uCARe

You Can Always Reduce Emissions

because you care

GA 815002

Deliverable number: D1.6
Deliverable title: Guiding document for pollutant reducing operations and maintenance of NRMM, PTW and HD

Document ID: uCARe-D1.6-v1.0
Dissemination level: Public
Main Author: S. Hausberger (TUG)
Issue date: 05-11-2019

EUROPEAN COMMISSION HORIZON2020 – Research and Innovation Action

Disclaimer and acknowledgement

This project has received funding from the European Union's Horizon 2020 Programme Research and Innovation action under grant agreement No 815002

Disclaimer

uCARe consortium

Document information

Additional author(s) and contributing partners

Name	Organisation
Heinz Steven	HS
Konstantin Weller	TUG
Benedikt Notter	Infras
Stephan van Zyl	TNO

Document Change Log

Version	Date	Comments
v0.5	29.10.2019	5th draft of content
v0.x		Revised version based on the comments of Empa (Thomas Bütler), TNO (Robin Vermeulen)
v1.0		First final version, approved by Executive Board, (will be) submitted to EC.

Document Distribution Log

Version	Date	Distributed to
V 0.1	13.08.2019	EB, GA
V 0.2	08.10.2019	Authors
V 0.3	15.10.2019	Authors
V 0.4	23.10.19	Authors, Reviewers
V 0.5	29.10.2019	Reviewers
V 1.0	05.11.2019	Submitted to EU portal

Verification and approval

	Name	Date
Verification Final Draft by WP leader	Norbert Ligterink (TNO)	04.11.2019
Check before upload by coordinator	Paul Tilanus (TNO)	05.11.2019

Executive summary

The deliverable analyses the current emission situation for:

- Non Road Mobile Machinery with diesel engines (NRMM)
- Power Two-Wheelers (PTW), i.e. mopeds and motorcycles
- Heavy Duty Vehicles (HDVs)

NRMM with diesel engines and HDVs contribute relative high shares mainly to NO_x and CO_2 emissions, the PTWs have relatively high contributions to HC and CO emissions.

For the three vehicle categories a number of measures has been identified a driver can directly take to reduce tail-pipe emissions. The main options are listed below:

Reduction of idling for HDV, NRMM and PTW

Avoiding idling for NRMM and HDVs, where stand still can have relevant shares in the daily operation. For modern diesel engines equipped with SCR catalysts, the NOx emissions increase significantly after approx. 5 minutes idling, since the catalyst cools down in idling below the temperature levels needed for proper NOx conversion. Therefore the relative emission reduction is much higher for Stage IV and EURO VI engines than for older models. The absolute reduction by switching off the engine however, is even higher for older models without aftertreatment systems. Certainly also for PTWs unnecessary idling of the engine should be avoided.

Avoiding harsh accelerations for PTW

For PTW the main potential for reducing environmental impact by the driver is avoiding harsh accelerations since in full load area hydrocarbon emissions massively increase. These hydrocarbons include also carcinogenic species such as benzene and aldehydes. Especially in urban areas therefore smooth accelerations are relevant die to the higher population density exposed to the exhaust gases. Beside a smoother acceleration the avoidance of high engine speeds reduces the noise emissions and is especially relebant in sensible areas.

Retrofit particle filers for NRMM

For NRMM also retrofit systems for particle filters are an attractive measure to reduce PM and PN emissions. The Swiss activities launching retrofits can be used as guideline and are described in this report.

Drop-in replacement fuel for hand held machines

For hand-held machinery, such a chain-saws, the use of “alkylate gasoline” instead of conventional gasoline can reduce the carcinogenic benzene emissions.

Maintenance of the vehicles

Performing proper maintenance and service and not tampering emission control systems helps to reduce environmental harm.

Table of contents

List of Figures

Definitions & Abbreviations

A/C-system	……..	Air-conditioning-system
ADAS	……..	Advanced Driver Assistance Systems
Approx.	……..	approximately
AT	……..	Automatic Transmission
BSE	……..	Brake specific emissions
C_d	……..	Drag coefficient
CNG	……..	Compressed Natural Gas
CO	……..	Carbon monoxide
CO_2	……..	Carbon dioxide
CF	……..	Conformity factor
DI	……..	Direct Injection
DOC	……..	Diesel Oxidation Catalyst
DPF	……..	Diesel Particulate Filter
e.g.	……..	Example given
EGR	……..	Exhaust Gas Recirculation
etc.	……..	Et cetera
EU-28	……..	Abbreviation of European Union with 28 member states
FC	……..	Fuel Consumption
GVM	……..	Gross Vehicle Mass
HBEFA	……..	Handbook Emission Factors for Road Transport
HC	……..	Hydrocarbon
HD	……..	Heavy Duty
HDE	……..	Heavy Duty Engine
HDV	……..	Heavy Duty Vehicle
HEV	……..	Hybrid Electric Vehicle
HVAC	……..	Heating, Ventilation and Air Conditioning
i.e.	……..	Id est
ICE	……..	Internal Combustion Engine
ISC	……..	In-service-conformity
LDV	……..	Light Duty Vehicle
L category	……..	Vehicle category including mopeds, motor cycles, quads and other small 3 or 4 wheeled vehicles
max.	……..	Maximum
MC	……..	Motorcycle
min.	……..	Minimum
MT	……..	Manual Transmission
NH_3	……..	Ammonia
NO	……..	Nitrogen monoxide
NO_2	……..	Nitrogen dioxide
NO_x	……..	Nitrogen oxide
NRMM	……..	Non-road mobile machinery
NSC	……..	NO_x Storage Catalyst
OBD	……..	On-Board Diagnostics
OEM	……..	Original Equipment Manufacturer
P	……..	Power
PC	……..	Passenger Car

PEMS	……..	Portable Emissions Measurement System
PM	……..	Particle Mass
PM_{10}	……..	Particle Mass in the size range below 10 micrometres
PN	……..	Particle Number
PTW	……..	Powered Two Wheeler
RDE	……..	Real Driving Emissions
RRC	……..	Rolling Resistance Coefficient
SCR	……..	Selective Catalytic Reduction
TPMLM	……..	Technical Permissible Maximum Laden Mass

1 Background uCARe

In Europe, traffic and transport have a large effect on local air quality, specifically passenger cars and commercial vehicles and non-road mobile machinery. While technical improvements and more stringent legislation have had a significant impact, traffic and transport emissions are still too high and air quality is still poor. Although the use of electric and other zero-emission propulsion technologies may drastically reduce the pollutant exhaust emissions from traffic, the slow introduction of such vehicles as well as the trend of increasing vehicle lifetimes means that vehicles with internal combustion engines are expected to dominate the fleet beyond 2030. This project is the first opportunity to improve emissions of vehicles, not by improving vehicle technology, but by actively involving vehicle users and enabling their contribution to clean driving.

So far, expertise on pollutant emissions has mainly been used to advise European policy makers on limited effectiveness of emission legislation (through real-world emission factors such as HBEFA and COPERT) and how to reduce traffic and transport pollutant emissions. The numerous mitigation methods are rarely extended to include the perspectives of users uCARe enables a next essential step: providing user targeted emission reduction measures. These measures will be implemented and evaluated in real-life pilot projects.

The overall aim of uCARe is *to reduce the overall pollutant emissions of the existing combustion engine vehicle fleet by providing vehicle users with simple and effective tools to decrease their individual emissions and to support stakeholders with an interest in local air quality in selecting feasible intervention strategies that lead to the desired user behaviour*. The overall aim is accompanied by the following objectives, where this report focusses on the first one for NRMM:

1. To identify **user-influenced vehicle emission aspects** (such as driving behaviour, machine operation, maintenance and modifications to the existing vehicle or machinery, but excluding purchase options or 'green procurement').
2. To determine the **emission reduction potential** of each vehicle emission aspect with help of the uCARe model developed within a toolbox.
3. To develop a **toolbox**, containing models and emission reduction measures, that enables stakeholders to identify the most appropriate intervention strategies that reflect the specific users and their motivation.
4. **Support policy makers** and other **stakeholders with an interest in air quality,** such as municipalities and branch organizations, **in identifying intervention strategies** that translate the measures into desired behaviour of the user.
5. **To test and evaluate** intervention strategies in a set of pilot projects conducted with various target user groups in at least four European countries. The pilot projects illustrate effectiveness and feasibility of the toolbox and intervention strategies developed on its basis.
6. Perform an **impact assessment** of the intervention strategies effectiveness, in terms of cost, penetration, achieved emission reduction and lasting effects.
7. **Actively feed** European cities and international parties with uCARe learning and results, via awareness raising campaigns, communication tools, interactive web application and other dissemination activities. Open access to the broad public to the toolbox, data and developed tools.
8. Summarise the findings **in blueprints for rolling out** different user-oriented emission reduction programmes, based on successful pilots.

The transport sector has a large effect on air quality. Main sources within the transport sector are passenger cars and commercial vehicles. The emissions from non-road mobile machinery (NRMM) and powered two-wheelers (PTWs) are less often discussed, however, local contribution to air quality issues can be high and users and owners of these vehicles can also contribute to emission reductions by some simple behavioural changes.
Elaborating options for all vehicle users to reduce environmental impacts is the main focus of the uCARe project. Behavioural changes have immediate effects on air quality and noise

while technological improvements take place for new vehicles, which need longer periods of time to enter the market and to reach higher shares in the fleet. Thus, in the short term the effects of measures set by vehicle users have higher impact than technology. But also in the long term a responsible way of usage for all kinds of vehicles and machinery is a key element for reducing energy consumption and related emissions.
This report summarises options the drivers of heavy duty vehicles, non-road machinery and two-wheelers have to reduce negative impacts on the environment. Since the uCARe project is focussing on passenger cars, this report on the "non-car" sector in not very extensive. Nevertheless we hope that the information and the options listed are useful for all persons interested in ecology.

2 Purpose of the document

This document aims mainly at information of drivers and fleet operators of non-road mobile machinery (NRMM), heavy duty vehicles (HDVs) and powered 2-wheelers (PTW, L-Category).
The document provides:

- background information on emission behaviour of these vehicle categories for readers interested in details
- suggestions how to operate the vehicles to reduce the environmental impact. The options to reduce emissions focus on activities the driver and/or vehicle holders can set.

As expected, literature, data and analysis on NRMM and PTWs is rather limited. Since the document is delivered early in the project, we may elaborate an updated version later, if more information becomes available.

3 Document Structure

Background information on emission behaviour and on possible actions to reduce emissions is given in the chapters 2 and 3.
The options for drivers and vehicle owners/keepers to reduce environmental impacts are summarised then in chapter 4.

4 Deviations from original DoW

4.1 Description of work related to deliverable as given in DoW

Guiding document for pollutant reducing operations and maintenance of NRMM, PTW and HD.

4.2 Time deviations from original DoW

It was agreed with the Project Officer to delay this document for the following reasons.

- It is more work than could be properly handled over the summer period.
- uCARe aims at covering all relevant aspects of the non-LDV domain.
- The reviewer availability in September was a problem, since uCARe requires a reviewer to be a non-author and a knowledgeable person.

4.3 Content deviations from original DoW

None.

5 Relevance of the vehicle categories

In this chapter the pollutant and greenhouse gas (GHG) emissions as well as on noise and fuel consumption are analysed. Other impacts, such as water pollution, land consumption etc. are not scope of the project but certainly are also relevant environmental aspects.

5.1 Vehicle description

Non Road Mobile Machinery (NRMM) covers a diversity of machines:

1) Machinery used in industry, including construction, with the most relevant ones: pilers, asphalt pavers, rammers, rollers, excavators, mixers, cranes, graders, bulldozers, tractors, skid steer loaders, dumpers, fork lifts, pumps and compressors, generator sets and also off-highway trucks,
2) Agriculture and forestry, with the most relevant ones: tractors, harvesters, chain saws, brush cutters and others,
3) Household, with the most relevant ones: lawn mowers and chain saws but also snow groomers, snow mobiles and skidos and off-road vehicles like quads,
4) Military, rail and land vessels, which are not covered in this investigation due to the very different usage.

The L-category vehicles consist mainly of 2-wheelers (mopeds, motorcycles) but also mini-cars and quads.

The Heavy Duty Vehicle (HDV) category covers rigid lorries, truck and trailer combinations, tractor and semi-trailer combinations as well as buses and coaches. HDVs are defined as vehicles with a certification from an engine test for pollutant emissions according to Regulation (EU) 582/2011 and 595/2009 and its amendments. Typically, vehicles with a reference mass exceeding 2610 kg fall into this category, with some exceptions between 2380 and 2840 kg. Thus all vehicle classes for goods transport (N1, N2, N3) and passenger transport (M1, M2, M3) can be HDVs if the reference mass is exceeding the aforementioned threshold. N1 and M1 HDVs have very similar mission profiles and technologies as their Light Duty counterparts. Therefore the options for reducing environmental impacts are similar to the LDVs. Thus, we do not deal with HDVs in the M1 and N1 categories in this report.

5.2 Shares in National Fleet and Emissions

Countries within the EU have to deliver inventories on their national emissions for all sectors. These inventories give a good overview on the contribution from different emission sources to the overall air quality and climate change issues. Certainly, local contributions can differ significantly from the national averages shown below, Table 1.

The inventories on transport emissions indicate:

- NRMM has a relevant share in CO_2 emissions which is mainly caused by large machinery in construction, agriculture and forestry.
- NRMM has a high share in NO_x and PM emissions which is mainly caused by machines with diesel engines in construction, agriculture and forestry.
- NRMM has a high share in CO and HC emissions which is mainly caused by smaller machines with gasoline engines (chainsaws, lawn mowers, etc.).

The higher shares in pollutant emissions compared to energy consumption and CO_2 emissions is a result of a later introduction of stringent emission limits for NRMM compared to cars and heavy duty on-road vehicles. The renewal of the machinery fleet in future will reduce the absolute emission levels. The shares of NRMM in the total transport emissions may however increase further, since emission limits and test procedures for cars and HDV are also adjusted.

The shares in Table 1 are given for different reference years since the figures are not available for the same reference year for all countries[1]. While the share of CO_2 remains rather constant between 2010 and 2020, the share of NRMM in NOx emissions decreases in the same period because the gradually more stringent NOx limit values seem to be better implemented by NRMM, while especially for diesel passenger cars, the gap between limit values and real-world emissions was widening before the introduction of RDE testing. The share of NRMM in total PM emissions, on the other hand, has been increasing, since only the Euro stage V for NRMM, introduced around 2019 (see Table 4), requires DPF use for Diesel machinery to meet the PN limits, while road vehicles have been serially fitted with DPF much earlier.

Table 1: Shares of non-road mobile machinery in national transport emissions

	AT	CH	D	NL
CO_2	8.5%	7.8%	8%	10%
NO_x	17%	14%	20%	20%
PM	37%	32%	53%	35%
PN	n.a.	n.a.	n.a.	n.a.
HC	27%	19%	25%	n.a.
CO	31%	30%	24%	13%
Source	AT Inventory RefYear 2018	CH inventory (RefYear 2015)	D inventory RefYear 2018	NL inventory RefYear 2017

Table 2 shows examples for the shares of PTWs in the transport emissions. For the L-category vehicles the conclusion from these inventories are:

- The shares in CO_2 and NO_x emissions are rather low, since these vehicles have a limited average yearly mileage driven, they have a comparable low fuel consumption and thus low CO_2 emissions per km and the main engine type is Otto 4-stroke with stoichiometric combustion and a 3-way catalyst. These engines typically have quite low NOx emissions (chapter 6).
- The shares in CO and HC emissions are high compared to the share in energy consumption. This is mainly a result from the exhaust gas legislation, which was not very stringent for PTWs before EURO 4. Especially the hydrocarbons can cause health effects, since they include carcinogenic and mutagenic components.

Table 2: Shares of L-Category vehicles in national transport emissions

	AT	CH	NL
CO_2	0.8%	1.4%	1.4%
NO_x	0.7%	0.8%	1%
PM	n.a.	3%	7%
PN	n.a.	n.a.	n.a.
HC	28%	19%	n.a.
CO	18%	11%	15%
Source	AT Inventory (RefYear 2018)	CH inventory (RefYear 2015)	NL inventory RefYear 2017

[1] The shares of NRMM in total transport emissions may vary depending on the reference year depending of the timeline of new emissions standards for all kinds of vehicles. However, the order of magnitude in the emissions shares does not change quickly, due to the rather slow fleet renewal rates.

Figure 1 shows the trend for HC and CO emission in Europe with the shares of PTWs. According to [3], mopeds and motorcycles have already more than 50% share in total HC emissions.

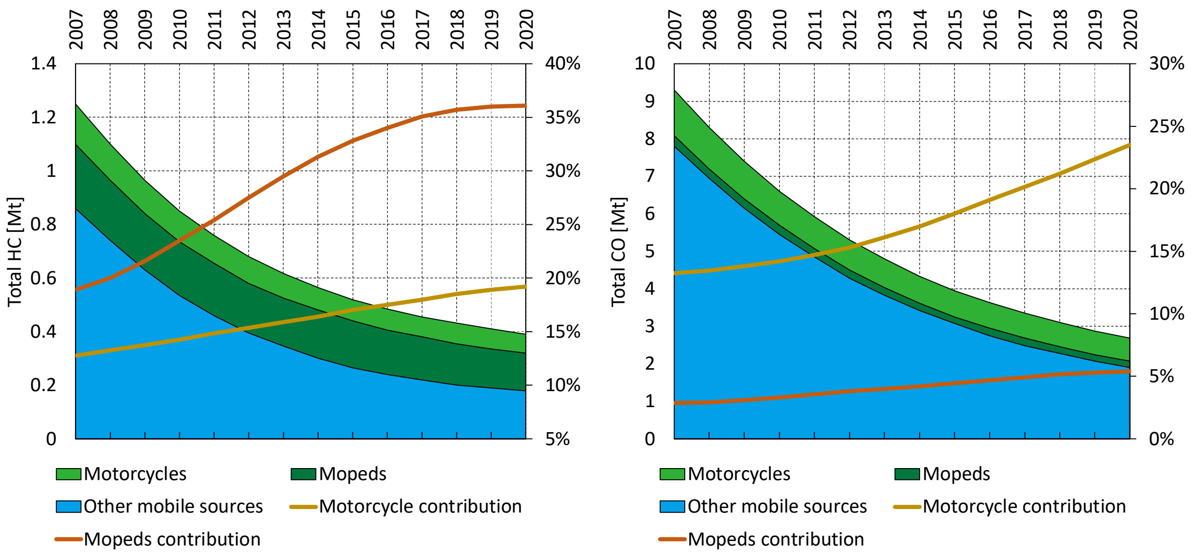

Figure 1. Evolution of PTWs HC and CO emission in Europe in comparison with emissions of all other road transport sources. [3]

Table 3 summarised the shares on HDVs in the total transport emissions. With some 15% share in fuel consumption and CO_2 emissions the HDVs contribute significantly to greenhouse gas emissions. Also NOx and particle emission shares are relevant. For NOx and particles, the absolute emissions are clearly decreasing due to the EURO VI emission standards (see chapter 6). CO and HC emissions from HDVs, which almost all are equipped with diesel engines, are on a low level.

Table 3: Shares of HDVs (N2, N3, M2, M3) in national transport emissions

	AT	CH	NL
CO2	16%	14.5%	19.4%
Nox	19%	23%	30%
PM	12%	17%	13%
PN	n.a.	26%	n.a
HC	4%	4%	n.a
CO	5%	4%	11%
Source	AT Inventory (RefYear 2018)	CH inventory (RefYear 2015)	NL inventory RefYear 2017

5.3 Shares in local air quality

While the shares of the different vehicle categories in the total transport emission inventories indicate the average relevance for different exhaust gas components, the local impact can be very different from the average. Furthermore the relevance for air quality depends also on the contribution from other sources to the total emissions, such as heating, industry, power plants, etc.

For Switzerland, average contributions of NRMM, L-category vehicles and HDVs to PM10 concentrations are available from a study commissioned by the Federal Office of the Environment [9], for the years 2005 and 2010.

Transport contributed roughly 10% of total PM10 concentrations, or between 2.5 and 3 $\mu g/m^3$ of a total concentration of 25-30 $\mu g/m^3$ averaged over all measuring stations in Switzerland (excluding background stations e.g. on mountain ridges).

About 40% of the total transport contribution originated from NRMM – roughly half-half from construction and agricultural machinery. The contributions of other NRMM vehicle families (industrial machinery, forestry, hand-held machinery, ships, military, aviation) are insignificant, either due to their limited spatial occurrence, or in the case of hand-held machinery, since most of these devices are petrol-powered, they do not emit as much PM as (older) diesel machinery. It should be noted that since these figures are valid for the years 2005-2010, they do not yet capture the full effects of the Swiss Ordinance on diesel particle filter requirements on construction sites, which requires all machinery >18 kW to be equipped or retrofitted with DPF and which was introduced stepwise for different size classes between 2009 and 2015 (see also Chapter 7).

Road transport contributes roughly 5.5% to 7% of the PM10 concentrations on average, but near roads with high traffic volumes the road transport contribution can rise to 25%. With the shares of HDV and L-category vehicles in the total transport emissions shown before, we can conclude that the contribution of L-category vehicles to PM10 concentrations is negligible (about 0.2% on average and 0.8% near main roads), while HDV contribute more significantly, i.e. about 0.9% - 1.6% on average and 4.2% - 5.6% near main roads.

According to Dutch air-quality monitoring, mobile machines make a substantial contribution to NO_2 concentrations in problematic urban areas.[2] Approximately 20% of the NO_2 can be attributed to construction machines, tractors, pumps and generators powered by diesel and gasoline.

6 Specific Emissions

The emission values provided in this chapter are the emission limits on one hand and typical real world values on the other hand. The latter are based on measurements on-board of the vehicles in real operation and on roller test bench measurements in real world cycles. For all vehicle categories with combustion engines, the real world emissions can differ largely between makes and models and are also different for varying operations (from idling to full load). Thus, the averages provided below can serve as illustration on possible environmental impacts but do not necessarily represent emissions in a specific operation.

6.1 Non-Road Machinery

For NRMM the engine is type approved and has to demonstrate in an engine test that the emission limits are met. From Stage V on, also an on-board test on a machine is required but yet only for monitoring without emission limits for the on-board test result.

The emissions from NRMM are limited by EU regulations since 1998 (Stage I). The current regulation (Stage V) is valid for new type approvals since 2018 and new registrations since 2019. The current regulations are Regulation (EU) 2016/1628 and 2017/655. Below an overview on emission limits for mobile machines with variable engine speed operation is given. Extra rules exist for different applications (marine, stationary operated engines, etc.).

[2] Aanpassing Nationaal Samenwerkingsprogramma Luchtkwaliteit 2018 (Modification of National Programme for Collaboration on Air Quality 2018), www.platformparticipatie.nl

Table 4: Overview on emission limits in the EU for mobile machines with variable engine speed operation

Stage I				Limits in [g/kWh]				[#/kWh]
Categ.	Power [kW]	Type appr.	Cycle	CO	HC	NOx	PM	PN
A	130≤ P ≤560	30.06.1998	NRSC	5.00	1.30	9.20	0.54	--
B	75≤ P <130	30.06.1998		5.00	1.30	9.20	0.54	--
C	37≤ P <75	30.06.1998		5.00	1.30	9.20	0.54	--
Stage II								
Categ.	Power [kW]	Type appr.	Cycle	CO	HC	NOx	PM	PN
D	19≤ P <37	31.12.1999	NRSC	5.50	1.50	8.00	0.80	--
E	130≤ P ≤560	31.12.2000		3.50	1.00	6.00	0.20	--
F	75≤ P <130	31.12.2001		5.00	1.00	6.00	0.30	--
G	37≤ P <75	31.12.2002		5.00	1.30	7.00	0.40	
Stage IIIa								
C Categ.	Power [kW]	Type appr.	Cycle	CO	HC + NOx		PM	PN
H	130≤ P ≤560	30.06.2005	NRSC, NRTC	3.50	4.00		0.20	--
I	75≤ P <130	31.12.2005		5.00	4.00		0.30	--
J	37≤ P <75	31.12.2006		5.00	4,7		0.40	--
K	19≤ P <37	31.12.2005		5.50	7,5		0.60	--
Stage IIIb								
C Categ.	Power [kW]	Type appr.	Cycle	CO	HC	NOx	PM	PN
L	130≤ P ≤560	31.12.2009	NRSC, NRTC	3.50	0.19	2.00	0.025	--
M	75≤ P <130	31.12.2011		5.00	0.19	3.30	0.025	--
N	56≤ P <75	31.12.2011		5.00	0.19	3.30	0.025	--
P	37≤ P <56	31.12.2011		5.00	4.70		0.025	
Stage IV								
Categ.	Power [kW]	Type appr.	Cycle	CO	HC	NOx	PM	PN
Q	130≤ P ≤560	31.12.2012	NRSC, NRTC	3.50	0.19	2.00	0.025	--
R	56≤ P <130	30.09.2013		5.00	0.19	3.30	0.025	--
Stage V								
Categ.	Power [kW]	Type appr.	Cycle	CO	HC	NOx	PM	PN
NRE-v/c-1	P <8	01.01.2018	NRSC, NRTC, PEMS monitoring	8.00	7.50		0.400	--
NRE-v/c-2	8≤ P <19	01.01.2018		6.60	7.50		0.400	--
NRE-v/c-3	19≤ P <37	01.01.2018		5.00	4.70		0.015	1x10**12
NRE-v/c-4	37≤ P <56	01.01.2018		5.00	4.70		0.015	1x10**12
NRE-v/c-5	56≤ P <130	01.01.2019		5.00	0.19	0.40	0.015	1x10**12
NRE-v/c-6	130≤ P ≤560	01.01.2018		3.50	0.19	0.40	0.015	1x10**12
NRE-v/c-7	1_P >561	01.01.2018		3.50	0.19	3.50	0.045	--

Figure 2 shows an assessment of average real world emission limits from NRMM with diesel engines. For NRMM with Stage IV certification only real world tests on 2 machines are available yet, [2], thus the emission levels for these vehicles are quite uncertain. No real world tests on machines with Stage V certifications were found, so results for these NRMMs are technology assessments. For stage III a/b in total 13 machines were measured, [8].

With Stage IV the larger machines (above 56 kW) obviously made a step towards lower NO_x and particle emissions. With stage V the further reductions are expected due to the stringent NO_x limits for machines between 56 and 560 kW rated engine power. In addition with stage V on board emission tests are introduced for the first time for NRMM. These tests have to be performed in real operation with PEMS (Portable Emission Measurement Systems) and are used currently for monitoring only[3]. For the smaller machinery (below 37kW), the NO_x limits are less stringent and thus emissions are assumed not to drop with Stage IV and V (no measurements for these classes below 37kW available yet).

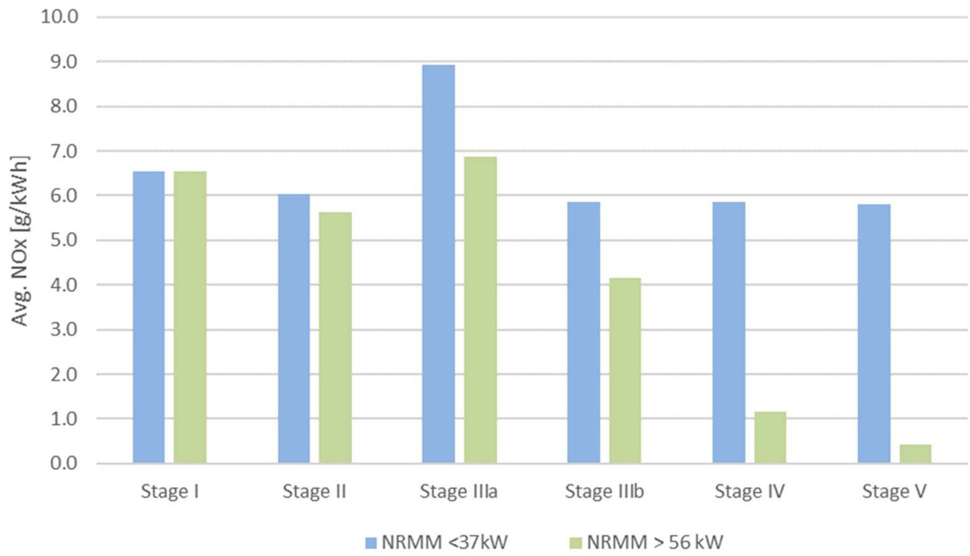

Figure 2: Average real world NOx emissions from NRMM in real use (data for NRMM < 37kW rated power and stage IV and V is based on technology assessments since no tests on new machinery is available yet)

Figure 3 shows average particle mass emission levels for diesel engines in NRMM. Particle emissions for machinery above 37kW were limited more stringent than for smaller engines from Stage III b on. With Stage V also particle number (PN) limits are introduced between 19 and 560 kW rated power. These limits will make the use of quite efficient particle filters necessary for all of the machines concerned and thus also PM and PN emissions will be further reduced.

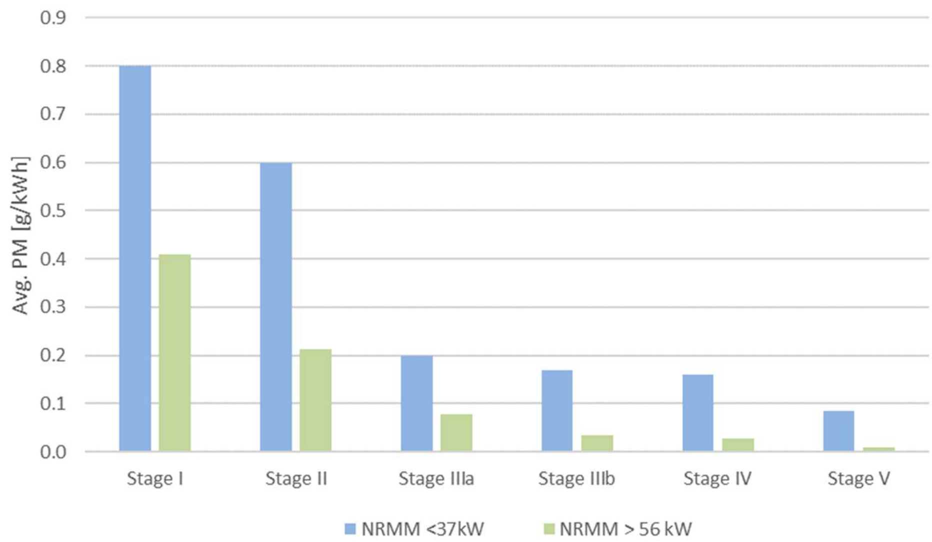

Figure 3: Average real world particle mass (PM) emissions from NRMM in real use (data for NRMM < 37kW rated power and stage IV and V is based on technology assessments since no tests on new machinery is available yet)

[3] When a machine exceeds emission limits in the PEMS test yet no consequences are in place. With a next step most likely limit values will apply also for PEMS results.

CO and HC emissions were quite low for all tested machines and do not raise concerns.

Emission factors for the Swiss NRMM emission inventory are available from a 2015 publication of the Federal Office for the Environment [10] or can be queried online [8].

From the emission limits and from the average real world emission data we can conclude:

- Newer machines have on average lower emissions of NOx and PM
- The emission reduction in Stage IV and V is related to a large extent to the aftertreatment systems

  Aftertreatment systems include:

  - a particle filter (PF) which efficiently removes approx. more than 90% of the particle mass and more than 95% of the particle number emissions. The filters are efficient in all particle size classes, i.e. also "nano-particles" below 100nm are removed efficiently.
  - An SCR catalyst (Selective Catalytic Reduction), which needs AdBlue[4] to convert NO and NO_2 to the harmless components N_2 and H_2O.
- Maintaining the functionality of the aftertreatment systems is essential to achieve low exhaust emissions. Tampering the systems is a harmful activity, which is illegal and can increase emissions by more than a factor of 10 just to save costs for AdBlue.

The vehicle holder has a high influence on the emission level of his machines by performing proper maintenance and service and not tampering emission control systems.

Although Stage IV and V machines are already rather clean, further improvements in the exhaust gas legislation and engine technology will bring cleaner machines in future. A shortcoming of recent SCR catalysts, relevant for the vehicle operator, is the poor performance at low catalyst temperatures. Below approx. 200°C gas temperature, AdBlue cannot be converted in the exhaust gas to NH_3. Beside this, the conversion efficiency in catalysts drops in general with lower temperatures. Exhaust gas temperatures below 200°C are typical in engine idling and low load operation. Without NH_3 the reduction of NO and NO_2 does not work in the SCR. The SCR catalysts can store several grams of NH_3 and due to his mass also heat is stored. Thus, shorter periods of low exhaust gas temperature do not immediately lead to a loss of SCR performance. However, several minutes of idling lead to massive increase of NO_x emissions for engines with SCR systems. When all NH_3 is consumed the emission level is like that of a machine without SCR. This cool down effect could only be prevented by the machine by active heating. By late fuel injection, throttling and other technologies, the exhaust gas temperature is increased during active heating which thus increases the fuel consumption. The simpler option is to switch off the engine if not needed. Even without active SCR heating, fuel is consumed during idling to keep the engine and auxiliaries running which can be saved when the engine is off.

If heating and/or cooling of the cabin is the reason to have the engine in idling long time, the operators should have the target conflict with fuel consumption and NO_x emissions in mind. The following section shows some typical effects of idling emissions.

A first example are on board test results at a Stage IV excavator (129 kW with SCR catalyst). Tests were performed during real operation by TNO over 131 hours, [1]. On average, the machine was 21 minutes per hour in idling, which represents 35% of the time.

[4] AdBlue is a solution of urea in water. Urea is converted in the hot exhaust into NH3, which reacts with NO and NO_2.

Amount of data collected	**131 hours**
Time spent idling per hour	**21 minutes/hour**
Average CO_2 emissions per hour	**42 kilograms/hour**
Average NO_x emissions per hour	**34 grams/hour**
Average NO_x emissions during idling (~900 and 1,000 RPM)	**49 grams/hour**
Average NO_x emissions per kWh	**0.5 grams/kWh**

Figure 4: Excavator tested in [1] and main test results.

Figure 5 shows a typical idling event described above for the excavator, with the cool down of the SCR catalyst and corresponding drop of NH_3 availability and NO_x conversion. The NO_x level in idling reaches more than 20mg/s approx. 7 minutes after the idling phase has started. This NOx level is clearly above the average NOx during engine work, which is below 10mg/s.

It is important to note, that the SCR cools down faster in idling than during engine stop, since the flow of cool exhaust leads to a better heat exchange from the SCR to the cooler exhaust gas compared to no gas flow if the engine has stopped.

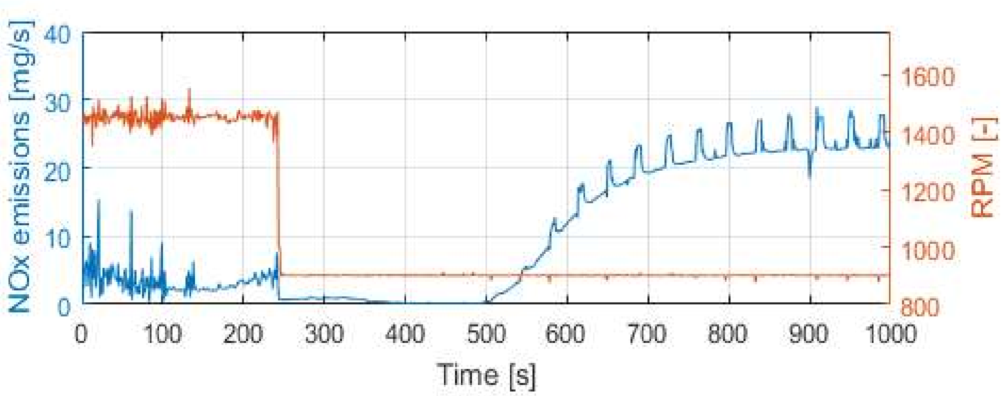

Figure 5: NO_x emissions and engine speed over time, [1]. The engine starts to idle in second 250. Low NO_x can be maintained here for approx. 4 minutes, then NO_x level increases due to the low SCR temperature and lack of NH_3.

With 35% time share of idling and with NO_x emissions above the average level in longer idling, the idling time of this machine contributed approx. 50% to the total NO_x emitted during the 131 hours monitored (Figure 6).

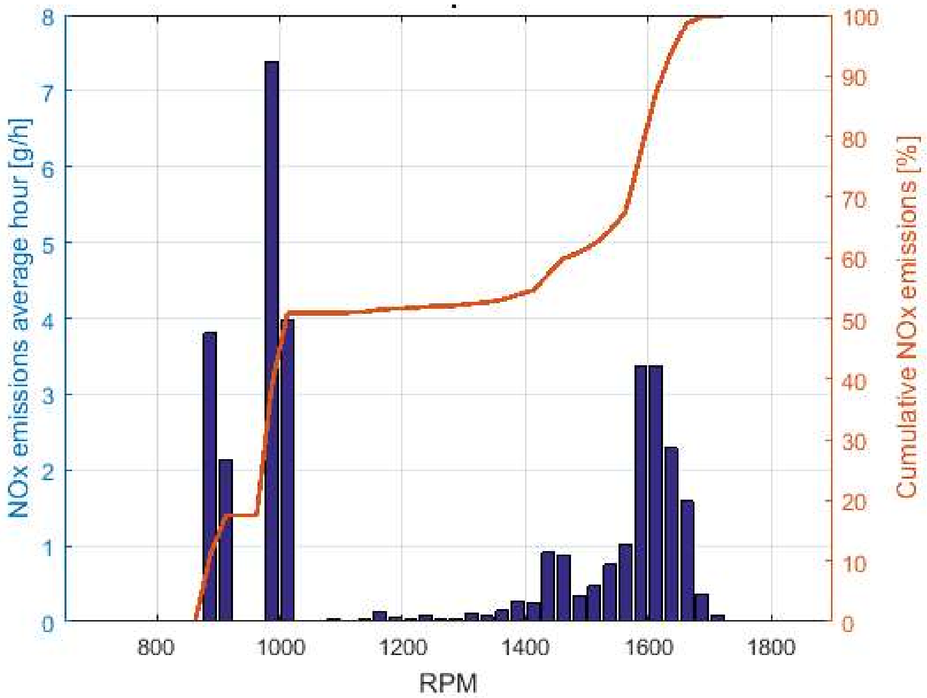

Figure 6: NO_x emissions and cumulative NO_x emissions vs. engine speed, for an average hour of operation. The total NO_x emissions per hour amount to an average of 34 grams. [1]

A dataset of 10 months of use of agricultural tractors in Switzerland (ongoing project of the Federal Office for the Environment) shows similar results. There about 30% of the operating hours and about 10% of the total fuel consumed are reported for the idling state.

Figure 7 shows the cumulative emissions simulated for different 110 kW diesel engines in an excavator. The NO_x emissions for the Stage IV version are in line with the figures above. The NO_x emission level increases from approx. minute 5 on, when the SCR temperature falls under the critical level for AdBlue dosing. Consequently the cumulative NO_x emissions, i.e. the sum of the second by second emissions, increase over proportional. Approx. 10 minutes after idling start, the SCR conversion has dropped to almost zero and a constant high NO_x emission level per second is reached. Consequently, the cumulative NO_x emissions increase linearly from this time on. For comparison also for a Stage III b engine and for a current EURO VI HD engine the NOx emissions in idling were simulated. Since the Stage III b has no SCR catalyst but controls NO_x with EGR, the idle emissions are quite constant over time and the cumulative emissions increase linearly. The EURO VI engine shows similar behaviour as the stage IV engine but on a clearly lower level.

The integrated fuel consumption has again a linear shape. In 30 minutes idling for the Stage IV engine a consumption of 1.5 litres was simulated. These values certainly depend a lot on the machine type and the auxiliaries running during idling. However, switching the engine off for a 30 minutes interval where the machine is not needed for work, saves some 30 gram NO_x and 1.5 litres of fuel. Besides saving fuel costs, also CO_2 emissions are reduced when the engine is not running in idling. Since each litre of diesel causes ca. 2.2 kg CO_2, saving fuel means also saving CO_2 emissions and reducing the impact of the machine operation on the global warming effect. In case of the excavator operation profile described above, with approx. 56% idling time, ca. 20% fuel and CO_2 emissions could be avoided if the engine is switched off in longer idling periods[5].

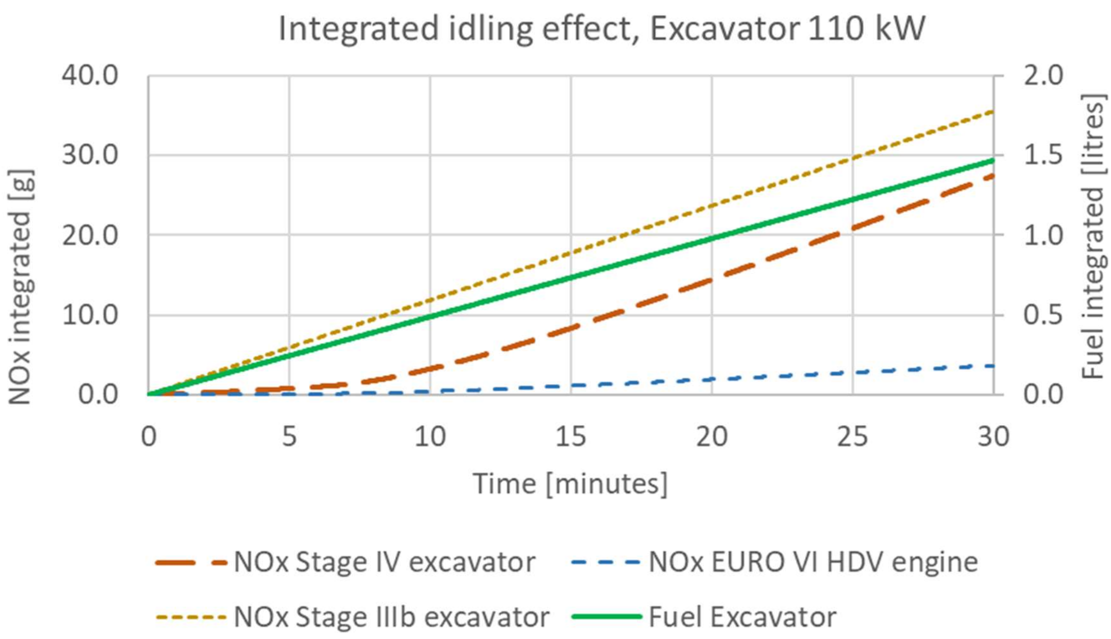

Figure 7: Cumulative NO_x emissions and cumulative fuel consumption simulated for different 110 kW engines in an excavator at idling. Idling starts at 0 minutes.

Since fuel costs have a relevant share in total operation costs, a 20% reduction is a relevant saving. For the excavator above, fuel costs have approx. 25% share in total costs of ownership, beside depletion and labour expenses. For larger machines the share in fuel costs increases due to increasing fuel consumption but unchanged labour costs.

When purchasing a new machine, yet no information on the fuel efficiency is available in a standardised form, such as for cars and trucks. Providing such an information could be a useful support in future but would need a corresponding Regulation from the European Commission and thus is not expected in near future.

Nevertheless, modern machines offer an automatic engine shut-off after some idling time (typically ca. 5 minutes). This option is a good investment to support the machine operators in fuel and emission saving behaviour. Software, recording the engine-off functions can help the vehicle owners to check if this function is turned off in real operation by the drivers.

6.1.1 Retrofitting options

For machines which are not equipped with a DPF and/or an SCR catalyst, retrofitting of NRMM with diesel particle filters (DPF) can significantly lower the PM and PN emissions of NRMM. Even with the current NRMM emission stage IV, new machines are not necessarily equipped with particle filters, since the limit values up to stage IV can also be reached with other exhaust treatment technologies [3]. It is expected that only the new PN limit value introduced with stage V (from around 2020) will force manufacturers to fit all new machines >18 kW with DPFs. However, given that a) some NRMM (especially agricultural tractors) reach rather high lifetimes, and b) the stock of machinery <18 kW is significant, this means that even by the year 2050 a relevant share of NRMM will not yet be equipped with DPFs

[5] With approx. 3l/h idling fuel consumption and 12l/h average consumption when the machine is operating we get 7l/h fuel consumption when the engine runs in idling and 5.3 l/h fuel consumption if the engine is always switched off instead of idling.

(Figure 8). Therefore, a retrofitting machinery with DPFs can have a significant impact, as shown by the example of the Swiss Ordinance on Air Pollution Control in Box 1 below.

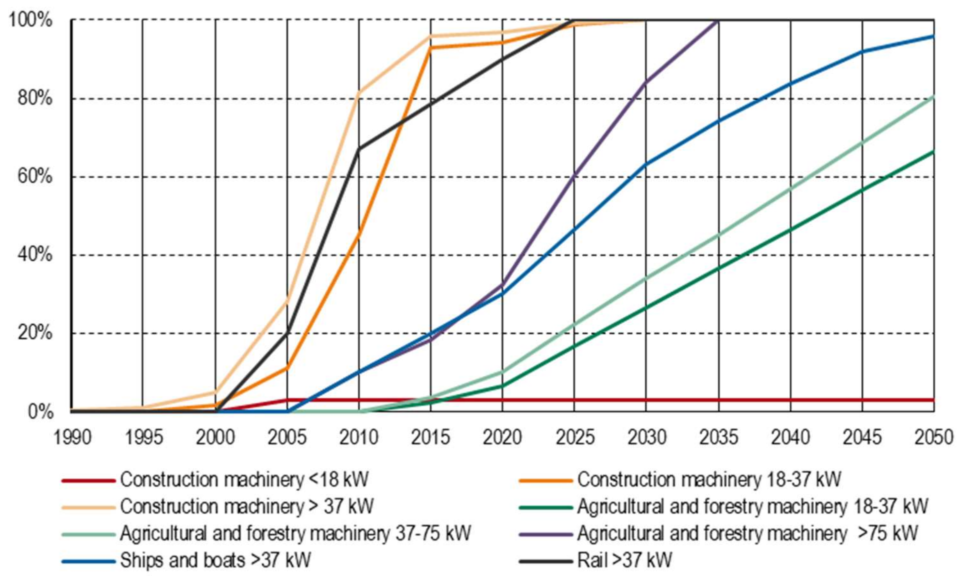

Figure 8: Shares of NRMM equipped with DPF in Switzerland (projected from 2015-2050). Note that for NRMM on construction sites, Swiss legislation requires DPF from 2009-2015 (source: [10]).

Retrofitting SCR catalysts is also possible, but the catalyst and the position of its installation have to be designed to reach sufficient NOx conversion rates in the typical engine operation points. As shown before for original equipment SCR systems, too low exhaust temperatures, e.g. due to an installation with long distance to the engine, bear the risk of low NOx conversion.

From the analysis of real world emission tests we can conclude:

- Idling can contribute high shares to the total NO_x emissions, especially for modern machines equipped with SCR due to cool down of the catalyst.
- Switching off the engine instead of idling avoids these emissions and also reduces the cool down effect. So NO_x emissions after re-start will be lower than after long idling.
- Comfort for the driver (cooling, heating) sometimes limits engine switch off phases but emission effects and fuel costs shall be considered in the decision. If the machine offers heating with residual heat or cooling with electric air conditioning, the engine should be switched off instead of idling.
- Retrofitting of (certified) DPF systems can reduce particle emissions from older machines significantly.

6.2 Powered Two Wheelers

As shown in chapter 5.2, the two-wheelers have relevant shares in HC and CO emissions. Beside exhaust gas emissions powered two-wheelers have also a relevant contribution to noise emissions. These emissions are discussed in the following chapters.

6.2.1 Exhaust gas emission

Table 5 and Table 6 show the emission limits for mopeds and motorcycles, starting from EURO 1 to the currently relevant EURO 4 limits.

Table 5: EU emission limits for powered two-wheeled mopeds (L1eB class)

EURO Class	Date new models	Test cycle	CO (g/km)	HC (g/km)	NOx (g/km)
EURO 1	17.06.1999	ECE R47	6.00	HC+NOx: 3.0	
EURO 2	17.06.2003	ECE R47	1.00	HC+NOx: 1.2	
EURO 4	01.01.2017	ECE R47	1.00	0.63	0.17
EURO 5	01.01.2020	WMTC	1.00	0.10	0.06

Table 6: EU emission limits for powered motorcycles (for L3e, L4e, L5e-A, L7e-A; >130km/h)

EURO Class	Date new models	Test cycle	CO (g/km)	HC (g/km)	NOx (g/km)
EURO 1	01.04.1998	ECE R40	8.00	4.00	0.30
EURO 2	01.04.2003	ECE R40	5.50	1.00	0.30
EURO 3	01.01.2006	ECE R40	2.00	0.30	0.15
EURO 4	01.01.2016	WMTC	1.14	0.17	0.09
EURO 5	01.01.2020	WMTC	0.50	0.10	0.09

Average emission levels found for powered two-wheelers in real world operation are available in the Handbook on Emission Factors (HVEFA 4.1, www.hbefa.net). Some examples for HC and for NO_x are shown in Figure 9 and Figure 10. Current mopeds and motorcycles cause less than 100mg NO_x/km which is roughly the level of current "EURO 6d-temp" diesel passenger cars but approx. a factor 10 lower than older EURO 5 diesel cars emit.

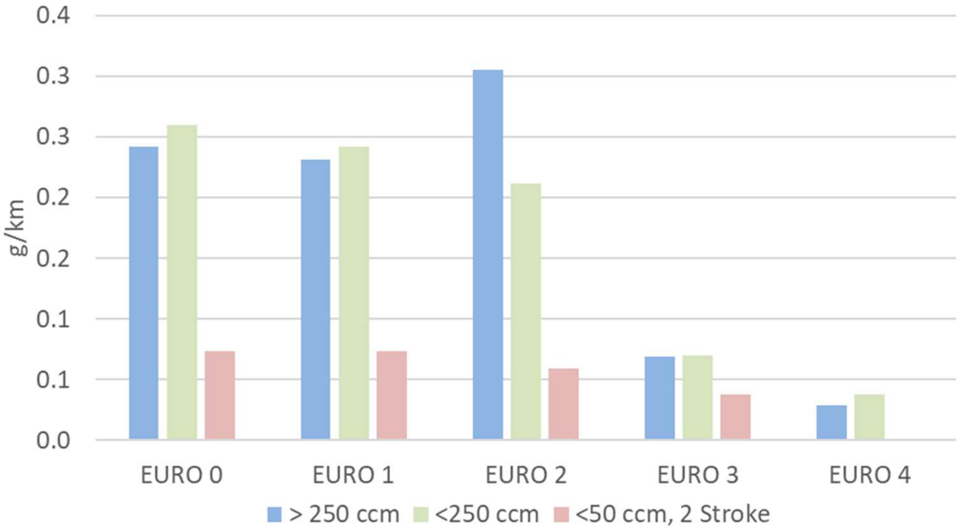

Figure 9: Average real world NOx emissions from powered two-wheelers. [4]

The hydrocarbon emission levels of motorcycles with EURO 4 approval are already quite low and in the range of gasoline passenger cars. For mopeds (<50ccm) yet no test data is available but looking at the EURO 4 limits, still rather high HC emissions from EURO 4 mopeds are expected.

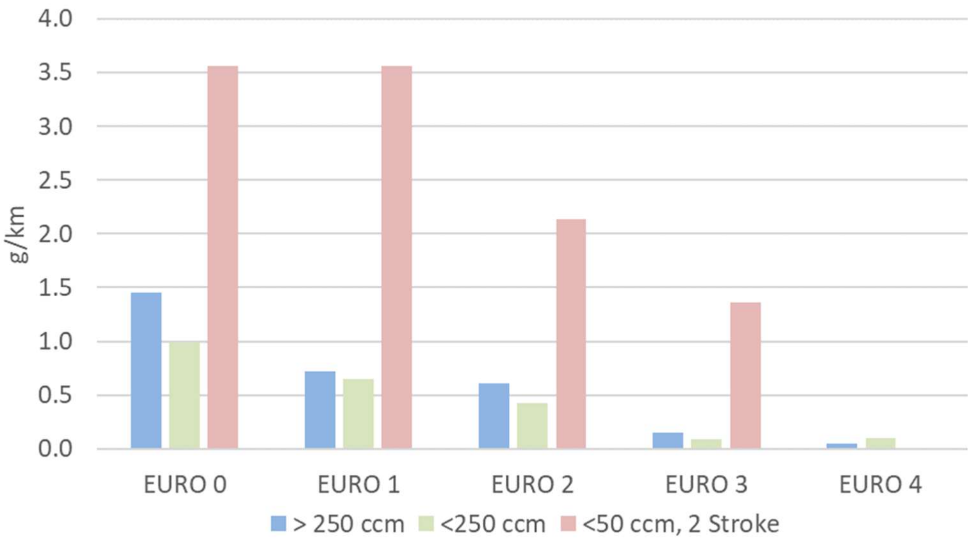

Figure 10: Average real world HC emissions from powered two-wheelers. [4]

The hydrocarbon emissions cover hundreds of different HC species, where some are very critical in terms of health effects. Especially benzene as a part of aromatic compounds, was so far found to have relevant concentrations in the exhaust. Especially at high power driving, the benzene emissions can increase, as shown in Figure 11. Thus, high power driving should be avoided at least in areas with high population density.

Table 7: list of some relevant HC species in exhaust gases of combustion

Species	Effects
C_2H_2 Acetylene	Non-toxic; anesthetic effects
C_4H_6 Butadiene	Carcinogenic, toxic, associated with cardiovascular disease
C_3H_6 Propene	Low toxic effects
C_6H_6 Benzene	Carcinogenic, toxic; harms central nervous system and hematopoietic system for chronic toxicity
HCHO Formaldehyde	Carcinogenic; trigger allergies; skin, respiratory, eye irritations
C_2H_6 Ethane	Weak anesthetic effects
CH_3OH Methanol	Harms central nervous system, but lower risk via respiratory tract
CH_4 Methane	Not toxic but strong greenhouse gas
NH_3 Ammonia	NH_3 vapors are irritating and caustic

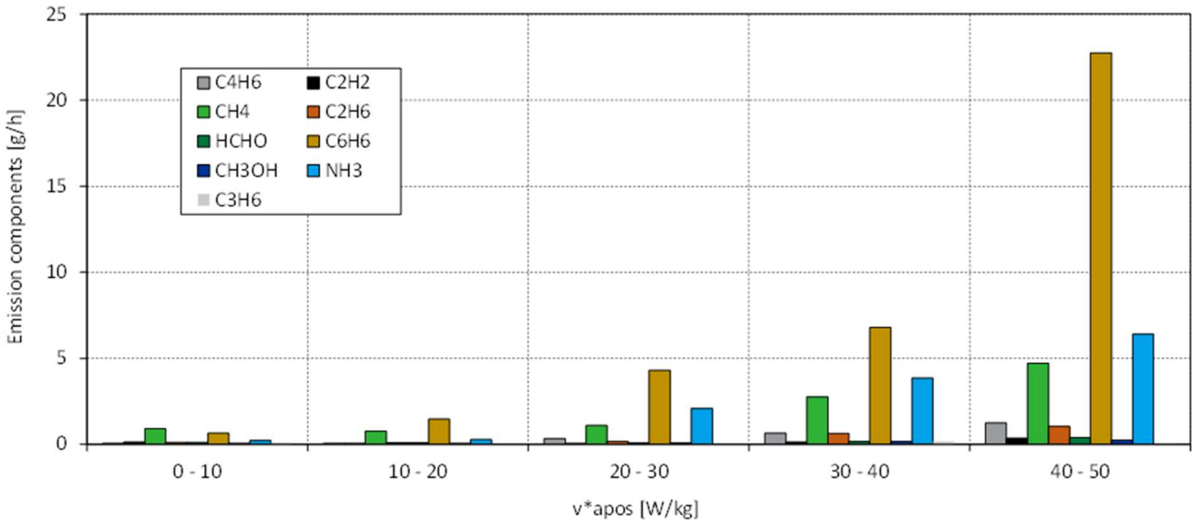

Figure 11: Non-regulated exhaust gas component emissions in real world tests as function of the "dynamic trip indicator $v*a_{pos}$ in [W/kg] for a EURO 3 motorcycle with 800ccm[6].

Beside emissions under hot running conditions, powered two-wheelers produce also rather high emissions in cold starts, when the catalyst is below operating temperature. Total emissions from cold start have a similar order of magnitude as the total hot emissions, [7]. Thus avoiding short trips reduces emissions over proportional to the mileage reduced.

Also evaporative emissions are relevant for mopeds and motorcycles. The fuel in the tank evaporates and with increasing temperature the gas volume in the tank expands and hydrocarbons are emitted. In modern PTWs, hydrocarbons are trapped in cartridge filters while the air escapes to the ambient. After some time the capacity of the cartridge filter to store these HC vapours is saturated and the emissions are released to the ambient. The HC emissions from evaporation increase with increasing tank temperature. Thus avoiding parking directly in the sun reduces HC evaporative emissions.

From the analysis the main conclusion for drivers of power 2-wheelers, who want to reduce environmental impacts is:

- avoid harsh accelerations at least in urban areas to reduce hydrocarbon emissions,
- do not park the vehicle in direct sun light if possible.
- do not tamper the vehicle, e.g. replacement of OEM exhaust system and removal of catalyst

Certainly a bad maintenance of the vehicle and (improper) tuning of engine and removal of catalyst components (tampering) can lead to very high emissions in all driving conditions.

6.2.2 Noise emission

The vehicle category of powered two wheelers is also a major source for complaints from the population related to the noise emission of this vehicle category. A series of research projects from EU member states and the commission related to this subject have been

[6] $v*a_{pos}$ means speed x acceleration, which shows the engine power needed for acceleration per ton of vehicle mass. It has to be noted, that these benzene emission results contain uncertainties due to the measurement principle (FTIR)

executed in the past, especially in connection with the introduction and application of the first EU-wide regulation for the noise limitation of motorcycles during type approval (78/1015/EEC).

6.2.2.1 Sound limits and real world noise emissions

The sound limits for motorcycles and other L-category vehicles are shown in Table 8. EU-wide sound limits were introduced with Euro 1 and remained unchanged for Euro 2 and Euro 3 vehicles. With Euro 4 the measurement methods as specified in UN-ECE Regulation 9 for vehicle categories L_2, L_5, L_6-B (light quadrimobiles) and L_7, Regulation 63 for vehicle categories L_1 and L_6-A (light on-road quads) and Regulation 41 for vehicle categories L_3 and L_4 (Motorcycles and motorcycles with side-car) became mandatory with Regulation 168/2013/EC from January 2017/2018 on. This led to a change in the vehicle classification, the measurement method and the limit values for motorcycles, while measurement methods and limits for the other L-categories still remained unchanged. But this is effectively also the case for motorcycles, because the lower limits only compensate the change in the measurement method. Only wide-open throttle acceleration test is mandatory according to the old method, a weighted average of a wide-open throttle test and a constant speed test is needed according to the new method.

That means the current sound limits for motorcycles and other L-category vehicles are still the same as 20 years ago.

Table 8: Sound limits for motorcycles and other L-category vehicles

	97/24/EC (Euro 1)		2002/51/EC, Euro 2		2002/51/EC, Euro 3		168/2013/EC, Euro 4 vehicles		
1. Two-wheel mopeds (category L_1)	sound limit in dB(A)	enforce-ment date	sound limit in dB(A)	enforce-ment date	sound limit in dB(A)	enforce-ment date	measurement method changed for L_3	sound limit in dB(A)	enforce-ment date
powered cycle								63	January 2018
moped, v_{max} <= 25 km/h	66	June 1999	66	July 2004	66			66	
moped, v_{max} > 25 km/h	71		71		71			71	
2. three-wheel mopeds (category L_2)	76		76		76			76	
3. Motorcycles (category L_3)							power to mass ratio index		
<= 80 cm³	75		75	July 2005	75	July 2007	<= 25	73	January 2017
> 80 <= 175 cm³	77		77		77		25 < pmr <= 50	74	
> 175 cm³	80		80		80		> 50	77	
4. Tricycles (categories L_4, L_5, L_6, L_7)	80		80	July 2004	80			80	

It is stated in Regulation 168/2013/EC, that new sound limit values shall be applied for Euro 5 vehicles from January 2021 on. The EU-Commission launched a research project in which proposals for such new limit values should be elaborated. The study was published by the EU-Commission in 2017[7], but the limit values are still under discussion.

6.2.2.2 Effects on real world noise emissions

Although the sound limit values for motorcycles will be further reduced in 2021, it can be foreseen that this will not improve the situation with respect to the noise annoyance caused by motorcycles. This category, even when equipped with original silencers, can still produce higher noise emission values than heavy duty trucks and the average driving behaviour is still related to high accelerations and high engine speeds, both leading to high noise levels. And there is still a high percentage of motorcyclists (in the order of 25 to 30%) using illegal

[7] Study on Euro 5 sound level limits of L-category vehicles, Written by Papadimitriou, G., Ntziachristos, L., Durampart, M., Dittrich, M., Steven, H., October – 2017, Publications Office of the European Union, 2017, ISBN 978-92-79-70064-4

exhaust and/or intake silencers producing even higher sound emission levels than the original vehicle parts.

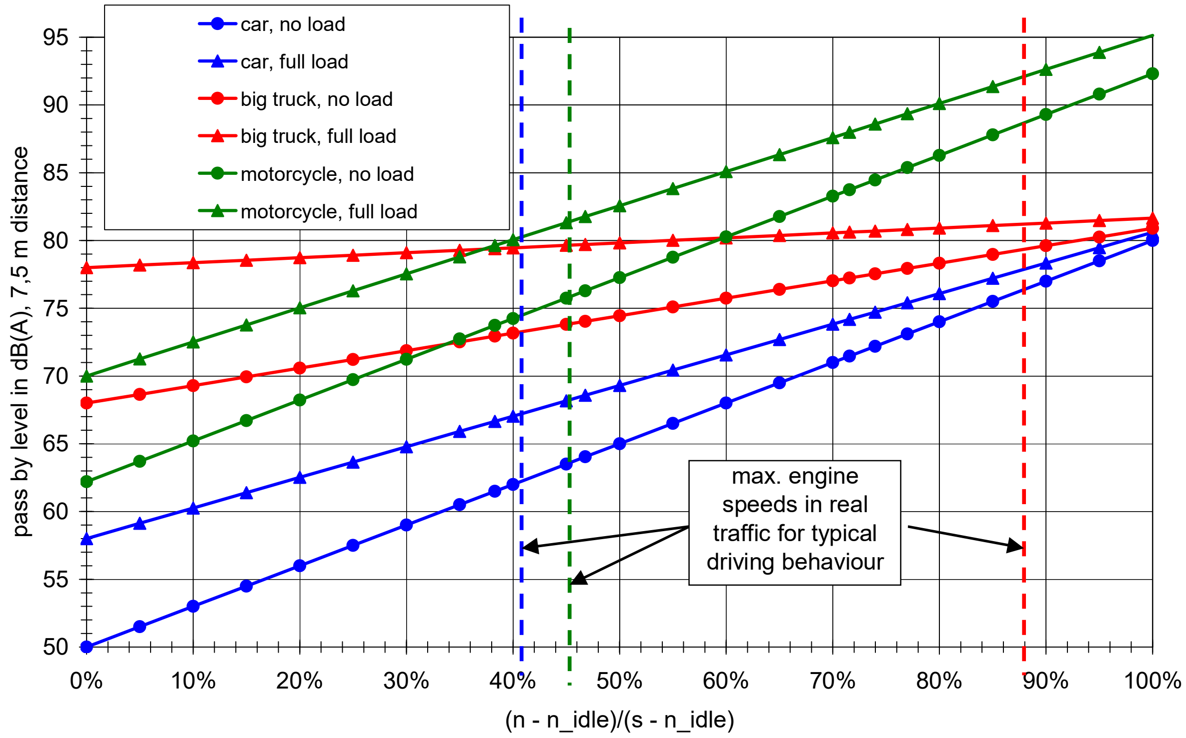

Figure 12: Pass-by noise levels of a car, a big truck and a motorcycle (average vehicles) as function of engine speed and load[8] (x-axis: 0% is idling engine speed, 100% is rated engine speed)

Figure 12 also shows that motorcycles have the highest noise reduction potential with regard to a change in driving behaviour. Unfortunately, a high percentage of motorcyclists prefer and practice a "sporty" driving behaviour with high engine speeds. But high engine speeds are not necessary for a "sporty" driving behaviour. This was already shown in a presentation for the GRB informal working group R 41 from 2005[9]. This group developed the amendments for the motorcycle sound measurement method specified in UN-ECE Regulation 41 and leading to the 04 series of amendments with a new method, a new vehicle classification based on power to mass ratio and to additional sound emission provisions (ASEP).

The following figures are taken from this presentation. It can be concluded that the acceleration potential in low gears (up to 3) at normalised engine speeds up to 30% is already higher than the threshold values for tyre slip and that the acceleration potential in higher gears in this engine speed range is by far high enough for a "sporty" driving behaviour, so that there is absolutely no need to use high engine speeds in real traffic.

[8] Noise Emission of Road Transport, H. Steven, presentation at the CALM network conference at 19.10.2004 in Brussels

[9] see http://www.unece.org/fileadmin/DAM/trans/doc/2005/wp29grb/17-R41WG-05e.zip

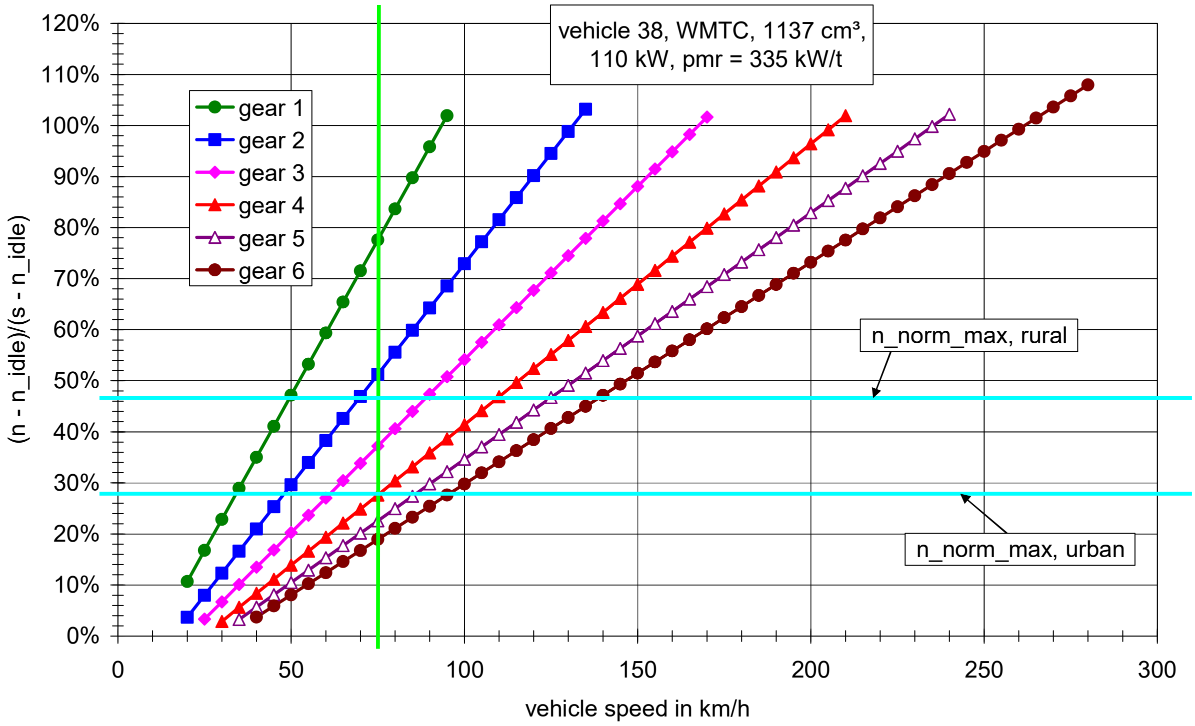

Figure 13: Normalised engine speeds versus vehicle speed for a motorcycle

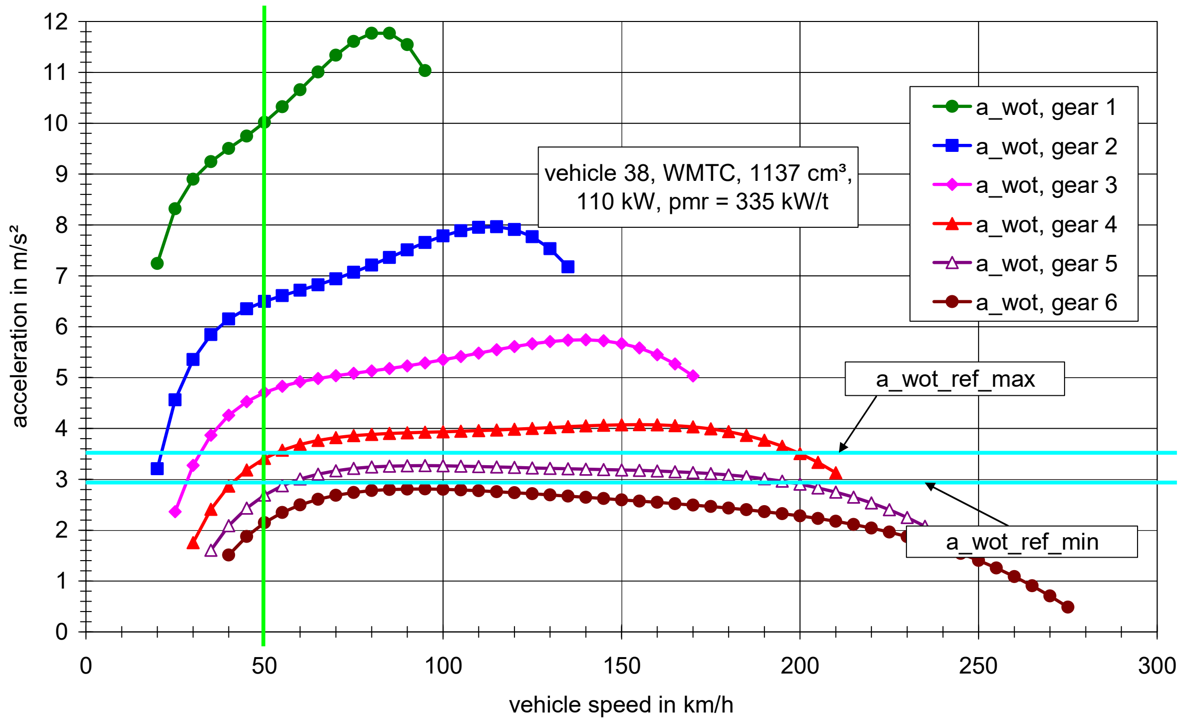

Figure 14: Acceleration potential as function of gear and vehicle speed

The following measures are recommended to policy makers in order to improve the situation:

- Roadside enforcement test campaigns based on tests with the vehicle in motion instead of the currently practised stationary nearfield test, because the latter is a test with no load on the engine and modern illegal exhaust systems can be constructed in that way that they fulfil the requirements of the stationary test but lead to much higher sound emission under full throttle acceleration.

- Improve the labelling system for replacement exhaust and intake silencers or other noise relevant vehicle parts in order to ease the detection of illegal parts during roadside enforcement tests.
- Improve the legal requirements to increase the possibility to confiscate illegal noise increasing vehicle parts.
- Campaigns to increase the motorcyclist's awareness about the annoyance potential of her/his driving behaviour in the vicinity of built-up areas with the aim to influence her/his driving behaviour towards a less noisy driving style near these areas. This driving style means primarily low engine speeds but not necessarily low accelerations or less driving pleasure.

6.2.2.3 Options to reduce noise emissions

As example for an early research, the German Environment Agency (UBA) launched a research project in the early 80's dedicated to the measurement of noise emission of all kind of road vehicles in real world operation with the aim to propose reduction measures for the noise emission in real traffic. Also amendments for the type approval noise tests in order to improve their effectiveness were elaborated. The results were published in 1984[10]. In this project powered two wheelers from mopeds to high powered motorcycles were included. Illegal manipulations of the vehicles proved to be a central problem. More than 50% of the Mofas and Mopeds measured in real traffic had illegal modifications dedicated to an increase of the maximum speed far beyond the legal speed limit but with the side effect of a significant increase in the noise emission (up to 10 dB(A)) compared to legal vehicles. The percentage of motorcycles with illegal modifications was 30%. But unlike for Mofas and Mopeds the modifications for motorcycles were mainly intended to increase the noise emission and thus related to intake and exhaust silencers. Noise increases up to 15 dB(A) were found in the examined vehicle sample. An increase by 10 dB(A) means basically a duplication of the noise.

Interestingly enough, the percentage of motorcycles with illegal modifications in the current fleet is still estimated to 30%, which shows, that all measures to hamper those modifications were not really effective.

One part of the project was dedicated to the influence of individual driving behaviour for a given vehicle. Three different driving styles were practised and compared: aggressive, normal and moderate. The aggressive driving style can be characterised by the target to reach the destination as fast as possible. This leads to significant higher accelerations (with peaks up to twice as high as for the normal driving style). This requires higher engine power values and thus higher engine speeds causing higher noise emissions as side effect compared to the normal driving style. In addition to that, it was concluded that this driving style increases fuel consumption and thus CO_2 emissions and wear. The time saving potential of the aggressive driving style was rather limited: On average 1.5 min over a distance of 5 km.

The moderate driving style can be characterised as the opposite: Drive anticipatory, avoid unnecessary acceleration phases and or high acceleration values and perform upshifts to the next higher gear during accelerations as soon as possible. This leads to lower engine

[10] Emission values for motor vehicles – scientific-technical preparation of legal regulations and EC-guidelines for the determination and reduction of the noise emission limits for trucks, busses, passenger cars and motorcycles, Hubert Frenking and Heinrich Steven, Forschungsinstitut Geräusche und Erschütterungen, Aachen, by order of the German Environment Agency, UFOPLAN-Ref No 84-105 05 101, June 1984

power requirements and lower engine speeds and thus to lower noise emission, lower fuel consumption and lower CO_2 emission compared to the normal driving style.

The difference in the noise emission between the aggressive and moderate driving styles was found to be 7 to 8 dB(A) for average noise levels and up to 15 dB(A) for peak values (95% percentiles).

<u>Determination of Noise emission values from motorcycles on the basis of practical driving collectives</u>

A complementary project also launched by the German Environment Agency a bit later[11] dealt with the results of urban journeys undertaken on 20 different motorcycles with a high variation in technical design features. During the journeys driving and operation conditions and noise emissions were continuously recorded. The aim of the project was the elaboration of proposals for amendments of the type approval measurement method for the noise emission of motorcycles with the target to bring the type approval noise emissions closer to the noise emissions in real traffic.

The different driving styles from the previous project were also practised in this project. The differences in the noise emission between the two extreme driving styles were on average (over all vehicles and driving situations) 8.5 dB(A); the reduction potential of the moderate style compared to the normal style was 3.5 dB(A) on average and 5 dB(A) for the more annoying peak values. Therefore, the results of this project confirmed the results of the previous study for a larger vehicle sample. Furthermore, the results showed that the differences in the noise emission in real traffic for the normal driving style between the loudest and the quietest of the 20 motorcycles was 9 dB(A) and that this difference was not related to differences in technical parameters like rated power, rated speed, engine capacity or number of cylinders rather than the individual technical design of noise relevant components and reduction measures. The quietest vehicle was the vehicle with the highest rated engine speed.

<u>Technical measures in order to prevent noise-intensive operation conditions for passenger cars and motorcycles</u>

Far ahead of its time was another project of the German Environment Agency whose results were published in 1986[12] (33 years ago). The aim of this project was to design, build and test a technical control device able to avoid unnecessary high engine speeds and thus limit the noise emission, fuel consumption and CO_2 emission of the vehicle in urban traffic. The control device was tested with a normal passenger car and a 750 ccm motorcycle. To enable to follow the normal urban traffic flow with its varying conditions the microcomputer steered control device adjusts an engine speed limit far below rated engine speed related to the power demand for the actual driving conditions. This ensures proper driving for road gradients as well as for towing a trailer or driving with a sidecar. When tested in urban driving the control device reduced engine speed peaks to halve of the values achieved in aggressive driving behaviour. This is equivalent to a reduction of noise peaks by 10 to 15 dB(A). The control device was completed with an infrared receiver providing external control through local transmitter when entering or leaving noise sensitive areas within an urban environment. But this technical measure was too futuristic at that time and was therefore not further developed.

In the 1980s the activities for the noise reduction of powered two wheelers as of other road vehicles focussed on technical measures for the noise relevant components of the vehicles. But from annoyance studies and complaints of the population about road traffic

[11] Determination of Noise emission values from motorcycles on the basis of practical driving collectives, Heinrich Steven, Forschungsinstitut Geräusche und Erschütterungen, Aachen, by order of the German Environment Agency, UFOPLAN-Ref No 105 05 115/02, December 1984

[12] Technical measures in order to prevent noise-intensive operation conditions for passenger cars and motorcycles, Harald Pauls and Heinrich Steven, Forschungsinstitut Geräusche und Erschütterungen, Aachen, by order of the German Environment Agency, UFOPLAN-Ref No 105 05 131, September 1986

noise it became clear that the (measurable) sound emission levels can only partly explain the ranking of different vehicle categories with respect to their annoyance potential. Motorcycles and other powered two wheelers always have the lead in such rankings, even if their measured sound levels were lower than those of heavy trucks. One reason is the fact that the high noise emission of motorcycles is perceived as unnecessary high e.g. compared to heavy trucks.

6.2.2.4 Proposals for further noise reduction

In the 1990s the German Environment Agency launched a research project[13] dedicated to the noise emission of powered two wheelers, in which all important aspects should be investigated:

- Technical measures,
- Legislation,
- Illegal manipulation and replacement parts,
- Roadside enforcement, surveillance and sanctions,

A consortium of different partners (engineers, psychologists, lawyers, police officers and people from the national motorcycle association) was established in order to ensure interdisciplinary cooperation.

Within this research project measures and strategies for their execution were developed which lead to a reduction of the noise emission of motorcycles in real traffic. Following tasks have been carried out:

1. Analyses of vehicle stock and the aftermarket for noise relevant accessory parts (intake and exhaust silencers) as well as the advertising for these parts,
2. Inquiries of motorcycle drivers for their attitudes and ratings with respect to the noise emission of their vehicles and investigation of the driving behaviour of different drivers on typical circuits for motorcyclists,
3. Measurements of the noise emission of different motorcycles on an ISO-test track for defined driving and engine conditions,
4. Evaluation of legislation for type approval and roadside enforcement and police surveys,
5. Development of measures and action plans for the reduction of the noise nuisance caused by motorcycles (responsible: Lärmkontor, in cooperation with the other project partners).

On the basis of the results of the different tasks recommendations for action plans have been developed and harmonised between the project partners.

The analyses of vehicle stock resulted in the following policy recommendations:

[13] Reduction of the noise emission of motorcycles – Proposals for further noise reduction, Reiner Brendicke (ifz), Elmar Forke (ifz), Klaus Jankowski (Uni Hamburg), Hartmut Kerwien (Uni Bielefeld), Hans-Joachim Koch (Uni Hamburg), Christian Popp (Laermkontor), Ulrich Schulz (Uni Bielefeld), Heinz Steven (FIGE), by order of the German Environment Agency, UFOPLAN-Ref No 105 06 075, March 1998

- The marking of the silencer must be made tamper-proof,
- Welding of the components or fixed connections between the components should be mandatory for the replacement silencers,
- Illegal replacement silencers should not be used as duplicates of approved replacement silencers,
- The attractiveness of silencers for racing bikes should be significantly reduced by binding noise limits also for racing bikes in order to reduce the illegal use on motorbikes on the road.

<u>The Inquiries of motorcycle drivers</u> can be summarised as follows:

- The investigations about the driving behaviour and the attitudes of motorcyclists to their sound emission have impressively illustrated that the change of the driving style represents an enormous reduction potential not only for the measurable noise pollution but also for the noise nuisance. The results of this task clearly show that the problem cannot be reduced only to vehicles with modified or illegal noise relevant components.
- However, the problem cannot be solved only by technical means, because the sound of the motorcycle is seen by many motorcyclists as an integral part of the appearance of the machine and “good sound” is associated for most drivers with high emission values.
- The above statements can be concretized as follows:
    - Motorcycling is in most cases a recreational activity for which there are (still) no relevant assessment criteria.
    - Many motorcyclists spend a relatively large amount of money on their leisure equipment, which they use only on relatively few days of the year. The vehicle is intended to experience driving pleasure (e.g. acceleration, speed etc.).
    - Motorcycle noise is not a nationwide but a mostly local problem in the environment of "attractive" routes.
    - Motorcycles are mainly driven during times when many people are looking for recreation - in the warm summer months, on weekends and evenings - and therefore acts disproportionately as a major source of conflict. This problem is especially critical in holiday resorts.
    - Information deficiencies exist, in particular, among the law enforcement agencies (for example, the distinction between legal and illegal noise relevant vehicle components) and the motorcyclists themselves (for example, motorcyclists are not aware that the noise emission that they perceive as “sound” is perceived as unnecessary noise nuisance by people looking for recreation).
    - A change of their driving behaviour to more silent driving behaviour cannot be achieved by argumentation only for most motorcyclists. And such change of the driving behaviour is even more difficult to achieve for drivers of motorcycles operating with illegal noise relevant components.
- To achieve such a change of driving behaviour, the awareness of the drivers about the harassment effect of their noise emission needs to be strengthened, which probably already has to start in the driving school or even earlier. However, in this context one has to avoid any demonization of the motorcycle. Rather, what is meant is that the driver is made more aware of the potential for disturbance and that this is no longer indifferent to him.

  In order to achieve a lasting effect in the context of driving instructions to obtain the driving licence for motorcycles, one would have:

- To give a higher priority to the knowledge and the awareness about the influence of the driving behaviour on the noise emission and how to practice a noise-reducing driving style,
- To make the high potential for annoyance from motorcycle noise more conscious and
- To make the driving instructors more aware of this problem.

Measurements of the noise emission of different motorcycles can be summarised as follows:

- Viewed across the EU, motorcycles are the loudest vehicle category in terms of their noise emission and annoyance potential. The results from this task illustrate the enormous impact of engine load even on vehicles with original silencers. Such engine load influence is no longer encountered in modern passenger cars.
- Here is still a noise reduction potential given, which can be used by further lowering the noise limit values. However, a prerequisite for this is a more practice-oriented and more manipulation proof or more cycle beating resistant noise measurement method, which certainly is not in hand of the PTW drivers.
- For amendments of the measuring method should also be considered that the motorcycle noise is characterized by a high information content, rapid level increases and rapid spectral shifts. Motorcycle noise is not the problem of roads with high traffic load and high average noise levels, but the problem of the individual vehicle, the individual technology and the individual driving style. These characteristics are not sufficiently considered in today's traffic noise control regulations.

Evaluation of legislation for type approval and roadside enforcement and police surveys

From the compilation of the various legal levels of control and the results of the expert interviews, some recommendations and suggestions could be derived. The recommendations are aimed primarily at the police departments responsible for controlling motorcyclists. The proposals should contribute to a discussion on the possible amendment of individual legislation in the present context.

The results for this task shall not be discussed in detail here, because there are big differences in the roadside enforcement regulations between EU member states, they were even found within Germany between the federal states. But one general aspect should be mentioned, which is most probably also valid in other EU member states.

It became clear from the questioning of the police services that perform roadside enforcement checks that too superficial and insufficiently consequent treatment of the violations by the registration authorities and the courts raises doubts as to the appropriateness of such police controls.

From today’s perspective one can conclude that some progress has been made since the time of this project with respect to technical issues like improvement of measurement methods, hampering of cycle beating measures and hampering the use of illegal noise increasing vehicle components but the situation for issues like influencing driving behaviour, administrative side conditions for roadside enforcement test etc. remain almost unchanged.

6.3 Heavy Duty Vehicles

As shown in chapter 5.2, the HDVs have relevant shares in CO2 and NOx emissions. Beside exhaust gas emissions powered also noise emissions are relevant. These emissions are discussed in the following chapters.

6.3.1 Pollutant emissions

Similar to the other road and non-road vehicles also for HDVs emission limits were introduced in Europe. EURO 1 started in 1993, the current regulation is EURO VI d. The letter after the "VI" indicates the update of the regulation. Since EURO VI "a" the on-board test methods were continuously extended. For HDVs the engine is type approved and has to demonstrate in an engine test and in an on-board test on a typical vehicle, that the emission limits are met. The on-board test has the same limits as the engine test, just a so called "conformity factor" is multiplied to the limits to consider the higher test uncertainties during on board measurements. When an engine is type approved, it can be mounted in any HDV. Therefore the emission limits are similar to those from NRMMs defined in g/kWh, where the kWh represent the engine work during the test.

On-Board measurements have been introduced with EURO VI the first time and improved the real world NOx emission level significantly. As mentioned above, from EURO VI a to VI d the On-Board test definition was extended towards lower engine loads and to include a higher share of engine cold start emissions. With EURO VI also the first time a PN (particle number emission) limit was introduced, leading to a general application of particle filters on HD engines.

Table 9: Emission limits for HD diesel engines in the EU.

Date	Class	Test cycle	CO	HC	NO_x	PM	PN
			[g/kWh]				[#/kWh]
1993	EURO I	ECE R 49	4.9	1.23	9.00	0.4	--
1995	EURO II	ECE R 49	4	1.1	7.00	0.15	--
2000	EURO III	ESC	2.1	0.66	5.00	0.1	--
2005	EURO IV	ETC	4	0.55	3.50	0.03	--
2008	EURO V	ETC	4	0.55	2.00	0.03	--
	EEV	ETC	3	0.40 (NMHC)	2.00	0.02	--
2013	EURO VI	WHTC	4	0.16	0.46	0.01	6E+11

Figure 15 and Figure 16 show the average NOx and PN emissions from two HDV categories in European driving from HBEFA 4.1 (www.hbefa.net). The tractor-trailer combination (40t maximum weight and half loaded) and the city bus (2 axle, half loaded) shall represent average driving of such vehicles.

The figures show drops in all relevant exhaust gas components from EURO V to EURO VI. As for NRMM, the HC and CO emissions are on a very low level already from EURO IV on. Beside these "regulated" exhaust gas components, some HDVs emit relevant levels N_2O (very strong greenhouse gas). Which is mainly a result of improper AdBlue dosing. It is expected that a "EURO VII" regulation will cover N_2O better.

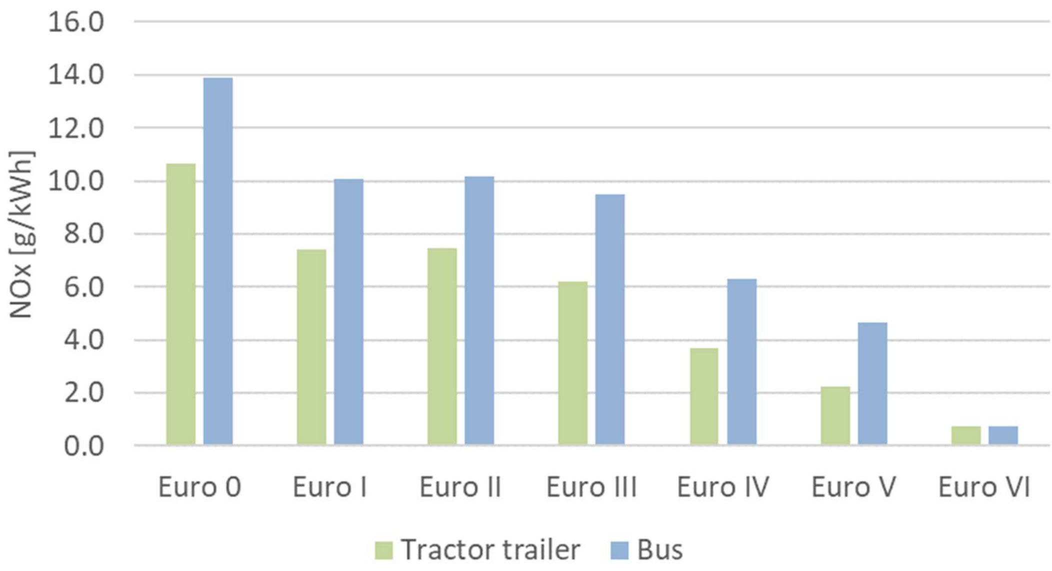

Figure 15: average NOx emissions from two HDV categories in European driving.

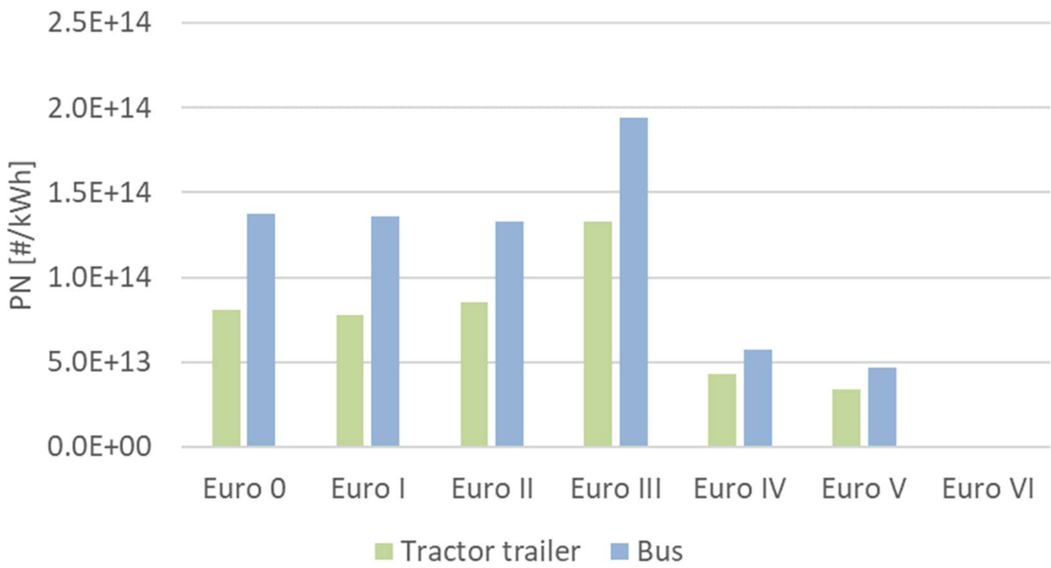

Figure 16: average PN emissions from 2 HDV categories in European driving (EURO VI is below $7*10^{10}$ #/kWh and therefore almost not visible in the graph).

In real world HDV operation also the SCR temperature is essential for low NO_x emissions. Compared to the NRMM the HD test procedure demands more efforts from manufacturers to maintain the SCR temperature on a level where AdBlue dosing is still possible. However, even for HDVs the regulations do not cover cold starts and low load completely. Thus, for EURO VI thermal management is not needed for long low load driving and directly after a cold start, since such situations are yet not properly covered. Therefore several vehicles show increasing emissions at low load and cold engine operation. Figure 17 shows average NO_x emissions from single EURO VI HDVs over an entire trip measured on-board. The green bar indicates the limit for on-board tests in type approval. The low load tests are not valid tests according to the current legislation, thus limits can be exceeded without legal consequences. In a next update of the exhaust gas legislation, we may expect an extension of valid test conditions to cover such driving conditions.

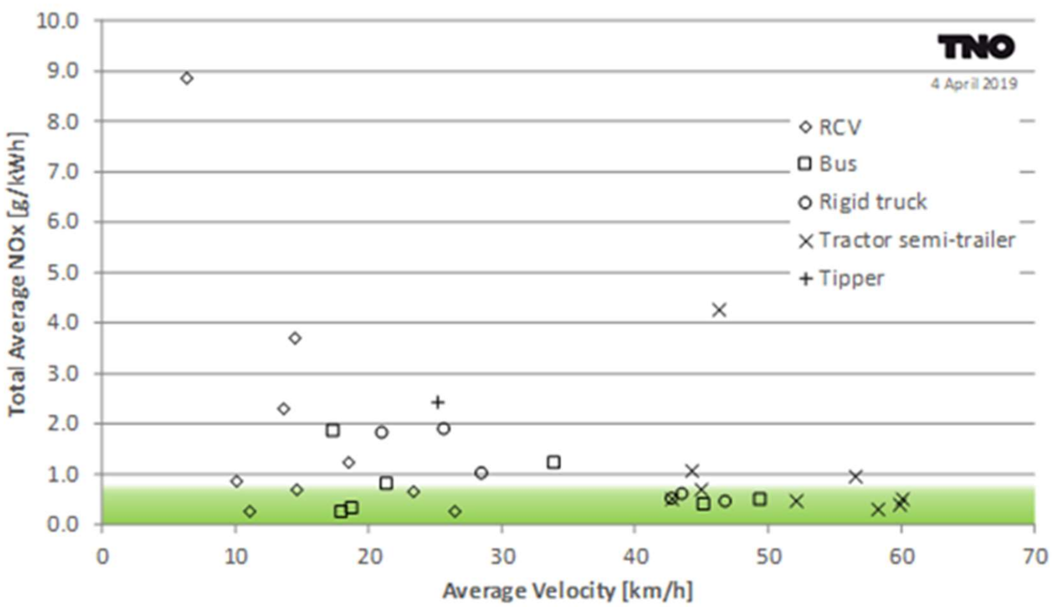

Figure 17: Average NOx emissions from single EURO VI HDVs over an entire trip (RCV: refuse collection vehicle) [5], [6]

As a HDV owner, one could select propulsion systems which have low emissions in the specific mission profiles. This however, needs on-board tests of different brands, diesel and CNG etc. which is a costly task, at least if not already real world test results are published. The ERMES group may be a source for such information (https://www.ermes-group.eu/web/). Test activities may also be set by stakeholder organisations. Without measurements it cannot be judged, if a EURO VI has high or low NO_x emissions in critical driving situations. This is also valid for gas vehicles (CNG, compressed natural gas), which can also lead to high NO_x and usually have higher particle emissions than the current diesel HDVs with a filter.

Similar to the NRMM, a main influence of the driver is avoiding long idling of the engine, since in such phases the SCR catalyst cools down, which reduces the NO_x conversion. Below approx. 200°C AdBlue dosing is no longer possible, which further reduces the NO_x conversion down to zero when all Ammonia stored in the SCR is consumed (see chapter 6.1).

Therefore idling NO_x emissions also increase with the duration of the idling time, an example for a EURO VI HD engine was shown in chapter 6.1 already. Consequently turning the engine off in idling saves fuel and emissions and is worth the effort even for a few minutes stand still. Especially in longer idling phases the NO_x emissions increase drastically due to the reduced SCR efficiency (Table 10).

Table 10: Calculated course of the NO_x idling emissions from a EURO VI tractor over time after the engine dropped to idling (after urban driving)

	0-0.5h	0.5-1h	1-1.5h	1.5-2h	2-2.5h	2.5-3h	3-3.5h	3.5-4h
	NOx emissions [g/h]							
Euro VI	19.9	34.4	45.3	53.2	57.6	60.2	61.7	62.5

A specific topic are trailers and trucks with cooling systems. Typical cooling power demands for a semi-trailer with deep-freeze temperatures are 6 to 7 kW. To provide the necessary mechanical or electrical power to run the compressors of the cooling system, extra diesel units are installed. If these units are older than Stage V (Table 4), no emission limits apply for these units with typically clearly less than 30 kW. With Stage V limits are introduced but these are much higher than those for the engine of the vehicle.

As a result, the emissions produced by the diesel unit for cooling per hour are similar or even higher than the emissions of the engine of the vehicle for NO_x, CO, HC and PM (Table 11 and Table 12).

Certainly, deactivating the cooling system is not a meaningful option to reduce the vehicle emissions. But during breaks, overnight and for longer loading and unloading activities the cooling system can be connected to the electric grid to provide the power for the compressor. Beside the savings of fuel costs and avoiding noise emissions, also NO_x emissions equivalent to many hours of driving can be saved by running in these phases on electric energy.

Table 11: Assessment of emissions produced by a Stage V diesel unit to run a deep-freeze system on a HDV

	Power delivered	Fuel	CO_2	NO_x	CO	HC	PM
	[kW]	[kg/h]	[kg/h]	[g/h]	[g/h]	[g/h]	[g/h]
Rigid truck	6.0	1.62	5.11	40.5	30.0	4.50	2.40
Semi-trailer	8.7	2.34	7.38	58.5	43.3	6.50	3.47

Table 12: Average emissions of the engine from HDVs during driving from HBEFA 4.1

	Euro Class	Fuel	NO_x	CO	HC	PM	PN
		[kg/h]	[g/h]	[g/h]	[g/h]	[g/h]	[#/h]
Rigid truck	Euro V SCR	10.90	122.9	133.7	1.00	2.53	1.6E+15
	Euro VI	10.25	31.9	10.4	0.88	0.55	2.7E+12
Tractor +trailer	Euro V SCR	16.37	170.9	126.9	1.55	2.93	2.3E+15
	Euro VI	15.08	61.8	12.0	1.27	0.64	3.9E+12

Beside this, the driver can make use of the Advanced Driver Assistance Systems (ADAS) in many modern HDVs. Such systems can maintain the vehicle speed in a most fuel economic range around the target speed. E.g. the velocity is slightly reduced shortly before the top of a hill, since the target speed is reached at the following downhill again without engine power demand just by the gravimetrical force. Depending on the topography and traffic situation such systems can safe some 2% to 3% fuel and emissions in long distance driving.

In urban driving, the driving style has a more pronounced impact on fuel consumption and emissions. By an anticipatory driving style, i.e. coasting the vehicle early before a stop event, adds distances without fuel consumption. Since the engine does not inject fuel in motoring operation, no fuel is consumed and no emissions are produced in such coasting distances. Thus a driving style with higher coasting shares has less fuel consumption than a style with long driving at higher speed and then sharper braking. Driver trainings are offered at several institutions. Typical effects are reductions in fuel consumption up to 10%. Without motivation of the drivers, most studies report, that the effect of training is dropping over time to almost zero. Positive motivation could be e.g. setting targets for the vehicle fleet consumption levels (e.g. the drivers team shall reach -4% compared to average of last year) with some bonus systems for the entire driver team. The fleet consumption and individual consumptions can be monitored by the vehicle owners using software packages offered by most OEMs.

6.3.2 Noise emission

The temporal development of sound limits for heavy duty vehicles is shown in Table 13. In the 20th century the sound limits were lowered by 11 to 12 dB(A) within a time period of 24 years (between 1972 and 1996). And unlike for cars and motorcycles, where the lowering of the limits did not lead to a corresponding decrease of the noise emission in real traffic, the lowered sound limits led to a significant decrease of the noise emission in real traffic in the order of 7 to 8 dB(A). The lower reduction in real traffic is due to the fact that the tyre sound contribution is almost negligible for the type approval sound measurement conditions, while this is not the case for real traffic situations and heavy duty vehicles with trailers or semitrailers and consequently more tyres producing rolling sound.

The sound limits established with Regulation 92/97/EC remained unchanged for a period of almost 21 years until July 2017 With Regulation 540/2014/EC new measurement methods, a new vehicle classification system and new sound limits for three time periods were specified (see Table 13). The amendments of driving conditions for the sound tests and the vehicle classification system were necessary in order to adapt them to the change in engine and vehicle technology. E.g. the old rated power class below 75 kW was superfluous, because there were no heavy duty vehicles on the market any more with such low rated power values. The new system differentiates between N_2 (trucks with gross vehicle mass up to 12000 kg) and N_3 vehicles (gross vehicle mass > 12000 kg) and two rated power classes for N_2 and three rated power classes for N_3 vehicles (see Table 13).

The sound limits for phase 1 that are currently in force were set in a way that 90% of the vehicles would not need additional or more advanced sound reducing measures. The phase 2 limits coming into force in 2022/2023 are 1 to 2 dB(A) lower than the current limits (1 dB(A) for the highest rated power class for N_3 vehicles), the phase 3 limits coming into force 2027 are 3 to 4 dB(A) lower than the current limit values. So, further noise reduction can also be expected in real traffic.

Table 13: Sound limits for heavy duty vehicles in the EU

	70/157/EC		77/212/EC		84/424/EC		92/97/EC		changed vehicle classification and method	540/2014/EC, phase 1		540/2014/EC, phase 2		540/2014/EC, phase 3	
Heavy duty trucks (category N_2, N_3)	sound limit in dB(A)	enforce-ment date	sound limit in dB(A)	enforce-ment date	sound limit in dB(A)	enforce-ment date	sound limit in dB(A)	enforce-ment date		sound limit in dB(A)	enforce-ment date	sound limit in dB(A)	enforce-ment date	sound limit in dB(A)	enforce-ment date
rated power (Pn) < 75 kW	89	1972	86	1982	81	1990	77	1996	N_2, Pn <= 135 kW	77	July 2017	75	July 2023	74	July 2027
75 kW <= Pn < 150 kW	89		86		83		78		N_2, Pn > 135 kW	78		76		75	
Pn > 150 kW	91		88		84		80		N_3, Pn <= 150 kW	79		77	July 2022	76	
									N_3, 150 kW < Pn <= 250 kW	81		79		77	
									N_3, Pn > 250 kW	82		81		79	
average car	82		80		77	1989	74		average car	72		70		68	July 2026

The noise reduction potential of the driving behaviour is rather limited for heavy duty vehicles compared to motorcycles or cars. One reason is the fact that the noise increase with increasing engine speed is much lower than for cars or motorcycles (see Figure 12). In addition to that, low noise driving behaviour means low engine speed driving behaviour which is at the same time low fuel consumption driving behaviour. And since heavy duty vehicles are commercial vehicles, in contrast to motorcycles and cars the owners have an interest that their drivers practise such driving behaviour.

7 Summary of Options to Reduce Emissions

This chapter summarises the findings already explained in the chapters before.

7.1 Non-Road Machinery

The main influences from the driver and vehicle holder are:

- Proper maintenance
    - Maintaining the functionality of the aftertreatment systems is essential to achieve low exhaust emissions. Tampering the systems is a harmful activity, which is illegal and increases emissions by ca. a factor of 10 just to save costs for AdBlue.
    - Performing proper maintenance and service and not tampering emission control systems helps to reduce environmental harm.
- Reduce idling
    - Idling can contribute high shares to the total NO_x emissions, especially for modern machines equipped with SCR due to cool down of the catalyst. However, idling emission levels from older machines are higher than those from Stage V but have a lower share on their total emissions.
    - Switching off the engine instead of idling avoids these emissions and also reduces the cool down effect of the SCR. So also NO_x emissions after re-start of the engine will be lower than after long idling.
    - Comfort for the driver (cooling, heating) sometimes limits engine switch off phases but emission effects and fuel costs shall be considered in the decision. If the machine offers rest heating or cooling with electric air conditioning, the engine should be switched off instead of idling.
    - Using quick coupling systems, including also the hydraulic system if relevant, allows faster changes of equipment which reduces again idling but leads also to more frequent selection of the most efficient tool for a given target (e.g. shovel width)
- Use of alternative fuels
    - A measure with significant health benefits affecting hand-held devices is the use of alkylate gasoline with low benzene contents. According to a study by the Swiss Federal Office for the Environment [11], alkylate gasoline reduces benzene emissions by an estimated 96%. Box 2 explores the effect of alkylate gasoline for hand-held devices in more detail.
- Retrofitting options
    - Retrofitting particle filters to machinery with diesel engines which have no serial filter.

7.1.1 Case Examples

Good examples were found for measures in the NRMM sector in Switzerland.

Box 1: Retrofit of construction machinery with DPFs in Switzerland

The Swiss Ordinance on Air Pollution Control (OAPC) requires includes a limit value of $1x10^{12}$ #/kWh on the particle number emitted by all machinery >18 kW operating on construction sites. This requires affected machines to be

a) either equipped with a diesel particle filter (DPF) by the OEM (Original Equipment Manufacturer), or

b) be retrofitted with a DPF listed on the so-called VERT list by the Federal Office for the Environment (FOEN).

In addition, an electronic surveillance system must be in place to ensure the proper functioning of the filter.

The VERT list [12, 14] contains both DPF types with a filtering rate of at least 97% as well as OAPC compliant engines, which is equivalent to Directive 97/68/EC compliance plus OAPC certification. The lists can be downloaded from:

- DPF types: https://www.bafu.admin.ch/bafu/en/home/topics/air/info-specialists/particle-filter-list/particle-filter-system-types.html
- OEM engines: https://www.bafu.admin.ch/bafu/en/home/topics/air/info-specialists/particle-filter-list/engine-types--oem-.html

The PN limit value of the OAPC entered into force in 2009 and is valid for machinery 18-37 kW from construction year 2010 and for machinery >=37 kW of all construction years; old machines had to retrofitted at the latest by 2015 [12, 13].

Its effects are visualized in Figure 18. The range that can be influenced by Swiss legislation lies between

- the upper boundary of the emissions that would result with EU regulations only – i.e. an increase of emissions with increasing activities until approx. the year 2000, then a gradual reduction due to the EU NRMM emission stages; and
- the lower boundary of emissions that would result if all machines had always been equipped with a DPF.

For construction machinery, the actual reduction compared to a scenario with only EU regulations amounts to >60% (up to 77%) of annual PM emissions in the years 2010-2020.

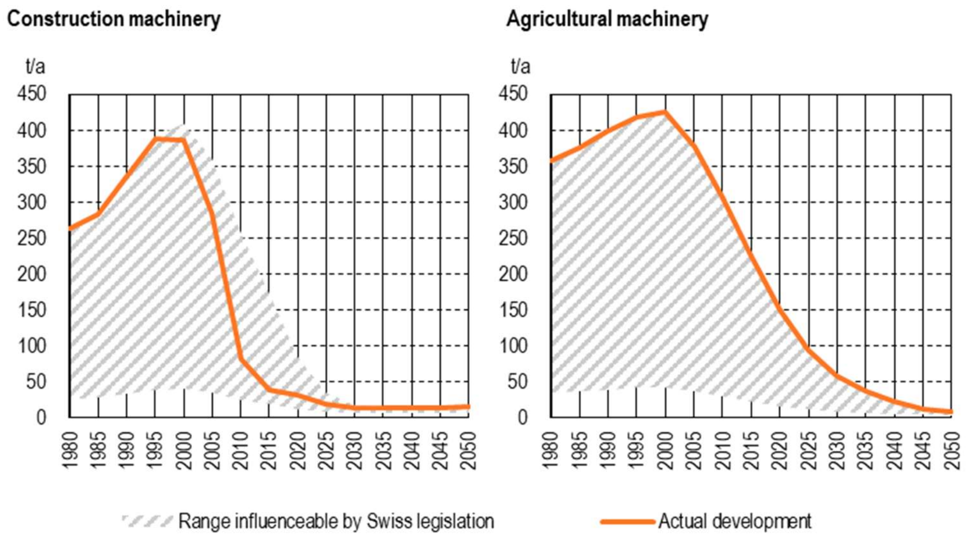

Figure 18: Effects of DPF legislation in Switzerland, comparing construction machinery with national legislation stricter than EU regulations and agricultural machinery with no national legislation besides EU regulations (source: [10]).

Box 2: Use of alkylate gasoline for hand-held devices

After health disorders like headaches, difficulties to concentrate, and nausea in forest workers had been linked by Swedish scientists to the benzene emissions of devices like chainsaws in 2006, the Swiss Federal Office for the Environment launched a campaign to promote the use of alkylate gasoline with a low content of aromatics like Benzene, Toluene or Xylene. The quality of this gasoline is regulated by the Swiss Norm SN 181 163.

Since the use of alkylate gasoline is voluntary, no exact figures on its pervasion exist. Supposing that a plausible share of 80% of professional operators of hand-held devices (gardening, agriculture, forestry) were to use alkylate gasoline in their 2-stroke machines, this would lead to a reduction of about 43% of benzene emissions; recreational/hobby use of gardening devices has a much lower impact: the use of alkylate gasoline by 50% of hobby users would only lead to a reduction of about 2% of the total benzene emissions [10].

7.2 Powered Two Wheelers

The main influences from the driver and vehicle holder are:

- Maintaining the functionality of the engine and the aftertreatment system is essential for a proper emission level. Tampering or tuning with improper hard- or software can lead to high emission levels.
- Drive anticipatory, avoid harsh accelerations and high engine speeds. Perform upshifts to the next higher gear during accelerations as soon as possible. Follow these guidelines especially in urban areas and other locations with population

around. Driving considerately reduces fuel consumption, CO2, hydrocarbon and noise emissions[14].

- Avoiding short trips reduces emissions over proportional due to the cold start effects (cold catalyst does not properly reduce emissions after a start).
- Avoiding parking directly in the sun reduces HC evaporative emissions.

7.3 Heavy Duty Vehicles

The main influences from the driver and vehicle owner are:

- Turning off the engine instead of idling saves fuel and emissions. Due to SCR catalyst cool down effects in idling, NO_x emission levels heavily increase after a few minutes of idling.
- Connecting the cooling system of the body or trailer to the electric grid during breaks, loading and unloading reduces fuel consumption, exhaust and noise emissions.
- Using the driver assistant systems to optimise velocity and gear position saves fuel and emissions.
- An anticipatory driving style, with coasting the vehicle early before a stop event, reduces fuel consumption, exhaust and noise emissions.
- Using tires with a label for a low rolling resistance. This saves propulsion energy and thus fuel and exhaust gas emissions.
- The new CO_2 label for HDVs (often called "VECTO" tool) can indicate effects from different options to compose a vehicle (e.g. tires, transmission, engine model, cabin,..). Lower fuel consumption and CO_2 emissions in VECTO shall indicate usually also a more fuel efficient vehicle set up or model in real operation[15]. Usually more fuel efficient vehicle designs result also in a reduction of exhaust and noise emissions.

[14] The difference in the noise emission between an aggressive and a moderate driving style was found to be 7 to 8 dB(A) for average noise levels and up to 15 dB(A) for peak values (95% percentiles).

[15] Mission profiles different to the ones calculated by VECTO may lead to different rankings and equipment not included in the VECTO method may also change results significantly, such as extra power take off for mixers etc.

References

[1] Schwingshackl M., Rexeis M.: Straßenverkehrsemissionen und Emissionen sonstiger mobiler Quellen Österreichs für die Jahre 1990 bis 2017 (Austrian Emission Inventory for Transport); IVT, University of Technology Graz, 12/2018

[2] Ligterink N., Louman R., et.al.: Use of construction machines and the associated NOx and CO2 emissions; TNO Report 2018 R10753; 2018

[3] L. Ntziachristos, S. Geivanidis, Z. Samaras and e. Al., "Study on possible new measures concerning motorcycle emissions.," Report for EC, 2008.

[4] Matzer C., Weller K., Dippold M., Lipp S., Röck M., Rexeis M., Hausberger S.: Update of emission factors for HBEFA Version 4.1; Final report, I-05/19/CM EM-I-16/26/679 from 09.09.2019, TU Graz

[5] TNO 2018, Vermeulen, R.J. et al., Tail-pipe NOx emissions of refuse collection vehicles with a Euro VI engine in daily operation in the Netherlands, TNO report TNO R 2018 10313v2, 15 June 2018

[6] Vermeulen et al., Dutch In-service emissions testing programme 2015 - 2018 for heavy-duty vehicles: status quo Euro VI NO_x emissions, TNO report TNO 2019 R10519, 10 April 2019

[7] Piasecki C.: Evaluation of Mobile Emission Measurement Technology in the Motorcycle Segment; TU Graz, September 2019

[8] INFRAS 2015: Online database of the Swiss NRMM emissions inventory. Federal Office for the Environment (FOEN), Ittigen. [https://www.bafu.admin.ch/bafu/en/home/topics/air/state/non-road-datenbank.html].

[9] Wimmer D.: Aufbau einer Simulationsmethodik für Verbrauch und Emissionen von Off-Road Maschinen (Set upp of a method to simulate fuel consumption and emissions from NRMM; Master Thesis at TU Graz; May 2016

[10] Heldstab, J., Leippert, F., Wüthrich, P., Künzle, T. 2013: PM10 and PM2.5 ambient concentrations in Switzerland. Federal Office for the Environment (FOEN), Ittigen. [https://www.bafu.admin.ch/dam/bafu/en/dokumente/luft/uw-umwelt-wissen/pm10_und_pm2_5_immissioneninderschweizzusammenfassung.pdf.download.pdf/pm10_and_pm2_5_ambientconcentrationsinswitzerland.pdf].

[11] FOEN 2015: Non-road energy consumption and pollutant emissions. Study for the period 1980 to 2050. Environmental studies no. 1519. Federal Office for the Environment (FOEN), Ittigen. [http://www.bafu.admin.ch/publikationen/publikation/01828/index.html].

[12] INFRAS 2008: Einsatzfelder und Nutzung des Alkylatbenzins. Lagebericht für die Schweiz im Auftrag des Bundesamtes für Umwelt und der Schweizerischen Metallunion. Bundesamt für Umwelt (BAFU), Ittigen.

[13] BAFU 2009: Luftreinhaltung auf Baustellen. Richtlinie über betriebliche und technische Massnahmen zur Begrenzung der Luftschadstoff-Emissionen von Baustellen (Baurichtlinie Luft). Bundesamt für Umwelt (BAFU), Bern. [http://www.bafu.admin.ch/publikationen/publikation/01014/index.html?lang=de].

[14] BAFU 2010: Luftreinhalte-Verordnung; Änderung vom 19. September 2008: Anforderungen an Baumaschinen und deren Partikelfiltersysteme. Merkblatt für den Vollzug. Bundesamt für Umwelt (BAFU), Ittigen. [https://www.bafu.admin.ch/dam/bafu/de/dokumente/luft/fachinfo-daten/luftreinhalte-verordnungaenderungvom19092008anforderungenanbauma.pdf.download.pdf/luftreinhalte-verordnungaenderungvom19092008anforderungenanbauma.pdf].

[15] VERT Association 2019: VERT Filter List 2019-1. VERT certified Particle FIlter Systems for Combustion Engines. October 2019. VERT Association, Niederrohrdorf,

Switzerland. [https://www.vert-dpf.eu/j3/images/pdf/article/48/VERT-Filter-Liste-Stand-Oktober-2019.pdf].