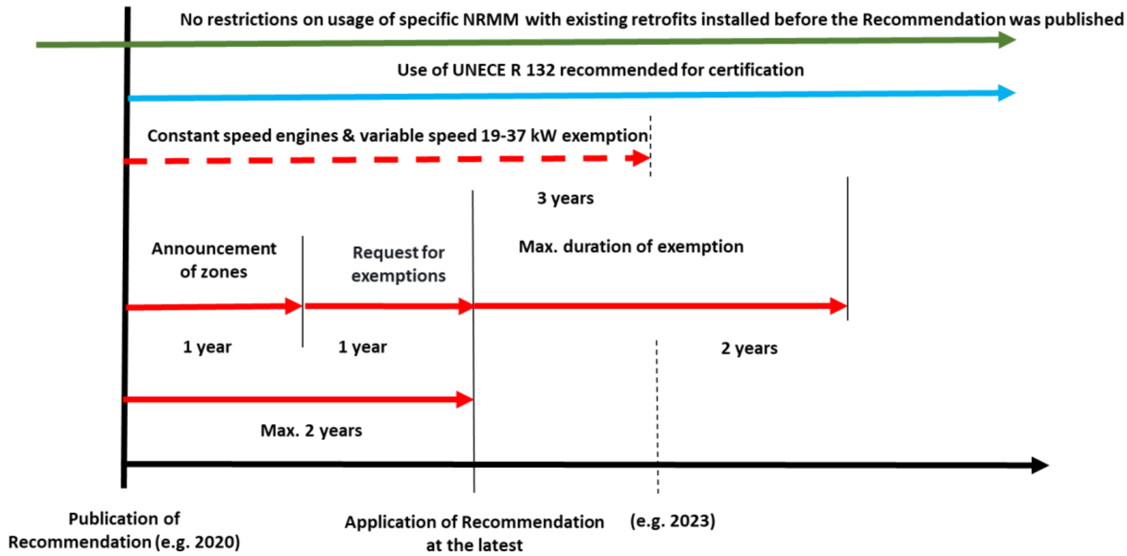

Figure 14-2 Timing of action according to proposed Recommendation

Annex III shows a draft of a Commission Recommendation. In order to be well interconnected with the relevant EU and UNECE Regulation definition of these papers have been used. It should be mentioned that in about 5 to 10 years the requirements might need to be up-dated and Stage V or engines retrofitted up to the Stage V level should become the standard requirement in zones.

The following table summarises the pros and cons of a Commission Recommendation which follows the lines mentioned above:

Table 14-12 Pro/Con assessment of a Commission Recommendation on NRMM retrofitting in zones

Criterion/Measure	Commission Recommendation on retrofitting	
	Member States should apply the Recommendation for retrofitting measures in polluted zones	
	Pro	Con
Why? What is the problem being addressed?	Currently retrofitting measures are taken in the EU without a general guideline. This causes confusion and loss of planning security of end-user and results in extra costs for the development of technologies. The Recommendation would help overcoming this problem.	No comparable measure for road. No certified retrofitting system under UNECE R 132 available at short term.
What is this initiative expected to achieve?	Reduction of PM, NO_2 and BC emissions in polluted zones, if desired by Member States, States or local authorities.	Harmonisation will only happen if Member States apply the Recommendation.

	Harmonisation of retrofitting measurers. Level playing field of restrictions for off-road and on-road engines in zones.	Most likely only small emission reduction because requirements can be achieved by machinery exchange within countries
What is the value added of action at the EU level?	Helps to comply with air quality limit values and critical loads; harmonises retrofitting activities.	No harmonisation of the whole sector (different certification for NRE > 560 kW and < 19 kW, IWW vessels and locomotives needed).
What legislative and non-legislative policy options have been considered? Is there a preferred choice or not? Why?	Recommendation and Commission Staff document.	None.
Who supports which option?	No support needed. EP and most MS in Council would have little problems with a Commission Recommendation.	None.
What are the benefits of the preferred option (if any, otherwise main ones)?	Official Commission Recommendation, to be published in the Official Journal. A Commission Staff document would be too weak and most likely not lead to the desired degree of harmonisation.	None.
What are the costs of the preferred option (if any, otherwise main ones)?	Estimated total costs are difficult to estimate since it is unclear how many cities would follow the Recommendation. The cost/benefit analysis showed benefits in few cases.	None.
Will there be significant impacts on national budgets and administrations? How will businesses, SMEs and micro-enterprises be affected?	No significant impact on national budgets. National administration needed for certification and surveillance. Most businesses concerned are SME. SME's would have to bear costs in first place and pass it to customers. Market prices for services offered by SME's would increase. Retrofitting firms are also SME's. They would benefit from retrofitting.	Efforts for field surveillance of proper functioning necessary.
Will there be other significant impacts?	Harmonisation of retrofitting activities in the EU.	No OEM warranty for retrofitted engines (warranty only for retrofitting kit).
When will the policy be reviewed?	In about 5-10 years after adoption since at that point of time most NRMM would have been retrofitted or Stages IIIB/IV be used and Stage V NRMM would have started penetrating the market.	

It should be underlined that the proposed Recommendation, if implemented, will not lead to large-scale retrofitting measures. There is sufficient availability of construction machinery with engines complying with Stages IIIB and IV since the Recommendation applies to zones only, e.g. to a small portion of the total NRMM fleet. A fall-back is always leasing, if necessary. In addition, there is the exemption clause.

Retrofitting will concentrate on the power class 19 to 37 kW since no Stage IIIB or IV compliant equipment is available. With these limitations retrofitters will have time to certify aftertreatment systems in accordance with UNECE R 132.

The proposal is that the Recommendation should be applied from 2022 onwards. Introducing the Recommendation too late would make it senseless because the air quality situation improves anyway in the long run and the older equipment will disappear from the scene. To give more time would look also odd in policy terms, since the whole approach is mainly made for emergencies (zones in which the air quality limits are exceeded).

Since the Recommendation allows Stage IIIB/IV to be used (and gives more time for gen sets) it will not cause damage to the market for new Stage V NRMM since at that point of time Stage V NRMM will be on the market. In fact, already now-a-days Stage V engines and NRMM are available[197]. In general, whilst there will be exceptions, industry is more likely to use the transition scheme where the step change from the prior Stage to Stage V is greatest and the cost of pre-Stage V engines that would need to be stocked for this scheme is lowest. This will be particularly the case for mobile gensets across the range of power, and for 19 – 37 kW NRMM, where in both cases there is a need to change from relatively simple non-after-treated Stage IIIA engines to electronically-controlled after-treated engines.

In summary: The environmental benefit will be mainly that some old equipment will be exchanged by Stage IIIB/IV equipment and that there will be pressure to move to Stage V since NRMM users/owners will see that authorities are active in this field and want to be on the safe side since a review after about 5 to 10 years would most likely require Stage V instead of Stages IIIB/IV. Some retrofitting will take place in the power class 19 to 37 kW. Cost will be very low, although not quantifiable in detail.

14.6.3 Option "Do nothing"

Do nothing is an option as well. The reasons why there is no need for action are given in the Tables above. In this respect there is another aspect to be considered: By co-incidence, in 2021 the Commission has to *"...submit a report to the European Parliament and to the Council regarding:*

(a) the assessment of further pollutant emission reduction potential, on the basis of available technologies and a cost- benefit analysis.

In particular, for engines of categories IWP and IWA, the assessment of the technological and economic feasibility of:

(i) a further reduction in the emission limit value for PN and NO_x emissions;

(ii) a further reduction in the A-factor for fully and partially gaseous-fuelled engines in the framework of a climate- neutral operation compared to diesel-fuelled engines; and

(iii) the addition of PN limit values to those engine categories for which such values have not been set out in Annex II to this Regulation;

(b) the identification of potentially relevant pollutant types that do not fall within the scope of this Regulation."

"Do nothing" at Commission level does not hinder Member States', regional and local authorities to take measures. For example: With Stage V coming into force in the coming year it might be considered

[197] See for example: https://www.cat.com/en_GB/campaigns/awareness/ready-for-stage-v.html
https://www.perkins.com/stagev
https://www.cat.com/en_US/news/engine-press-releases/caterpillar-marine-announces-development-of-new-iww-solutions-for-eu-stage-v.html
www.liebherr.com/diesel-engines

most appropriate to request that in polluted zones only Stage V NRMM are allowed to operate. This would, for example, make sense in zones in which only newest diesel technology it accepted for on-road vehicles.

In order to check this option, Table 14-13 shows pro/con arguments in a "negative" form, e.g. the Commission just informs EP and Council that it concluded after assessing the issues raised in Article 60 that no EU wide measure is necessary.

Table 14-13 Pro/Con assessment of the option "no measure taken"

Criterion/Measure	No Commission measure on retrofitting	
	The Commission just informs EP and Council that it concluded after assessing the issues raised in Article 60 that no EU wide measure is necessary	
	Pro	Con
Why? What is the problem being addressed?	"Do nothing" allows MS as well as regional and local authorities to take tailored measures, if desired. Avoidance of subsidiarity problems; pollution problems are tackled best at local level. Air quality is slowly improving in MS and measurers already taken in the NRMM sector are making already a contribution. UNECE R 132 application would take place under UNECE.	No forced accelerated emission reduction. Harmonisation of certification will only happen if Member States apply the UNECE R 132.
What is this initiative expected to achieve?	Avoidance of additional costs. No interference in NRMM market.	Reduction of PM, NO_2 and BC emissions in polluted zones fully in hands of Member States, States or local authorities. No additional support to comply with air quality limit values and critical loads. No help with regards to the harmonisation of retrofitting measurers. Retrofitting measures are taken in the EU without a general guideline. This could cause confusion and loss of planning security of end-user and results in extra costs for the development of technologies. No certified retrofitting system under UNECE R 132 available at short term.
What is the value added of action at the EU level?	None	In theory there could an added value of EU-wide action.
What legislative and non-legislative policy options have been considered? Is there a preferred choice or not? Why?	All options have been considered but found to be unnecessary.	None

Who supports which option?	No support needed. If some Member States would like to see EU wide action, they should make proposals and a working group should be established.	Some MS in Council might wish to take EU wide measures. But unlikely since no comparable measures for road have been taken.
What are the benefits of the preferred option (if any, otherwise main ones)?	Member States, States and local authorities can continue their policies without interference from the Commission.	None
What are the costs of the preferred option (if any, otherwise main ones)?	None	The EU 28 cost/benefit analysis found only a few benefits for retrofitting. However, uncertainties are high and calculations at a lower territorial level could lead to different results.
Will there be significant impacts on national budgets and administrations? How will businesses, SMEs and micro-enterprises be affected?	None	None
Will there be other significant impacts?	None	None
When will the policy be reviewed?	Irrespective of the fact that the Commission can always take initiative, in the beginning of the twenties since the EU Regulation requires further assessments.	

Other policies might have an impact on the retrofitting issue and change the picture, e.g.

- In January 2019 the particle limit values for occupational health have been tightened which could result in additional retrofitting requirements,
- In 2019/2020 the Commission will publish the results of the fitness check of the air quality limit values which might request to comply with lower limits,
- Commission work on public procurement.

If one considers that legislative activities at EU level will largely be suspended before the end of 2019 as a result of the elections to the European Parliament and the reappointment of the Commission, then at least it makes sense to do nothing in the near future.

In the coming years the Commission will have additional review options. These could be used to tighten the emission limited values further and make an additional contribution to reduce air pollution, if necessary.

In summary it seems also to be feasible to take no action, to trust that Member States will take all necessary steps to comply with EU limits and that a harmonisation of the certification of retrofitting measures will take place automatically with the help of UNECE R 132.

14.7 Conclusions

- There is a time limited window for retrofitting between about 2020 to 2030. After 2030 Stages IIIB, IV and V will dominate the sector.
- From the policy options studies the option "Recommendation" or "Do nothing" seem to be most appropriate.
- The option "Mandatory Retrofitting" of all NRE cannot be recommended since it is in conflict with a number of aspects, e.g. the subsidiary principle and non-existence of similar measures in Member States, lack of sufficient retrofitting capacity and certified systems, conflict with the replacement engine rules laid down in the NRMM Regulation, non-existence of similar measures for the on-road sector, unclear repercussions on the NRMM second-hand market and high absolute costs.
- More appropriate seems to be the second option, a non-binding Recommendation to be applied in polluted zones. A Commission Recommendation gives guidance to Member States which consider taking such measures as well as to the few countries, regions or cities which actually have already taken measures; from the Commission's perspective it would be mainly a contribution to harmonisation, meeting at the same time the requirements mentioned in the recital of the Regulation.
- Aspects to be covered by a Commission Recommendation have been identified and an example has been drafted. Most appropriate seems to be to cover construction machinery falling into the category NRE within the power range 19-560 kW, to require certification under UNECE R 132 and to ensure guidance and surveillance.
- With regard to the timing, the implementation scheme of the Regulation (EU) 2016/1628 should be taken into account.
- It is recommended that in polluted zones either Stage IIIB or IV engines must be used or engines must be retrofitted in accordance with UNECE R 132; in practical terms the option to allow stages IIIB/IV will make retrofitting for variable speed engines in the power class 37-560 kW superfluous in most of the cases since there are enough NRMM available or in use which meet these emission stages; these engines have just to be used in places where the fact of their low emissions is most beneficial; if necessary leasing is another option.
- NRMM equipped with constant speed engines or with variable speed engines in the power class 19 to 37 kW should get one extra year for retrofitting since there are no stage IIIB/IV engines on the market.
- "Do nothing" is a valid option since only very few Member States seem to be interested in retrofitting. Thus, little or no retrofitting takes place and one could question the need of action at EU level. Moreover, the harmonisation of certification will happen after adoption of UNECE R 132 in the coming years more or less automatically.
- Other policies might have an impact on the retrofitting issue and change the picture, e.g.
    - In January 2019 the particle limit values for occupational health have been tightened which could result in additional retrofitting requirements,
    - In 2019/2020 the Commission will publish the results of the fitness check of the air quality limit values which might request to comply with lower limits,
    - Commission work on public procurement.
- If one considers that legislative activities at EU level will largely be suspended before the end of 2019 as a result of the elections to the European Parliament and the reappointment of the Commission, then at least it makes sense to do nothing in the near future.
- In the coming years the Commission will have additional review options. These could be used to tighten the emission limited values further and make an additional contribution to reduce air pollution, if necessary.

15 Financial incentives

15.1 Introduction

Financial incentives can be granted in various forms. These include straight grants, loans, tax deductions, other types of tax incentives or incentives in other monetary forms, whether positive or negative. Financial incentives could include the purchase of new NRMMs, the retrofitting of used NRMMs and the scrapping of NRMMs.

As a general rule, incentives should be created to change the framework conditions so as to increase market demand for an engine/NRMM with a particular environmental performance. Incentives can support market acceptance of energy efficient vehicles in two ways:

- Through a pull effect by increasing consumer demand for these engines/NRMM.
- Through a push effect, by making it more attractive for manufacturers to carry out a specific development to offer engines/NRMM that benefit from these incentives.

Incentives are most effective when both effects can be triggered. The first effect applies to engines/NRMM that meet the defined criteria and are offered on the market, including smaller markets.

15.2 EU framework

State Aid for Environmental Protection and Energy Aid can be granted on the basis of the guidelines, general block exemption regulation and directly under the Treaty.

All financial incentives must furthermore be compatible with the EC Treaty, e.g. they have to comply in particular with Article 110 of the EC Treaty, which prohibits any discrimination through internal taxation. Member States are also under an obligation to respect the EC Treaty provisions on State aid. As set out in Article 107 of the EC Treaty, granting State aid by Member State is prohibited unless it is compatible with the common market.

More specific guideline has been given by the Commission in a number of documents (European Commission, 2009a; European Commission, 2013b; European Commission, 2014b; European Commission, 2018b).

Financial incentives granted by authorities on different levels in Member States must comply with following principles:

a) Non-discrimination

Incentives must be non-discriminatory with regard to the origin of the product concerned. They should avoid favouring only the sale of engines/NRMM of domestic manufacturers and should not include vehicle characteristics which could discriminate against similar NRMM coming from other Member State(s) than the one, where the incentives are applicable.

b) Community type-approval legislation

In case of new engines/NRMM incentives must be compatible with the Community type-approval legislation, which provides for the mandatory technical requirements for new off-road engines and NRMM.

c) State aid rules

If the amounts of aid exceed certain ("de minimis") thresholds or the scheme does not meet the automatic conditions for compatibility with EU State aid rules under the block exemption regulation the scheme must be notified to the Commission. For example, if a Member State wishes to grant notifiable investment aid to certain undertakings for the purchase of new NRMM or a retrofitting device which go beyond or in the absence of NRMM specific EU standards, the scheme will have to comply with the requirements set out in the EU Guidelines on State aid for environmental protection. This includes making sure that the size of the incentive avoids overcompensation of additional costs of the cleaner engine or NRMM compared to a suitable, less environmentally friendly alternative.

d) Notification under Directive 98/34/EC

In accordance with Directive 98/34/EC, technical regulations have to be notified at a draft Stage. Technical regulations include so-called de facto technical regulations which are inter alia:

"technical specifications or other requirements or rules on services which are linked to fiscal or financial measures affecting the consumption of products or services by encouraging compliance with such technical specifications or other requirements or rules on services; technical specifications or other requirements or rules on services linked to national social security systems are not included." (third indent of the second subparagraph of point 11 of Article 1 of Directive 98/34/EC).

e) As they are linked to compliance with certain technical requirements (for example PM or NO_x emissions) financial incentives that are based on these requirements are de facto technical regulations within the meaning of the Directive thus triggering the obligation to notify such draft measures under Directive 98/34/EC. This notification will be treated in accordance with the procedure applicable under that Directive.

In addition to the mandatory principles mentioned above and in order to limit the fragmentation of the internal market and maximise the effectiveness of the financial incentives across the EU, it is highly recommended that Member States introducing these incentives also apply the recommended principles.

Moreover, incentives should not be limited to NRMM equipped with a specific power-train or auxiliary technology. This would be discriminatory with respect to other vehicles with the same environmental performance. Such an approach would leave room for granting financial stimulus to technologies or products selected on an arbitrary basis, create difficult definition problems and create an unlevelled playing field.

Finally, instead of technology-based criteria, there should be incentives for all NRMM with a desired environmental performance.

In order to ensure fair treatment of NRMMs with similar performance and to maximise the effectiveness of the incentives, it is also proposed that the incentive be proportional to the performance. It is recognised that the application of thresholds may be a way to provide sufficient transparency to the customer, but it is recommended to apply the steps in such a way that the difference between incentives above and below the threshold is limited and that the existing number of thresholds is sufficient to ensure an appropriate level of proportionality.

The level of incentive should not exceed the extra cost of the technology in order to reduce the risk that the incentive will be used to subsidise manufacturers. This means that financial incentives should not exceed the additional cost of technical equipment imported to comply with the relevant emission limit values, including the cost of installation on the equipment. As the retrofitting of the NRMM in use requires the installation of the technical device, the maximum limit also applies in this case.

Implemented thresholds for the financial incentives should take into consideration the PM and NO_x emission limits defined by the relevant EU legislations.

Recently, in February 2019 the Commission, DG ENV, reported to the EP on funding to reduce emissions in the transport sector and mentioned that, for the period between 2014 and 2020, €1.8 billion were allocated under the European Structural and Investment Fund to support air quality measures. Moreover, other indirect investment was provided through the low carbon economy, environmental protection, resource efficiency and the transport network infrastructure[198].

[198] In the current programming period 2014-2020, Member States have allocated EUR 1.8 billion to support air quality measures under the European Structural and Investment Funds. In addition, further indirect contributions potentially beneficial to clean air are expected to come from the 2014-2020 European

If the Commission aims at establishing an own incentive programme it could consider integrating measures into these Funds or take projects like cleaner mobility[199] or the NAIADES III programme as examples. Currently the European Union is Partner of the CLINSH (CLean INland SHipping) demonstration project which will assess the effectiveness of emissions control technology, alternative fuels and shoreside power systems. CLINSH was officially launched on 1 September 2016. Seventeen project partners have committed to investments totalling over € 8.5 million, with co-financing provided by the European Union's LIFE Programme.

15.3 Member States' measures

Financial support for NRMM retrofitting is extremely rare. At present, there does not appear to be a financial support programme for the retrofitting of NRMM in the Member States, apart from small incentives in the city of Berlin for the retrofitting of inner-city passenger ships. But there could also be other financial support, e.g. the "Berufsgenossenschaft Bau" in Germany co-finances the retrofitting of construction machinery with € 2000 in order to improve working conditions during construction work.

Germany supported inland waterway vessels, but the multi-year German support programme ends in 2018. The aim was to improve the environmental performance of engines, but not automatically with retrofitting devices. The support amounted to 22.50 €/kW[200]. Support for IWW was also given by Belgium and the Netherlands.

A new financial support system is under discussion in Germany but not decided yet. Industrial associations published their proposals which go far beyond the current programme[201]. The requested support per kW engine output is shown in Table 15-1.

Table 15-1 Financial support requested by German industrial associations for retrofitting measures

Engine power In kW	Active DPF in €/kW	Passive DPF in €/kW	SCR in €/kW	SCR and DPF in €/kW
100	140	115	200	300
150	130	105	135	205
300	115	95	110	190
400	105	85	95	180
500	100	80	70	170
750	90	75	50	135
900	85	70	45	110
1200	80	65	40	100

Financial support is also requested for water/emulsion technologies, see Table 15-2.

Table 15-2 Financial support requested by German industrial associations for water/emulsion technologies

Engine	100	150	200	300	400	500	600	800	1100	1400	1700	2000

Structural and Investment Funds' investments in the low-carbon economy (EUR 45 billion), environmental protection and resource efficiency (totalling EUR 63 billion) and network infrastructure (totalling EUR 58 billion), notably supporting vulnerable regions and citizens.

[199] 69 project proposals have been submitted requesting three times the available grant amount of EUR 350 million, for a total investment value of EUR 4.2 bn. Results are expected by October 2018. These investments will help promote cleaner transport in Europe, and thus further reduce emissions.

[200] In addition, a small financial support programme for inner-city passenger vessels has been launched recently in the City of Berlin.

[201] Binnenschifffahrt 03/2018

power in kW											
Support in €/kW	400	300	200	135	100	80	70	60	55	50	45	40

In addition, a fixed sum installation cost is requested for the main propulsion engine up to 299 kW of 50000 € and > 300 kW of 70000 €. For auxiliary engines the requested amount is 20000 €. For generator sets on vessels the requested fixed amount is up to 149 kW equal to 20000 €, for up to 299 kW equal to 30000 € and for >300 kW equal to 40000 €.

In Europe, there are around 10,000 inland vessels in Rhine countries, and more than 3,000 vessels in Danube countries[202]. Assuming an average power per vessel of 1000 kW and average financial support of 100 €/kW an EU wide support programme would cost about 13000 times 100000 = 1.3 billion €, just to give an order of magnitude estimate.

The retrofit capacities are limited, and often individual solutions are required so that a program should run for several years, if adopted.

The German UBA published a proposal on the retrofitting of railways. Based on costs of retrofitting with particulate filters of:

- < 560 kW about 20 to 30 k€
- > 560 kW about 40 to 50 k€

for locomotives and of about 25 k€ for railcars it proposed three-year support program covering about 1/3 of the investment costs. This proposal has not been implemented.

In total in the EU about 17000 railcars, 7000 shunting locomotives and 11000 mainline locomotives are in operation (Arcadis, 2009). Just to give an idea of the order of magnitude of costs: A retrofitting programme for all railcars for example would cost about 25000 € times 17000 equal to 425 million €.

15.4 Policy option "Financial incentives"

As mentioned above, financial incentive schemes are highlighted as a possible instrument in the Regulation[203]. Financial incentives could most likely be implemented somewhat faster than mandatory retrofit programmes, depending on internal institutional procedures. Such a measure could help to promote additional measures for national and local governments to establish more environmental zones for NRMM. In addition, the measure could contribute to the momentum of the implementation of measures that are highly influenced by the business plans of each competent authority, in particular its organisational capacity and the availability of the necessary financial resources.

Various EU and national funds are available for the preparation and implementation of national, regional and local air pollution control policies. However, financing projects to reduce air pollution usually competes with other societal challenges. In the operational programmes (OP's) for the major funding mechanisms (e.g. ERDF and Cohesion Fund), air quality is seen as an integrated measure with other priority areas (e.g. energy, waste, nature) rather than solely through air quality improvement priorities. This may be related to the lack of resources available to the regions to achieve mitigation measures, as the improvement of air quality may not have been prioritised in the OP's earmarked budgets.

Alternatively, the financing of the retrofitting of NRMMs could be offered if Member States provide certain co-financing. Such measures could be implemented by defining funding needs and assessing sources of funding and options for their integration.

[202] See: http://www.inland-navigation-market.org/en/rapports/2018/q2/5-fleet-2/
[203] Financial support for an accelerated introduction of Stage V NRMM is not considered here since the environmental impact would be most likely small and it is doubtful whether such a measure would result in additional Stage V NRMM purchases.

The general question whether a budget is available for retrofitting measures at EU level cannot be assessed. The current multiannual financial framework is being executed. It lasts until 2020. On 2.5.2018 the Commission proposed a budgetary plan for the period 2021 to 2027 (European Commission, 2018a) .

With regard to the sub-category NRE, for budgetary reasons, it seems impossible to provide financial support for the retrofitting of all NRMMs. If at all, only selected sub-areas or performance classes within these sub-areas could be funded in selected areas. In the light of the EP's reasoning, it would be useful to limit financial support to NRMM used in urban areas where the air quality limit value is exceeded. Moreover, it makes sense to limit the measure to NRMM actually used in urban areas, e.g. construction work machinery[204], in order to focus the support further.

It should be noted that the European Commission also supports inland waterway transport through various financing and funding programmes, such as the Connecting Europe Facility, Horizon 2020, the European Strategic Investment Fund and Cohesion Policy. A funding database provides an overview of the public funding available for inland waterway transport (European Commission, 2011)[205].

When discussing retrofitting for inland waterway vessels one should recall that the relevant associations had already very critical comments with regard to the limit values laid down in Regulation (EU) 2016/1628. DB (Bundesverband der deutschen Binnenschifffahrt e.V.) and VSM (Verband für Schifffahrt und Meerestechnik e.V.) highlighted in their position paper the high costs for the equipment and the running of after-treatment devices as well as safety aspects, drawing at the same time attention to small and medium size character of inland waterway operators which causes financing problems. The corresponding European associations[206] supported this view. These associations stressed also the technical difficulties to meet the limits adopted[207].

On the other hand, this industry seems now to be ready to retrofit if the financial support is sufficiently high. Support for IWW is being discussed at EU level as well as at the level of the Rhine Commission. Therefore, financial measures envisaged for this sector would have to be integrated into the larger scope of the Commissions' IWW policy.

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[204] The construction industry has also listed requirements with regard to retrofitting which mainly aim at obtaining financial support, avoiding additional requirements on engines already retrofitted and providing an EU level-playing field for such measures.

[205] The Commission White Paper of 28 March 2011, highlights the particular role to be played by railways and inland waterways in achieving climate targets. Given that the progress of those modes of transport compares unfavourably with that of other sectors in relation to improving air quality, the Commission and Member States' authorities, within their respective remits, should provide different ways of supporting innovation in emission technology so that the continuing increase in the volume of freight shifted to rail and inland waterways goes hand-in-hand with an improvement in air quality in Europe.

[206] European Skippers' Organisation (ESO-OEB), European Shippers Council (ESC), European Barge Union (EBU), European Federation for Inland Ports (EFIP), European Sea Ports Organisation (ESPO)

[207] "Looking at the nitrogen oxides reduction that should be realized with the Stage V standards and the reduction that LNG as a clean alternative fuel can maximally meet, there remains a gap. Stage V requires a reduction between 80 and 93% of nitrogen oxides for engine categories of 300 kW and higher, compared to the current CCRII standards. Several studies, a.o. by TNO show that meeting Stage V standards using LNG (dual or single fuel) is only feasible with after treatment systems (for NOx and PN) for this engine category. Besides, the Tier IV standards already require a reduction of approximately 75% of nitrogen oxides, compared to the current CCR2 standards.
This leads to the conclusion that LNG as a fuel alone would not be a sufficient solution for inland shipping to meet Stage V standards. After treatment systems would be necessary and in the highly competitive market of inland navigation it will be impossible for entrepreneurs to invest in both clean fuels and after treatment systems.
This would mean that adopting a Stage V emission standard contradicts current EU stimulating LNG policies. For example, in the Clean Power for Transport Package (alternative fuels infrastructure directive) and the TEN-T Regulation where requirement for core ports are laid down to have LNG bunker infrastructure facilities by 2025. Also the EU has invested in several LNG stimulating projects via EU subsidies. For inland shipping e.g. in the LNG Masterplan and for maritime shipping e.g. the Rotterdam-Gothenborg LNG connection.
De-stimulating the uptake of LNG in inland shipping will also negatively impact maritime shipping, looking at the chain effects and close connectivity between inland and maritime shipping. Not only for LNG as fuel, but as a result also as cargo."

Financial support should be given to the same power classes already identified in the chapter "Policy Options" as most appropriate.

Table 15-3 shows the advantages and disadvantages of financial incentives for NRE engines in urban areas where the air quality limit value is exceeded. The initiative should be left to the Member States, i.e. they should select the particular retrofit case and ensure co-financing. Financial support from the Commission might be granted if these cases comply with the general rules to be established for this programme.

Table 15-3 Pro/Con assessment of a financial support programme of the Commission co-financing Member State action on retrofitting NRE engines in polluted urban areas

Criterion/Measure	Financial incentive for retrofitting according to UNECE R 132	
	NRMM which comply the Recommendation proposed in chapter XIV receive financial EU support if co-financing of Member States is guaranteed	
	Pro	**Con**
Why? What is the problem being addressed?	Support to reduce Reduction of PM, NO_2 and BC emissions.	No comparable measure for road. No certified retrofitting system under UNECE R 132 available at short term.
What is this initiative expected to achieve?	Accelerated reduction of emissions in order to support air quality and climate protection measures of Member States	Reduction will happen anyway due to Stage IIIB/IV and Stage V limits and the turnover of existing fleets.
What is the value added of action at the EU level?	Helps to comply with air quality limit values and critical loads; Programme harmonises retrofitting activities for engines in the power range 56-560 kW.	PM and in particular NO_2 compliance measures of Member States concentrate on road transport. Forced measures would help harmonisation but harmonisation seems not to be needed since national, regional and local authorities are aware of UNECE R 132. Practical harmonisation is currently not needed since there are nearly no retrofitting activities in Member States.
What legislative and non-legislative policy options have been considered? Is there a preferred choice or not? Why?	EU financial support programme integrated in EU budget.	Administrative EU framework required.
Who supports which option?	Large parts of the EP and unknown number of Member States.	Parts of the EP and most likely some Member States which could not profit from the financial support.

What are the benefits of the preferred option (if any, otherwise main ones)?	Less pollution with beneficial effects for human health and the environment.	Cost/benefit of retrofitting differ for sub-categories and power classes.
What are the costs of the preferred option (if any, otherwise main ones)?	To be estimated	No cost/benefit analysis done, taking into account all possible measures to reduce PM, NO_2 and BC emissions. Only very few Member States, region or cities take such a measure. Repercussions on NRMM markets for new and second-hand machines have not been studied but might be significant.
Will there be significant impacts on national budgets and administrations? How will businesses, SMEs and micro-enterprises be affected?	Impact on national budgets. National administration needed for treating applications and for certification and surveillance. Most businesses (end-users) concerned are SME. SME's would have to bear costs in first place and would have to bear administrative procedures. Market prices for services offered by SME's might increase, depending on the support provided. Retrofitting firms are also SME's. They would benefit from retrofitting.	Administration and procedures for applications needed. Field surveillance of proper functioning necessary. Technical feasibility of NO_x retrofitting and in general Stage IIIB/IV retrofitting might require additional efforts. Safety aspects (visibility/heat) to be checked by technical services.
Will there be other significant impacts?	Harmonisation of retrofitting activities in the EU.	In the long run a harmonisation will most likely take place without EU intervention. Possible repercussions on NRMM approval under EU machine and safety regulations, no OEM warranty for retrofitted engines.
When will the policy be reviewed?	Programme time limited.	

Consideration should be given to integrating a Commission financial support programme proposed by DG GROW into DG ENV's air quality measures to support local actions.

EU financial incentives must, if desired, be given in an unbureaucratic form and be high enough to be effective. They should be linked in cases where Member States implement a national programme, as the existence of a national programme indicates the interest of Member States in such a measure. The EIB seems to be the most experienced EU institution in this respect. However, the actual granting must be in the hands of the Member States, as they can follow the correct implementation.

The size of the budget required can be estimated with simple assumptions: The financial incentive should not exceed 50% of the actual cost. If the average cost per retrofit is estimated at 5000 € and the number of engines to be retrofitted at one million, the total amount required would be 2.5 billion €, to be distributed over several years. This applies in the case of retrofitting of the NRE sub-sector.

Railcars [208] and inland waterway vessels [209][210] also contribute pollution problems in some cities. However, vehicles and vessels are also elsewhere so that this criterion make little sense for decision making. For railcars, locomotives and Inland waterway vessels financial incentives, if desired, must be given using more General criteria. On the other hand, the IWW industry seems now to be ready to retrofit or to repower vessels if the financial support is sufficiently high. Support for IWW is being discussed at EU level as well as at the level of the Rhine Commission. Therefore, financial measures envisaged for this sector would have to be integrated into the larger scope of the Commissions' IWW Policy.

As the cost-benefit analysis shows, IWW retrofitting is cost-effective, although the absolute reduction in emissions is quite small. However, replacing an old engine with a stage V engine is usually also cost-effective. So, the question is whether financial incentives should all focus on retrofitting. If the incentives were directed in this way, it could have a significant impact on the market for new Stage V engines, because the market is very small, and each individual retrofitted engine may replace or postpone a new purchase. Financial incentives should therefore apply to both, retrofitting and the purchase of a Stage 5 engine. The purchase of a new engine should only be subsidised if an old engine is scrapped.

The same applies to financial incentive schemes for locomotives. In the case of railcars, a programme could focus on retrofitting because there is no narrow market.

As in the case of NRE engines, financial incentive schemes should be set up in cooperation with Member States and Member States' contributions should at least be equal to or higher than those of the EU.

Overall, financial incentive programmes for IWW, locomotives and railcars make more sense than programmes for the NRE subcategory. They also require significantly fewer financial resources. The Commission should therefore continue the discussions in the relevant bodies in a targeted manner.

15.5Conclusions

- Financial incentives have to respect a number of aspects laid down in EU legislation, among other requests measures should be performance based and non-discriminatory in regard to both technologies used to achieve the performance level and equal access/opportunity for economic operators in any member state.
- Procedures and maximum incentive levels have to be well defined.
- For practical reasons implementation should be in hands of Member States.
- Retrofitting Inland water vessels is not a priority in many Member States. Most active are Germany, Belgium and The Netherlands which launched incentive programmes in the past.
- Experience shows that it is unlikely that retrofitting will take place in the IWW sector without financial support since costs are considered as too high by vessel owners.
- Currently, apart from a financial support programme for passenger vessels in Berlin and the CLINSH demonstration project of several project partners, including the European Union, no incentive programme for NRMM retrofitting is known.
- In the light of the non-existence of incentive programmes the effectiveness cannot be assessed.
- Financial incentives for retrofitting only might have a positive impact on retrofitting but a negative impact on the introduction of stage V.

[208] Some railcars operate at least partly in urban areas
[209] Some inland waterway vessels pass through cities located at rivers
[210] 'category IWP': (a) engines exclusively for use in inland waterway vessels, for their direct or indirect propulsion, or intended for their direct or indirect propulsion, having a reference power that is greater than or equal to 19 kW; (b) engines used in place of engines of category IWA provided that they comply with Article 24(8); and (6) 'category IWA': auxiliary engines exclusively for use in inland waterway vessels and having a reference power that is greater than or equal to 19 kW

- Overall, financial incentive programmes for IWW, locomotives and railcars make more sense than programmes for the NRE subcategory. They also require significantly fewer financial resources. The Commission should therefore continue the discussions in the relevant bodies in a targeted manner.

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Annex I: Questionnaire for Member States

I. Personal data

1) This questionnaire was answered by:
2) Name:
3) Organisation:
4) E-Mail address:
5) Phone:

II. Forced national, regional and local retrofit programmes[211]

1) In your country, is there national legislation which forces retrofitting?
2) If so, please give reference:
3) If so, please indicate categories of mobile machines which fall under the legislation:
4) If so, can retrofitting be avoided by usage of mobile machines which meet defined requirements?
5) If so, what are these requirements?
6) In your country, is there regional legislation which forces retrofitting?
7) If so, please indicate the region(s) and give reference(s):
8) If so, please indicate categories of mobile machines which fall under the legislation:
9) If so, can retrofitting be avoided by usage of mobile machines which meet defined requirements?
10) If so, what are these requirements?
11) In your country, is there local legislation which forces retrofitting?
12) If so, please indicate the local area(s) and give reference(s):
13) If so, please indicate categories of mobile machines which fall under the legislation:
14) If so, can retrofitting be avoided by usage of mobile machines which meet defined requirements?
15) If so, what are these requirements?
16) If retrofitting programmes exists at national, regional or local level, what administrative and institutional steps have been taken in order implement, enforce and monitor the programme?
17) Are you aware of any planned retrofitting programmes in your country?
18) If so, please give details.

III. Financial support for retrofitting[212]

1) In your country, is there national legislation which supports retrofitting financially?
2) If so, please give reference(s):
3) If so, please indicate categories of mobile machines which enjoy financial support:
4) If so, please indicate annual budget volume and duration of programme:
5) In your country, is there regional legislation which supports retrofitting financially?
6) If so, please indicate categories of mobile machines which enjoy financial support:
7) If so, please indicate the region(s) and give reference(s):
8) If so, please indicate annual budget volume and duration of programme:
9) In your country, is there local legislation which supports retrofitting financially?
10) If so, please indicate categories of mobile machines which enjoy financial support:
11) If so, please indicate annual budget volume and duration of programme:
12) If so, please indicate the local area(s) and give reference(s):
13) If financial support for retrofitting is provided at national, regional or local level, what administrative and institutional steps have been taken in order implement, enforce and monitor the support programme?
14) Are you aware of any planned financial support programmes for retrofitting NRMM in your country?
15) If so, please give details.

IV. Certification of retrofitting devices[213]

[211,2,3] In case of more than one region or local area, please copy the sheet and provide one sheet for each region or local area

1) In your country, does national legislation require certification of retrofitting devices level?
2) If so, what kind of certification system is applied? Please give reference(s):
3) In your country, does regional legislation require certification of retrofitting devices?
4) If so, what kind of certification system is applied? Please give reference(s):
5) In your country, does local legislation require certification of retrofitting devices?
6) If so, what kind of certification system is applied? Please give reference(s):
7) If the certification systems applied in your country differs from UNECE R 132, please explain why you do not make use of R 132:
8) If the certification system applied in your country is UNECE R 132, please explain the steps taken in your country to implement R 132:

V. Confidentiality

The person listed under I agrees that the answers provided to the questions listed under points II to IV are used in a general form in the reports drafted as part of the study the study "Technical support for the review obligations under Regulation (EU) 2016/1628 (NRMM)".

Date:
Signature:

Annex II: Answers to questionnaire

Member State	Forced national, regional and local retrofit programmes	Financial support for retrofitting	Certification of retrofitting devices	Details of the answer
Austria				
Belgium	NO	NO	NO	In the Flemish region the "ecology premium" financial support programme can be applied for diesel particle filter for non-road mobile machinery with the exception of lawnmowers and fork and scissor lifts with a power <37 kW and Selective Catalytic Reduction System (SCR) for non-road mobile machinery with the exception of lawnmowers and fork and scissor lifts with a power <37 kW.
Bulgaria				
Croatia				
Cyprus	NO	NO	NO	
Czechia				
Denmark	NO	NO	NO	See comments in text of this chapter.
Estonia	NO	NO	YES	Modifications to the engines are permitted if new emissions are approved in accordance with the relevant emissions legislation. There are no certification requirements for retrofitting devices.
Finland	NO	NO	YES	Certification in accordance with UNECE R 132 possible.
France				
Germany	YES	For IWW	YES	See comments in text of this chapter.
Greece				
Hungary	NO	NO	YES	Retrofitting is not obligatory but national legislation allows retrofitting. UNECE R 132 is not mandatory but retrofitting devices must be approved.
Ireland				
Italy	NO	NO	YES	Certification in accordance with UNECE R 132 possible, if requested by the manufacturer.
Latvia				
Lithuania	NO	NO	YES	Certification in accordance with UNECE R 132 possible.
Luxembourg	NO	NO	YES	Retrofitting considered but not decided yet. Certification in accordance with UNECE R 132 or national legislation required.
Malta				
Netherlands				
Poland	NO	NO	NO	A few retrofitting activities take place in the mining industry.
Portugal	NO	NO	NO	
Romania	NO	NO	YES	Romania intends to introduce UNECE R 132 in national legislation in 2019.
Slovakia	NO	NO	NO	
Slovenia				
Spain				
Sweden	NO	NO	YES	See comments in text of this chapter.
United Kingdom	NO	NO	YES	See comments in text of this chapter.

Annex III: Example of Commission Recommendations

Example

Commission Recommendations with regard to the retrofitting of 'Non-Road Mobile Machinery'

I. Introduction

Emissions of 'gaseous pollutants' and 'particulate matter' of 'non-road mobile machinery' ('NRMM') contribute to 'ambient air' pollution problems, in particular with regard to the 'pollutants' 'particulate matter' and nitrogen dioxide. Although 'NRMM' emission limit values have been tightened in several steps in the last about 20 years, a number of Member States, States and in particular cities within Member States have taken measures aiming at accelerating the emission reduction. These measures focus on the emissions of 'particulate matter' since these contribute to 'PM_{10}' and '$PM_{2.5}$' pollution. As a rule, the measures require to use either within defined 'zones' 'NRMM' which meet specific emission limit value stages or which are retrofitted with a certified system. The measures focus on 'NRE engines' used within- the defined 'zones', often taken on initiative of the local level since this level has been identified to be in most of the cases as best placed to design 'air quality plans'.

Although no such measures have been taken yet at national, state or local level with regard to nitrogen dioxide (NO_2) pollution, it is not unlikely that this might be the case in near future as well since the NO_2 'ambient air' 'limit values' as well as 'critical levels' are exceeded and 'selective catalytic reduction (SCR)' 'exhaust after-treatment systems' are available.

It is obvious that from all 'NRMM' mainly those equipped with 'NRE engines' increase PM and or NO_x pollution cities. For example, in the direct vicinity of 'construction sites' by up to several µg/m^3 an order of magnitude that might contribute to exceedances of the relevant 'limit values' or 'target values' in 'zones'. Moreover, other 'NRE engines' used in 'zones' make also a contribution.

Cost benefit calculations for EU 28 show that the benefits of retrofitting existing 'NRE engines' are in many cases not higher than the associated costs. However, the cost/benefit situation might look different for individual regional or local cases. Moreover, in many zones all possible measures have to be taken in order to comply with 'ambient air' 'limit values', irrespective of cost/benefit considerations.

Against this background, special emission measures for 'NRE engines' aiming at reducing PM and/or NO_2 pollution in relevant zones, in particular through the use of 'exhaust after-treatment systems' on existing 'NRMM' are justified in certain cases. 'NRE engines' which power IWW vessels and railcars, however, should be excluded since these emit, as a rule, only a small part of their total emissions in the 'zones'.

Retrofitting existing 'NRMM' which are already equipped with a 'exhaust after-treatment systems' at the point of time of 'type-approval' is more complex and more costly. Moreover, the PM and NO_x emissions from NRE engines are quantitatively not as relevant as the emissions from road traffic. Therefore, it is justified allowing at the choice of the machine owner - as an alternative to retrofitting - the use of low-emission 'NRMM' already complying with the lowest mandated EU emission levels for new machinery.

Overall, the biggest overall reduction in emissions from non-road mobile machinery could be obtained by increased use of the latest Stage V engines. Consequently, any recommendations should support, and not undermine or hinder, the greater use of non-road mobile machinery fitted with stage V engines.

II. Scope

The objective of these Recommendations is to provide guidelines to Member States, State and local authorities for national, regional or local low emission zones applied to non-road mobile machinery ('NRMM'). If applied the Recommendations provide an EU-wide step toward the harmonisation of such measures. This results in cost savings with regards to the development and certification of exhaust after-treatment systems. Moreover, it improves the planning security for 'NRMM' 'end-users' as well as for builders and operators of relevant works.

The Recommendations are valid for 'NRE engines' retrofitting measures since these are of greatest relevance for air pollution and are also in the focus of Member States' measures.

III. Definitions

Since this Recommendation is linked to a number of other legal acts it is necessary to clarify terms used in this Recommendation on the basis of definitions used in these acts.
The following definitions laid down in Regulation (EU) 2016/1628 are used:

'CI engine' means an engine that works on the compression-ignition ('CI') principle;
'constant-speed engine' means an engine the EU type-approval of which is limited to constant-speed operation, excluding engines the constant-speed governor function of which is removed or disabled; it may be provided with an idle speed that can be used during start-up or shut-down and it may be equipped with a governor that can be set to an alternative speed when the engine is stopped;

'end-user' means any natural or legal person, other than the manufacturer, OEM, importer or distributor, that is responsible for operating the engine installed in non-road mobile machinery;

'exhaust after-treatment system' means a catalyst, particulate filter, deNO_x system, combined deNO_x particulate filter or any other emission-reducing device, with the exception of exhaust gas recirculation and turbochargers, that is part of the emission control system but is installed downstream of the engine exhaust ports;

'gaseous pollutants' means the following pollutants in their gaseous state emitted by an engine: carbon monoxide (CO), total hydrocarbons (HC) and oxides of nitrogen (NO_x); NO_x being nitric oxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2 equivalent;

'national authority' means an approval authority or any other authority involved in and responsible for, in respect of engines to be installed in non-road mobile machinery or of non-road mobile machinery in which engines are installed, market surveillance, border control or the placing on the market in a Member State;

'non-road mobile machinery' means any mobile machine, transportable equipment or vehicle with or without bodywork or wheels, not intended for the transport of passengers or goods on roads, and includes machinery installed on the chassis of vehicles intended for the transport of passengers or goods on roads;

'NRE engines' means (a) engines for non-road mobile machinery intended and suited to move, or to be moved, by road or otherwise, that are not excluded under Article 2(2) of Regulation (EU) 2016/1628 and are not included in any other category set out in points (2) to (10) of Article 4 (1) of Regulation 2016/1628;

'particulate matter' or 'PM' means the mass of any material in the gas emitted by an engine that is collected on a specified filter medium after diluting the gas with clean filtered air so that the temperature does not exceed 325 K (52 °C);

'reference power' means the net power that is used to determine the applicable emission limit values for the engine;

'technical service' means an organisation or body designated by the approval authority as a testing laboratory to carry out tests, or as a conformity assessment body to carry out the initial assessment and other tests or inspections, on behalf of the approval authority, or the authority itself when carrying out those functions;

'variable-speed engine' means an engine that is not a constant-speed engine.

The following definitions laid down in Regulation UNECE R 132 are used:

'Class I Retrofit Emission Control device (REC)' means a retrofit emission control device which is intended to control particulate matter emissions only, and which does not increase the direct NO_2 emissions;

'Class III Retrofit Emission Control device (REC)' means a retrofit emission control device which is intended to control NO_x emissions only;

'Class IV Retrofit Emission Control device (REC)' means a retrofit emission control device which is intended to control both particulate matter emissions and NO_x emissions;

‘DeNO$_x$ system’ means an exhaust after treatment system designed to reduce emissions of oxides of nitrogen (NO$_x$) (for example, passive and active lean NO$_x$ catalysts, NO$_x$ absorbers, and selective catalytic reduction (SCR) systems);

‘Particulate reduction REC’ means a REC that has a particulate mass or particle number emission reduction efficiency which qualifies it to be certified as meeting the classification class as defined in this Regulation. The regeneration system and strategy are part of the particulate reduction REC;

‘Reduction efficiency’ means the ratio between the emissions downstream of the REC system (EREC) and the engine baseline emissions (EBase) and both measured in accordance with the procedures defined in this Regulation and calculated as defined in paragraph 8.3.4 of this Regulation;

‘Reduction level’ means a reduction efficiency in per cent to be met by the retrofit emission control device (REC) in order to be certified as meeting the reduction level specified in paragraph 8.3 of this Regulation.

‘Retrofit Emission Control device (REC)’ means any particulate reduction system, NO$_x$-reduction system or combination of both which is used for retrofit purposes. This includes any sensors and software essential to the operation of the device. Systems that only modify the existing engine system controls are not considered to be REC.

The following definitions laid down in Directive 2008/50/EC are used:

‘ambient air’ shall mean outdoor air in the troposphere, excluding workplaces as defined by Directive 89/654/EEC where provisions concerning health and safety at work apply and to which members of the public do not have regular access;

‘air quality plans’ shall mean plans that set out measures in order to attain the limit values or target values;

‘critical level’ shall mean a level fixed on the basis of scientific knowledge, above which direct adverse effects may occur on some receptors, such as trees, other plants or natural ecosystems but not on humans;

‘limit value’ shall mean a level fixed on the basis of scientific knowledge, with the aim of avoiding, preventing or reducing harmful effects on human health and/or the environment as a whole, to be attained within a given period and not to be exceeded once attained;

‘PM$_{2,5}$’ shall mean particulate matter which passes through a size-selective inlet as defined in the reference method for the sampling and measurement of PM$_{2,5}$, EN 14907, with a 50 % efficiency cut-off at 2,5 μm aerodynamic diameter;

‘pollutant’ shall mean any substance present in ambient air and likely to have harmful effects on human health and/or the environment as a whole;

‘target value’ shall mean a level fixed with the aim of avoiding, preventing or reducing harmful effects on human health and/or the environment as a whole, to be attained where possible over a given period;

‘zone’ shall mean part of the territory of a Member State, as delimited by that Member State for the purposes of air quality assessment and management;

The following definitions laid down in Directive 97/68/EC are used:

‘approval authority’ shall mean a Member State's competent authority or authorities responsible for all aspects of type-approval of an engine or of an engine family, for issuing and withdrawing approval certificates, for serving as the contact point with the approval authorities of the other Member States, and for verifying the manufacturer's conformity of production arrangements;

‘information document’ shall mean the document set out in *Annex II of Directive 97/68/EC* that prescribes the information to be supplied by an applicant;

‘technical service’ shall mean the organization(s) or body(ies) that has(have) been appointed as a testing laboratory to carry out tests or inspections on behalf of the approval authority of a Member State. This function may also be carried out by the approval authority itself;

‘type approval’ shall mean the procedure whereby a Member State certifies that an internal combustion engine type or engine family with regard to the level of emissions of gaseous and particulate pollutants by the engine(s), satisfies the relevant technical requirements of this Directive

IV. General recommendation on emission requirements for ‘NRMM’ equipped with ‘NRE engines’ in ‘zones’ with high ‘PM_{10}’ and ‘$PM_{2.5}$’ concentrations in ‘ambient air’

It is recommended to require the following in defined ‘zones’ with high ‘PM_{10}’ and ‘$PM_{2.5}$’ concentrations in ‘ambient air’. Both options should be permitted as alternatives:

‘CI engine’ (‘variable speed engine’ and ‘constant speed engine’[2]) 19 kW ≤ P < 560 kW Power Class, expressed as ’reference power‘
Option 1. Use of non-road mobile machinery fitted with an engine either type-approved according to Directive 97/68/EC emission level Stage IIIB (variable speed engine categories L to P) [1] or Stage IV (variable speed engine sub-categories Q or R)[1] or type-approved according to Regulation (EU) 2016/1628 emission level Stage V (variable and constant speed engine sub-categories NRE)[1]. The emission level is confirmed by the marking affixed to the engine.
Option 2. Use of non-road mobile machinery fitted with an engine type-approved at a minimum to Directive 97/68/EC, emission level Stage I (engine category A to C[1] or Stage II (engine categories E to D (>19 kW))[1] or IIIA (engine sub-categories H to K[1] equipped with a ‘Particulate reduction REC’ as defined as ‘Class I Retrofit Emission Control device (REC)’ in order to achieve both the defined ‘Reduction level’ and a PM level not exceeding that of Stage IIIB, IV or V as applicable to match the corresponding engine category in option 1. In the case of a Particulate reduction REC to meet Stage V it shall additionally comply with the requirements set out Annex 13 in supplement 1 to the 01 series of amendments of UNECE Regulation R 132.

[1] Engines produced to the same emission levels type-approved to either Directive 2000/25/EC, Regulation (EU) 2015/96, or Regulation (EU) 2018/985, or alternatively type-approved to an equivalent regulation recognised by Directive 97/68/EC, Regulation (EU) 2015/96 or Regulation (EU) 2017/654 should also be permitted.

[2] Application to constant speed engines and engines in the power range 19-37 kW based upon implementation according to the timing set out in section XIV and exemption scheme set out in section IX.

V. General recommendation on emission requirements for ‘NRMM’ equipped with ‘NRE engines’ in ‘zones’ with high nitrogen dioxide (NO_2) concentrations in ‘ambient air’

It is recommended to require the following in defined ‘zones’ with high nitrogen dioxide pollution in ‘ambient air’:

‘CI engine’ (‘variable speed engine’ and ‘constant speed engine’[2]) 19 kW ≤ P < 560 kW Power Class, expressed as ’reference power‘
Option 1. Use of non-road mobile machinery fitted with an engine type-approved according to Directive 97/68/EC emission level Stage IIIB (variable speed engine categories L to P)[1] or IV (variable speed engine sub-categories Q or R)[1] or type-approved according to Regulation (EU) 2016/1628 emission level Stage V (variable and constant speed engine sub-categories NRE)[1]. The emission level is confirmed by the marking affixed to the engine.
Option 2. Use of non-road mobile machinery fitted with an engine type-approved at a minimum to Directive 97/68/EC, emission level Stage I (engine category A to C[1] or Stage II (engine categories E to D(>19 kW))[1] or IIIA (engine sub-categories H to K[1] equipped with a ‘$DeNO_x$ system’ as defined as ‘Class III Retrofit Emission Control device (REC)’ in order to achieve both the defined ‘Reduction level’ and a NO_x level not exceeding that of Stage IIIB, IV or V as applicable to match the engine categories in option 1. In the case of a Class III REC to meet Stage V it shall additionally comply with the requirements set out Annex 13 in supplement 1 to the 01 series of amendments of UNECE Regulation R 132.

[1] Engines produced to the same emission levels type-approved to either Directive 2000/25/EC, Regulation (EU) 2015/96, or Regulation (EU) 2018/985, or alternatively type-approved to an equivalent regulation recognised by Directive 97/68/EC, Regulation (EU) 2015/96 or Regulation (EU) 2017/654 should also be permitted.

[2] Application to constant speed engines and engines in the power range 19-37 kW based upon implementation according to the timing set out in section XIV and exemption scheme set out in section IX.

VI. General recommendation on emission requirements for ‘NRMM’ equipped with ‘NRE engines’ in ‘zones’ with high ‘PM_{10}’ and ‘$PM_{2.5}$’ and high nitrogen dioxide (NO_2) concentrations in ‘ambient air’

It is recommended to require the following in defined ‘zones’ with high nitrogen dioxide and high PM_{10}’ and ‘$PM_{2.5}$’ concentrations in ‘ambient air’:

‘CI engine’ (‘variable speed engine’ and ‘constant speed engine’[2]) 19 kW ≤ P < 560 kW Power Class, expressed as ’reference power‘
Option 1. Use of non-road mobile machinery fitted with an engine type-approved according to Directive 97/68/EC emission level Stage IIIB (variable speed engine categories L to P)[1] or Stage IV (variable speed engine sub-categories Q or R)[1] or type-approved according to Regulation (EU) 2016/1628 emission level Stage V (variable and constant speed engine sub-categories NRE)[1]. The emission level is confirmed by the marking affixed to the engine.
Option 2. Use of non-road mobile machinery fitted with an engine type-approved at a minimum to Directive 97/68/EC, emission level Stage I (engine category A to C[1] or Stage II (engine categories E to D (>19 kW))[1] or IIIA (engine sub-categories H to K[1] equipped with a combined ‘Particulate reduction REC’ and a ‘$DeNO_x$ system’ as defined as ‘Class IV Retrofit Emission Control device (REC)’ in order to achieve both the defined ‘Reduction level’ and both NO_x and PM levels not exceeding that of Stage IIIB, IV or V as applicable to match the engine categories in option 1. In the case of a Class IV REC to meet Stage V it shall additionally comply with the requirements set out Annex 13 in supplement 1 to the 01 series of amendments of UNECE Regulation R 132.

[1] Engines produced to the same emission levels type-approved to Directive 2000/25 /EC, Regulation (EU) 2015/96, or Regulation (EU) 2018/985 or alternatively type-approved to an equivalent regulation recognised by Directive 97/68/EC, Regulation (EU) 2015/96 or Regulation (EU) 2017/654 should also be permitted.

[2] Application to constant speed engines and engines in the power range 19-37 kW based upon implementation according to the timing set out in section XIV and exemption scheme set out in section IX.

VII. General recommendation on after-treatment devices

It is recommended that the certification of the ‘Retrofit Emission Control device (REC)’ should take place in accordance with UNECE Regulation No. 132 ("Regulation No 132 of the Economic Commission for Europe of the United Nations (UNECE) — Uniform provisions concerning the approval of Retrofit Emission Control devices (REC) for heavy duty vehicles, agricultural and forestry tractors and non-road mobile machinery equipped with compression ignition engines [2018/630]"). Additional verification measures are allowed, if necessary, but shall be of no relevance for the certification as such.

VIII. Installation

It is recommended that the National authorities concerned require that installation of a retrofit device complies with sections 18, 19 and 20 of UNECE Regulation R 132 and require installation and operating instructions according to Annex II of that Regulation.

IX. Exemptions

It is proposed that a specific ‘NRMM’ equipped with an ‘exhaust after-treatment system’ which has already been certificated by a ‘technical service’ and installed on that specific non-road mobile machine before the date of publication of this Recommendation can be used without further restrictions.

It is proposed that an exception to the requirements in sections IV, V and VI above can be granted at national, State or local level, for an individual NRMM, if a proof is submitted by a ‘technical service’ which shows that the retrofitting of the ‘NRMM’ in question is not possible for technical reasons. In that case the application for an exception should be made within one year after the date of announcement of zones at national, state or local level and be valid for a maximum period of two years. Exceptions for the use of ‘NRE engines’ in defined ‘zones’ are to be limited to a minimum.

X. Documentation

It is proposed that European Commission add a facility to the IMI data bank mentioned in Article 44 of Regulation (EU) 2016/1628, so that ‘National authorities’ of Member States can insert defined data on ‘Retrofit Emission Control device (REC)’ certified in accordance with UNECE R 132 into that IMI data bank as a means to facilitate sharing of information and avoid the need for duplication of records at national, State or local level. The recorded information should include, at a minimum, the following information on the retrofit emission control device:

(a) The type-approval number granted according to Regulation R 132
(b) The application range, including the non-road engine category(ies) to which the device can be applied, according to its type-approval

For the ‘NRMM’ used in defined ‘zones’ the emission level of the engine can be ascertained from the marking affixed to the engine. In the case of a retrofitted engine this can be ascertained from a combination of the marking affixed to the engine and that affixed to the retrofit emission control device. Where those markings cannot be identified the operator should contact the manufacturer, importer or distributor for replacement markings or other documentation attesting to the emission level of the engine and, where applicable, retrofit emission control device.

XI. Information policy

It is proposed that Member States, States and/or local authorities publish, in advance of implementing these Recommendations, guidance in which the measures are explained as well as the administrative and legal repercussions and consequences for the ‘end-user’ of ‘NRMM’.

XII. Legal provisions, institutional provisions and surveillance

Member States, States or local authorities should lay down, if necessary, legal provision on the use of ‘NRMM’ equipped with ‘NRE engines’ in defined ‘zones’ in order to ensure legal clarity.
Member States, States or local authorities should establish, if not already done, the institutions necessary for the administrative implementation and enforcement of the legal provisions. It is recommended to publish guidance for the surveillance.

Member States, States or local authorities should ensure surveillance of the application of the legal provisions.

XIII. Penalties

It is recommended that Member States, States or local authorities lay down, if needed, legal provisions on penalties associated with non-compliance with the legal provisions.

XIV. Timing

It is recommended that Member States, States and/or local authorities ensure a minimum of two years between announcing within which zones these requirements will apply and the date from which these requirements will be enforced in those zones.

NRMM equipped with constant speed engines or with variable speed engines in the power class 19 to 37 kW should get one extra year for retrofitting since there are no stage IIIB/IV engines on the market.

In the period between the publication of this Recommendation and its application it is recommended that Member States, States or local authorities encourage ‘end-users’ which plan to retrofit ‘NRE engines’ to apply exclusively the provisions of UNECE R 132 for the certification process.

XV. Incentives

Member States, States and/or local authorities are encouraged to offer incentives which are complying with EU legislation in order to accelerate the introduction of ‘NRMM’ equipped with Stage V engines and installation of retrofit emission control devices achieving a level of reduction in both NO_x and PM corresponding to Stage V for the respective engine power category.

Definition of UNECE categories:

Categories	Net Power kW
Stage I	
A	130 ≤ P ≤ 560
B	75 ≤ P < 130
C	37 ≤ P < 75
Stage II	
E	130 ≤ P ≤ 560
F	75 ≤ P < 130
G	37 ≤ P < 75
D	18 ≤ P < 37
Stage IIIA	
H	130 ≤ P ≤ 560
I	75 ≤ P < 130
J	37 ≤ P < 75
K	19 ≤ P < 37
Stage IIIB	
L	130 ≤ P ≤ 560
M	75 ≤ P < 130
N	56 ≤ P < 75
P	37 ≤ P < 56
Stage IV	
Q	130 ≤ P ≤ 560
R	56 ≤ P < 130

Annex IV: Total costs figures

Agriculture and Construction

The following figures (Figure IV - 1, Figure IV - 2 and Figure IV - 3) present the total costs in M€ for each retrofitting technology. A parametric analysis was performed by assigning low and high values for the costs of retrofitting. The costs are calculated per power class and per emission Stage.

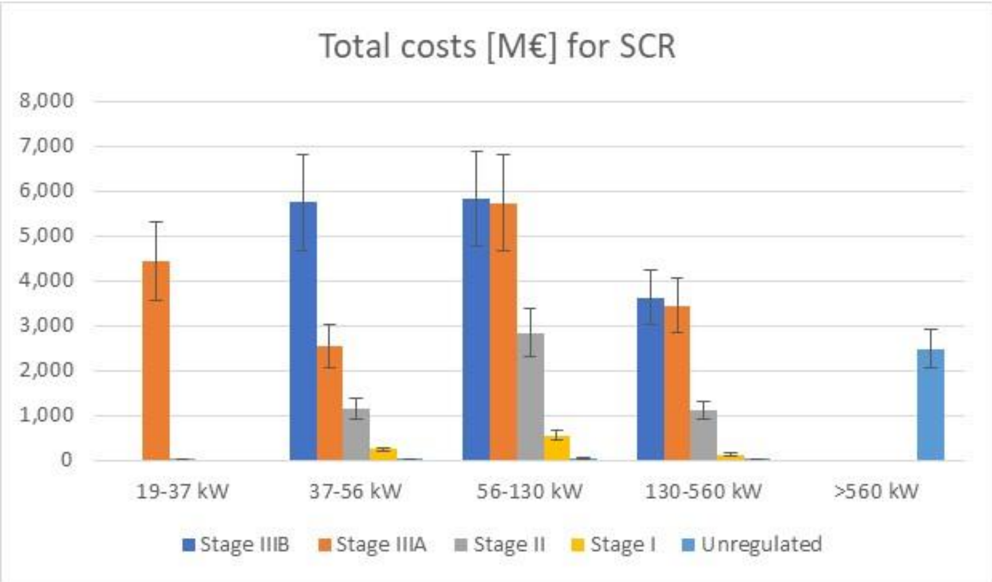

Figure IV - 1 Total costs for agriculture/construction sector for SCR retrofitting

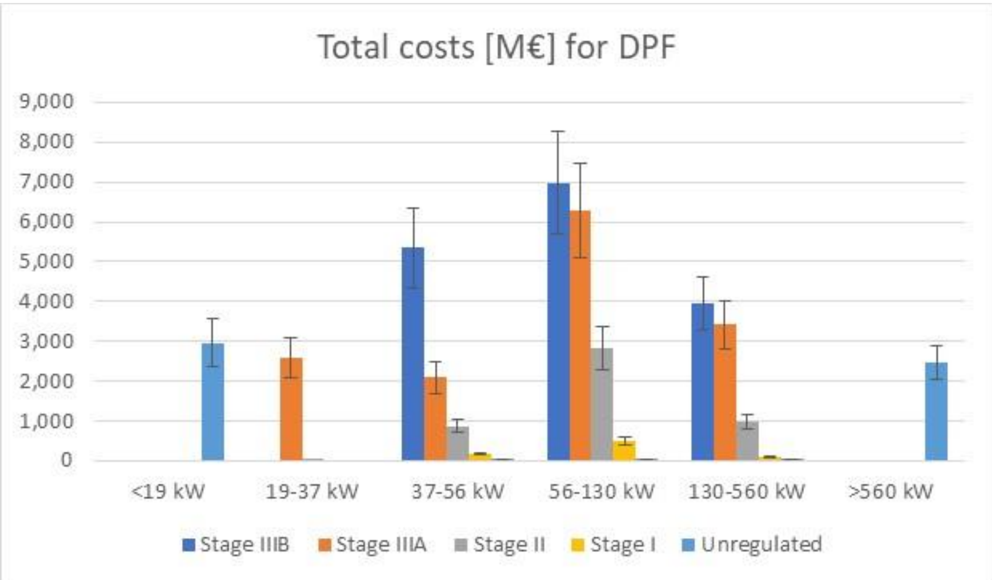

Figure IV - 2 Total costs for agriculture/construction sector for DPF retrofitting

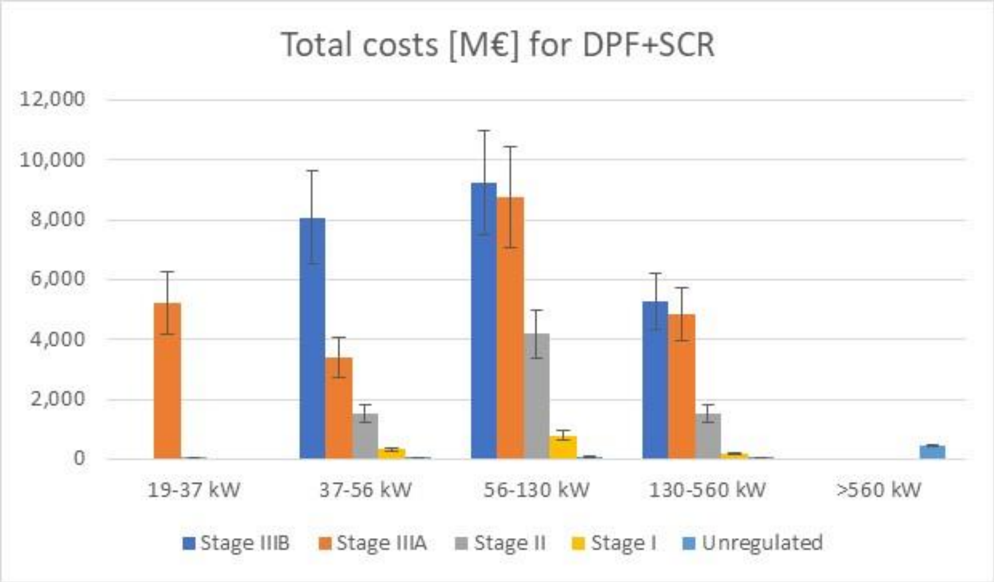

Figure IV - 3 Total costs for agriculture/construction for DPF+SCR retrofitting

Inland Waterways and Railways

The following figures (Figure IV - 4, Figure IV - 5 and Figure IV - 6) present the total costs in M€ for each retrofitting technology. A parametric analysis was performed by assigning low and high values for the costs of retrofitting. The costs are calculated per emission Stage.

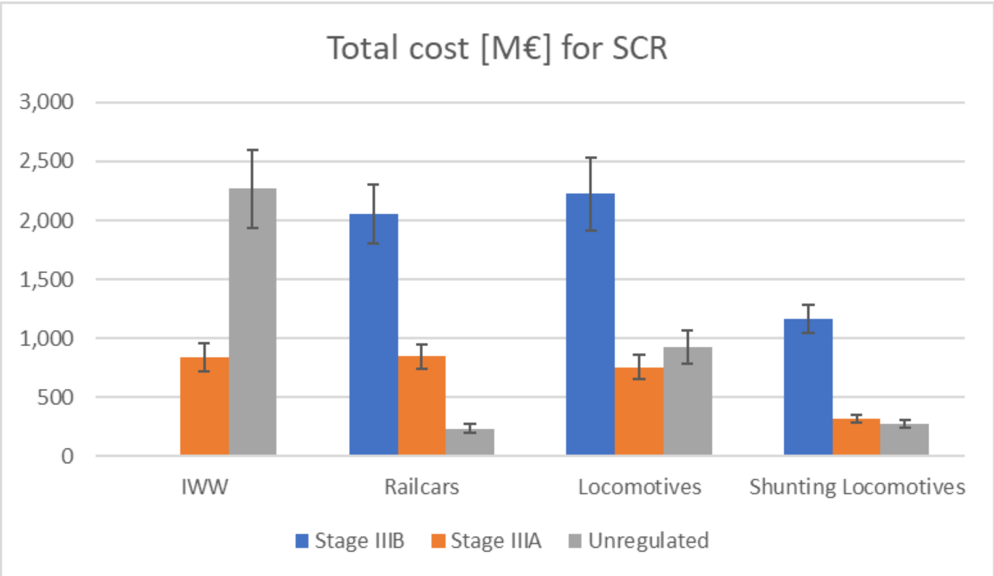

Figure IV - 4 Total costs for inland waterways and railways for SCR retrofitting

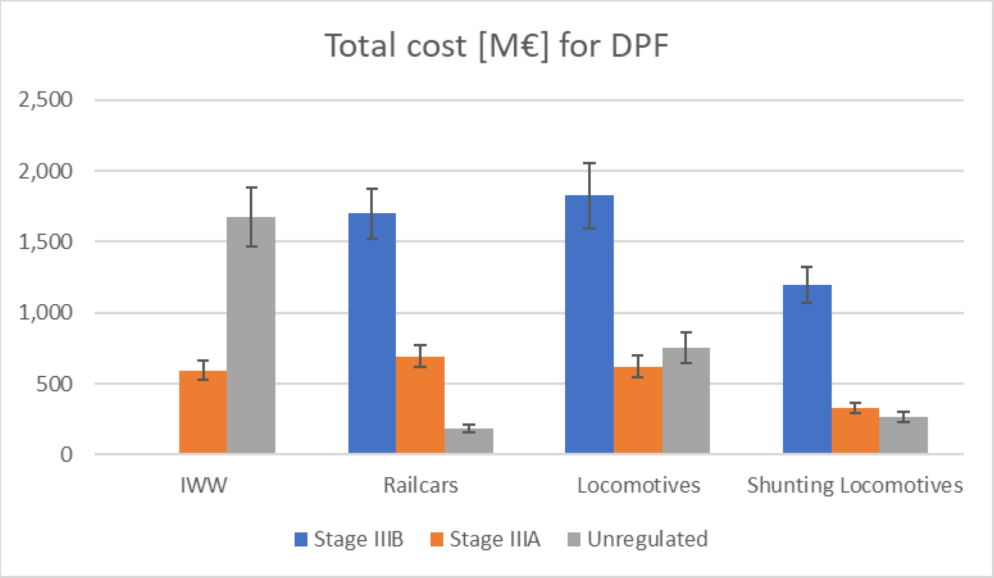

Figure IV - 5 Total costs for inland waterways and railways for DPF retrofitting

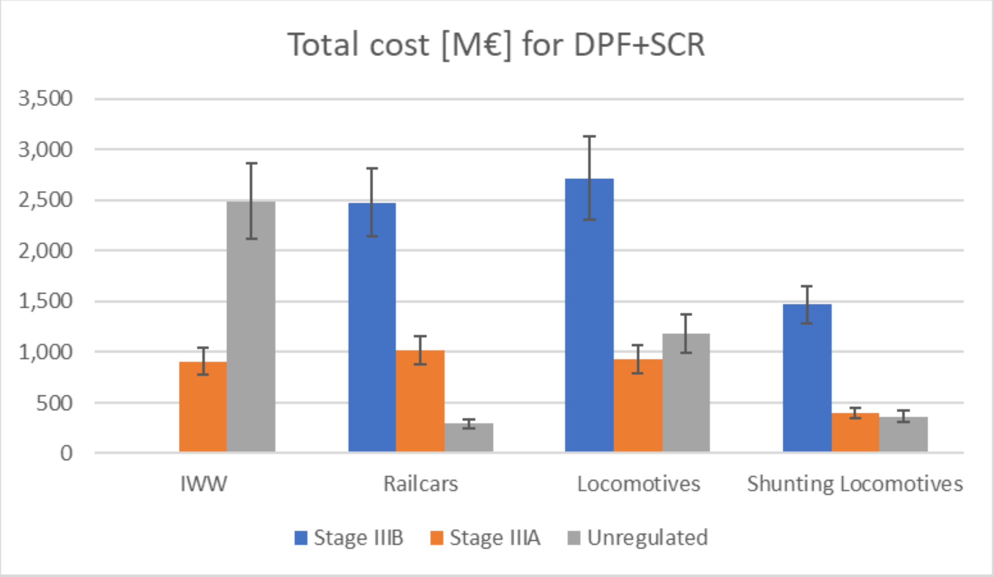

Figure IV - 6 Total costs for inland waterways and railways for DPF+SCR retrofitting

Annex V: Cost-effectiveness figures

Agriculture and Construction

The following figures (Figure V - 1, Figure V - 2, Figure V - 3 and Figure V - 4) present the cost-effectiveness in €/kg pollutant for each retrofitting technology and for each pollutant. The cost-effectiveness results (i.e. costs required per kilogram of pollutant emissions saved) are calculated per power class and per emission Stage.

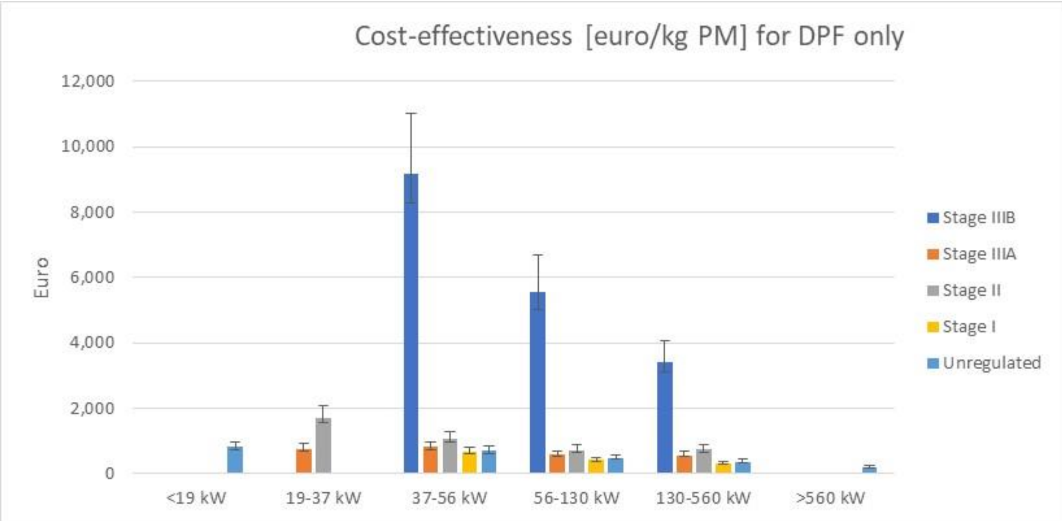

Figure V - 1 Cost effectiveness for agriculture/construction for PM for DPF retrofit

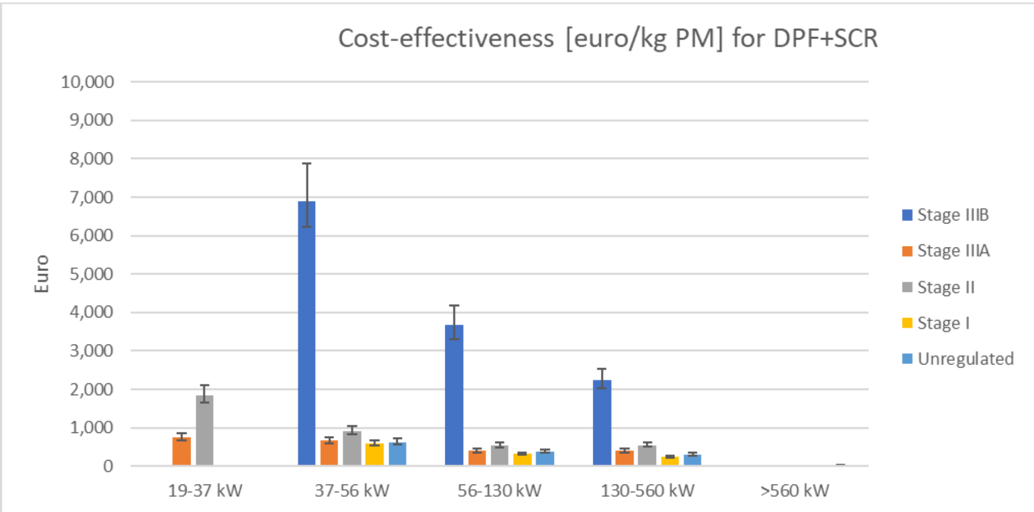

Figure V - 2 Cost effectiveness for agriculture/construction for PM for DPF+SCR retrofit

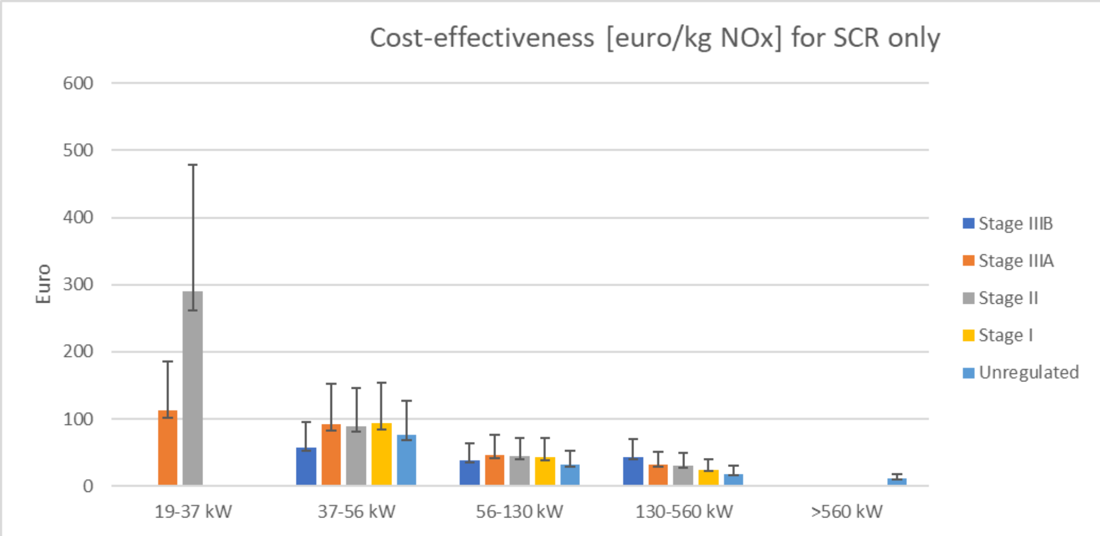

Figure V - 3 Cost effectiveness for agriculture/construction for NO_x for SCR retrofit

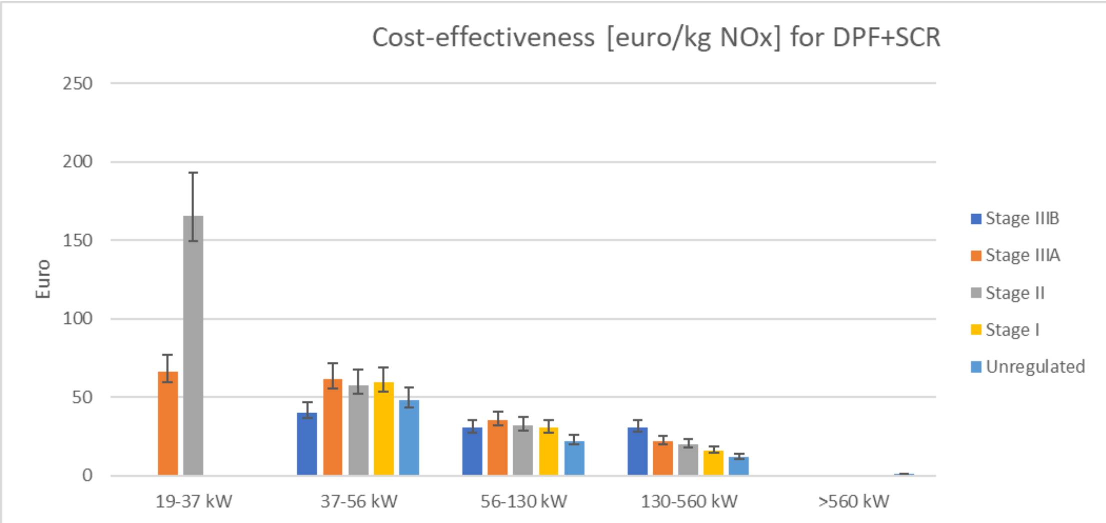

Figure V - 4 Cost effectiveness for agriculture/construction for NO_x for DPF+SCR retrofit

Inland Waterways and Railways

The following figures (Figure V - 5, Figure V - 6, Figure V - 7 and Figure V - 8) present the cost-effectiveness in €/kg pollutant for each retrofitting technology and for each pollutant. The cost-effectiveness results (i.e. costs required per kilogram of pollutant emissions saved) are calculated per power class and per emission Stage.

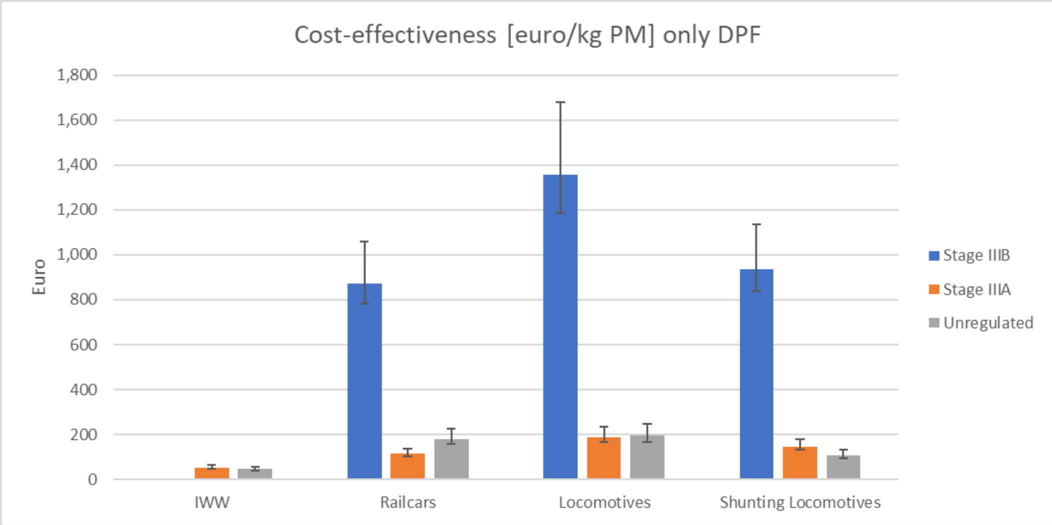

Figure V - 5 Cost effectiveness for inland waterways and railways for PM for DPF retrofit

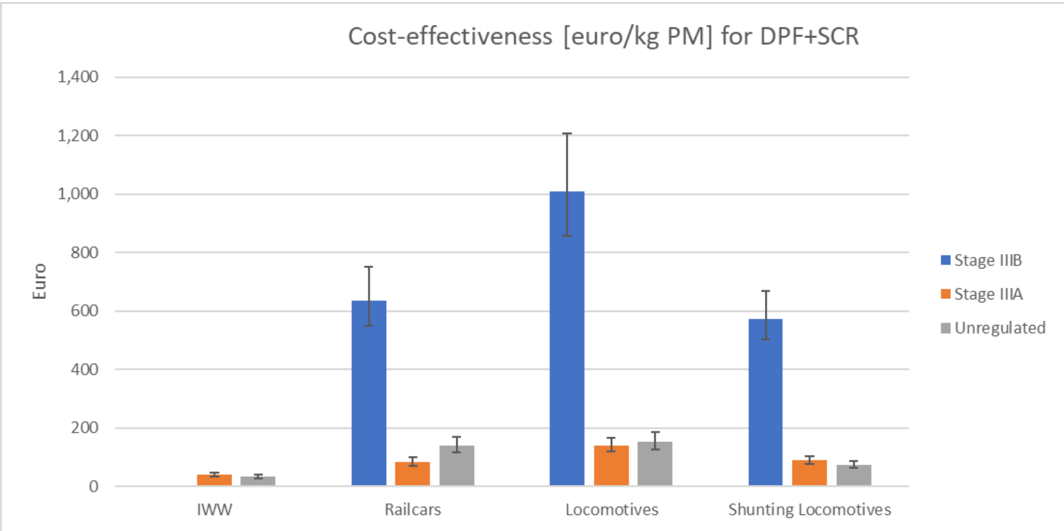

Figure V - 6 Cost effectiveness for inland waterways and railways for PM for DPF+SCR retrofit

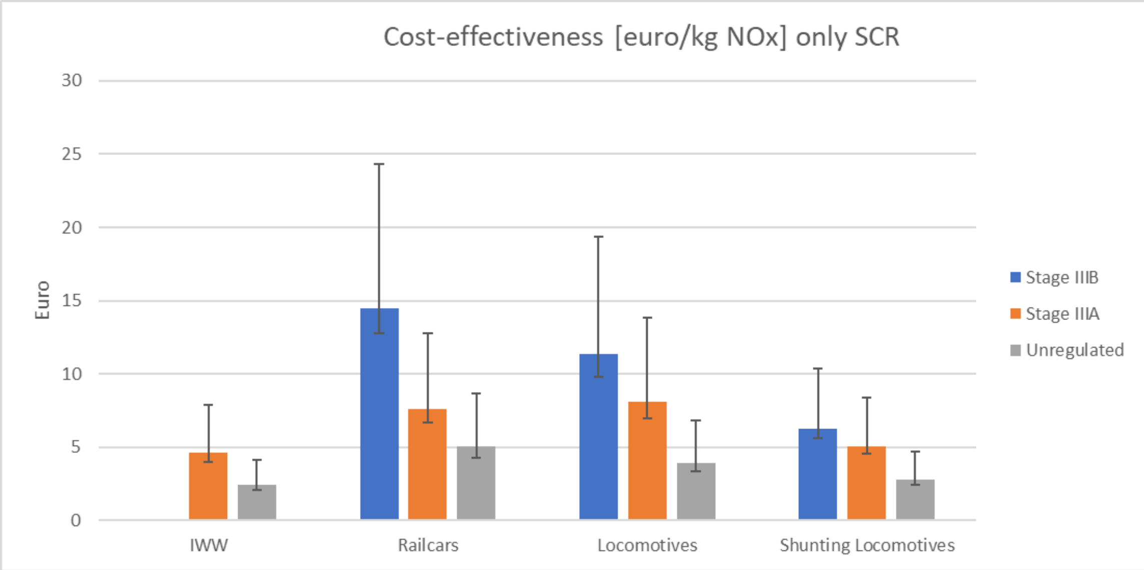

Figure V - 7 Cost effectiveness for inland waterways and railways for NO_x for SCR retrofit

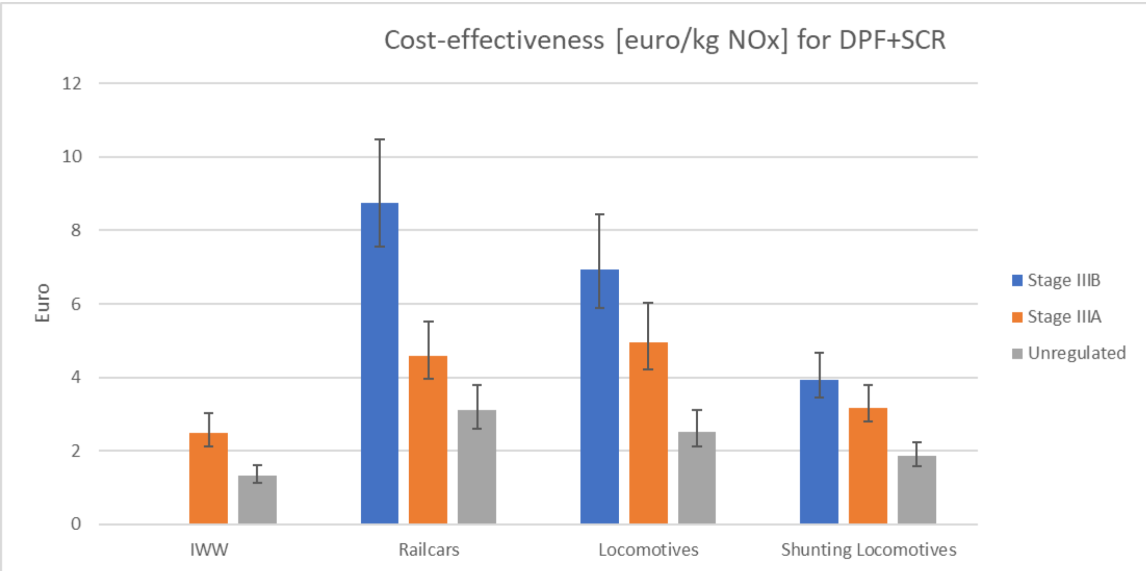

Figure V - 8 Cost effectiveness for inland waterways and railways for NO_x for DPF+SCR retrofit

Annex VI: Cost of retrofit compared to the cost of a new engine and the cost of a new NRMM

The results of the analysis presented in chapter 12 clearly demonstrate the cases for which retrofitting is cost beneficial from the point of view of the society. From the owner's perspective the decision on whether to retrofit may depend mainly on financial criteria. As an example of how such decision can be substantiated a few examples are indicatively presented in the following. A detailed analysis of all different options covering the entire range of NRMM is outside the scope of this study.

Assuming that Stage IIIB and Stage IV will not be retrofitted as most of this machinery is already equipped with some kind of aftertreatment devices (see also section 5.1) we only examine the case of Stage IIIA here. In 2020 the machinery (and the engine) to be retrofitted will be at least 9 years old as Stage IIIB was introduced after 2011 for all power classes. One way is to compare the retrofitting costs against the residual value of the machinery after 9 operating years. For an estimation of the residual value, the cost of a new engine needs to be defined first.

Although there is a very large variability in the cost of a new engine, a good approximation that can be used for this analysis is 50 €/kW, which reflects average values found online. This is the baseline cost of the engine, without any aftertreatment devices installed. The additional cost for this engine to comply with any emissions Stage has to be added to this baseline cost. These values are taken from Figure 5-4, multiplied with a factor of 1.5 to account for overheads. Thus, the cost of a new engine is calculated using the following equation:

$$cost\ of\ a\ new\ engine = 50 * engine\ power + additional\ cost\ for\ higher\ Stage\ engine * 1.5$$

The cost of a new NRMM is then estimated based on the cost of the engine. The cost of the engine can be a significant part of the NRMM, ranging from just 15% to as much as 65% of the total cost of the NRMM, given the large number of applications. Assuming a 9 years old machinery, as explained above, and that the engine/NRMM value is depreciated linearly, the residual value of a Stage IIIA engine or NRMM in 2020 (after 9 years of operation as explained previously) is calculated using the following equation:

$$residual\ value\ \text{of engine or NRMM} = cost\ of\ new\ engine\ or\ NRMM * \frac{(useful\ life - 9)}{useful\ life}$$

For the power class 19-37 kW the useful life is 12 years, whereas for all other power classes the useful life is 16 years (see also section 4.2). Based on the above methodology, the residual value of the Stage IIIA engine and of the machinery (range of values as explained previously) have been calculated and are summarized in Table VI – 1. The cost of retrofitting of the Stage IIIA engine/NRMM and the costs for a new engine and a new NRMM complying to Stage V limits are also included in the same table.

Table VI - 1 Calculated residual values for new Stage IIIA engines/NRMM compared to cost of retrofitting and cost of a new Stage V engine

Power class	Residual value of a Stage IIIA engine in 2020	Residual value of a Stage IIIA NRMM in 2020	Cost of DPF + SCR retrofitting	Cost of a new Stage V engine	Cost of a new Stage V NRMM
19-37 kW	350	538 – 2,333	10,125	2,749	4,229 – 18,327
37-56 kW	1,371	2,109 – 9,140	10,875	3,987	6,134 – 26,580
56-75 kW	1,925	2,962 – 12,833	11,625	6,474	9,960 – 43,160
75-130 kW	3,004	4,622 – 20,027	11,625	8,131	12,509 – 54,207
130-560 kW	10,063	15,482 – 67,087	20,250	22,988	35,366 – 153,253
>560 kW	17,500	26,923 – 116,667	20,250	40,308	62,012 – 268,720

For the lower power classes, up to about 75 kW, the residual value of the NRMM is lower than the cost of DPF + SCR retrofitting (combined system). This would rather discourage the NRMM owner to decide for retrofitting without any financial incentives. The cost for buying a new engine complying with Stage V limits would be a cheaper solution than retrofitting. Even the purchase of a new NRMM would be an option for those NRMM that the cost of the engine is a significant part of the new NRMM cost.

For the higher power classes, above 75 kW, the residual value of the NRMM is high enough to consider retrofitting (especially for >560 kW) or just replacing the engine (more appealing for <560 kW). Similarly, to the lower power classes, the purchase of a new NRMM would also be an alternative to retrofitting for those NRMM that the cost of the engine is a significant part of the new NRMM cost.

Again, it is noted that the above calculations apply only in the case of a late Stage IIIA machinery. Evidently, the older the machinery, the lower is its residual value making retrofitting a less attractive option for the NRMM owner.

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