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Diesel Engines Exhausts: Myths and Realities

Transmited by the secretariat

The UNECE Transport Division secretariat has prepared a document on diesel engines exhausts which it reproduces below for the consideration of the Working Party on the Standardization of Technical and Safety Requirements in Inland Navigation (SC.3/WP.3) and would welcome comments at its forty-third session (26-28 June 2013).

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Diesel Engines Exhausts: myths and realities

A background note – version 3.0

I. Introduction

1. Every day, millions of diesel-powered vehicles busily move consumer goods and raw materials from ports, distribution centers and rail yards to stores and industrial facilities throughout the world. Diesel powered ships, trains and trucks play a pivotal role for local, regional and global commerce Most of the rivers barges, freight trains and ocean-going ships are also powered by diesel, as are the overwhelming majority of trucks and lorries.

2. Diesel-powered equipment is also a major part of the supply chain that moves crops from the farm to the dinner table. Diesel-powered farm tractors, combines and irrigation pumps are just a few examples of the types of equipment that literally drive one of the most important industries of national economies.

3. Diesel engines are not only fundamental in mobile vehicles and machinery, but also widely employed in stationary applications such as pipeline pumps, electric and water plants, industrial machinery, mining tools, factories and oil fields.

4. Unmatched in their reliability, durability, fuel efficiency and mobility., diesel engines contribute play a fundamental role to allow economic development of human societies. Notwithstanding this undeniable success, diesel engines are also associated with a number of environmental, noise- and health-related impacts.

5. The objective of this background note is to provide basic information about some recent and important developments in air pollution; illustrate the results of recent studies on the harmful effects of diesel exhausts to public health; and inform about technological developments of diesel engines or their replacement by electric ones that minimize or even remove these harmful effects.

6. Section II contains a list of the main air pollutants and their effects on human health and the environment.

7. Section III provides information on the difference between emissions and emission concentrations.

8. Section IV contains a brief review of UNECE-relevant policies and agreements related to air quality, health and environmental issues.

9. Building on published information, Section V provides information on the emissions of the main air pollutants and the sources that generate them (stationary and mobile sources).

10. Section VI focuses on the compliance with existing international agreements, as well as EU legislation. It reports briefly on an assessment of the atmospheric concentration of the main air pollutants in Europe and considers in further detail the emissions of some of these pollutants in e ECE Member States. This second part of the assessment includes, in particular, data on the distance between actual emissions of air pollutants and those that would allow respecting emission

reduction ceilings as stipulated by the most recent and most recently amended Protocol of the Convention on Long-Range Transboundary Air Pollution (CLRTAP) and for the EU countries by the EU National Emissions Ceiling (NEC) Directive.

11. Section VII considers the interactions between sectoral emission sources and exposure to air pollution. It also includes a brief review of measures that have been implemented in different economic sectors to reduce the emissions of pollutants.

12. Considering that a recent finding by the World Health Organization (WHO) led to the classification of diesel exhaust emissions as carcinogenic, section VIII focuses on diesel emissions and measures that could contribute to the reduction of their air pollutant emissions.

13. The information in this background note is a compilation of facts from the work in the framework of CLRTAP, its Task Force on Health, the European Environment Agency (EEA), the work undertaken in the framework of the Inland Transport Committee and its subsidiary bodies, particularly the World Forum for the Harmonization of Vehicle Regulations (WP.29).

II. Main air pollutants and their effects on human health and the environment

14. A recent report from the European Environment Agency (EEA) (EEA, 2012) provides a brief description (partly reported in Box 1) of the main air pollutants and their effects on human health and the environment. This list includes the "criteria air pollutants" regulated in the United States of America by the Clean Air Act Amendments of 1970 (and its following modifications) because they can harm health and the environment: particle pollution (often referred to as particulate matter), ground-level ozone (O_3) (represented in the list below by its precursors), carbon monoxide (CO), sulfur oxides (SO_X), nitrogen oxides (NO_X), and lead (Pb) (US EPA, 2012). Sulfur dioxide (SO_2) and nitrogen oxides (NO_X) are also precursors of acid rain formation.

15. The EEA report also includes descriptive information on other pollutants (polycyclic aromatic hydrocarbons (PAHs)/Benzo(a)pyrene (BaP), dioxins and furans (PCDD/Fs), polychlorinated biphenyls (PCBs), hexachlorobenzene (HCB), and hexachlorocyclohexane (HCH)) that are not considered in this analysis.

16. Additional information on air pollutants, including considerations on their characteristics, sources, sinks, mixing ratios in the atmosphere (differentiating between ambient air and indoor air), and health effects are also available in dedicated literature, such as Jacobson (2002).

III. Analysis of emissions and emissions' concentration.

17. Many air pollutants, including NO_X and sulfur dioxide (SO_2), are directly emitted into the air from anthropogenic activities such as fuel combustion or releases from industrial processes. Other air pollutants, such as O_3 and the major part of PM, form in the atmosphere following emissions of various precursor species, having either anthropogenic or natural origin. Natural sources of aerosol particle emissions that are included in PM may occur from volcanic eruptions, soli-dust and sea-spray uplifts, natural biomass burning fires, and biological material release. Major anthropogenic sources include fugitive dust emissions, fossil-fuel combustion, anthropogenic biomass burning and industrial emissions (Jacobson, 2002).

Box 1. Description of the main air pollutants (gaseous pollutants, particulate matter and heavy metals)

Sulphur oxides (SO_x): SO_x are emitted when fuels containing sulphur are burned. They contribute to acid deposition, the impacts of which can be significant: adverse effects on aquatic ecosystems in rivers and lakes, and damage to forests. Further, the formation of sulphate particles results in reflection of solar radiation, which leads to net cooling of the atmosphere.

Nitrogen oxides (NO_X): NO_X are emitted during fuel combustion, as practiced by industrial facilities and the road transport sector. As with SO_X, NO_X contribute to acid deposition but also to eutrophication of soil and water. Of the chemical species that NO_x comprises, it is nitrogen dioxide (NO_2) that is associated with adverse effects on health: high concentrations cause inflammation of the airways and reduced lung function. NO_x also contribute to the formation of secondary inorganic particulate matter and tropospheric (ground-level) ozone with associated climate effects.

Ammonia (NH_3): NH_3, like NO_X, contributes to both eutrophication and acidification. The vast majority of NH_3 emissions - around 94 % in Europe - come from the agricultural sector, in connection with activities such as manure storage, slurry spreading and the use of synthetic nitrogenous fertilizers.

Carbon monoxide (CO): CO is produced as a result of fuel combustion. The road transport sector, commercial and household sector, and industry are important sources. Long-term exposure to low concentrations of CO can result in neurological problems and potential harm to unborn babies. CO can react with other pollutants to produce ground-level ozone. Elevated levels of ozone can cause respiratory health problems and can lead to premature mortality.

Non-methane volatile organic compounds (NMVOC): NMVOC, important O_3 precursors, are emitted from a large number of sources including paint application, road transport, dry-cleaning and other solvent uses. Certain NMVOC species, such as benzene (C_6H_6) and 1,3-butadiene, are directly hazardous to human health. Biogenic NMVOC are emitted by vegetation, with amounts dependent on the species and on temperature.

Particulate matter (PM): on terms of potential to harm human health, PM is one of the most important pollutants as it penetrates into sensitive regions of the respiratory system. PM is emitted from many sources, and is a complex heterogeneous mixture comprising both primary and secondary PM; primary PM is the fraction of PM that is emitted directly into the atmosphere, whereas secondary PM forms in the atmosphere following the oxidation and transformation of precursor gases (mainly SO_X, NO_X, NH_3 and some volatile organic compounds (VOCs)).

Heavy metals (HMs): the HMs arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), chromium (Cr), copper (Cu), nickel (Ni), selenium (Se) and zinc (Zn) are emitted mainly as a result of various combustion processes and industrial activities, like metals works and smelters. As for Benzo(a)pyrene (BaP), heavy metals can reside in or be attached to PM. As well as polluting the air, HMs can be deposited on terrestrial or water surfaces and subsequently builds up in soils or sediments. HMs are persistent in the environment and may bio-accumulate in food chains.

Source: EEA, 2012a

18. The concentration of air pollutants in the lower part of the atmosphere does not only depend on levels of emission of pollutants and their precursors, on specific characteristics of the pollutant (such as their average lifetime against phenomena like photolysis), as well as changes in meteorological conditions (Jacobson, 2002 and EEA, 2009) . The transport in the atmosphere, over long distances and across national boundaries, of anthropogenic acid-deposition precursors such as SO_2 and NO_x (and the subsequent acidification of water bodies) was particularly relevant in the process leading to the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP), the first agreements dealing with air pollution at the international level (Jacobson, 2002).

19. These considerations are important to bear in mind that complex links exist between the emissions of air pollutants and the air quality (the latter being measured via the ambient/atmospheric concentration of pollutants). As a result, changes in the emissions of selected pollutants do not always lead to a corresponding change in their atmospheric concentrations, even if they are a necessary step towards the improvement of air quality.

IV. Policy approach to emissions at national and regional level.

20. Several national governments have developed national legislation to offer an umbrella or framework regulation to improve air quality and monitor and curb emissions of air pollutants.

Table 1. Limit values of the European Air Quality Directive for the protection of human health

Averaging Period	Limit value	Margin of tolerance	Date by which limit value is to be met
Sulphur dioxide			
One hour	350 µg/m³, not to be exceeded more than 24 times a calendar year	150 µg/m³ (43 %)	— (¹)
One day	125 µg/m³, not to be exceeded more than 3 times a calendar year	None	— (¹)
Nitrogen dioxide			
One hour	200 µg/m³, not to be exceeded more than 18 times a calendar year	50 % on 19 July 1999, decreasing on 1 January 2001 and every 12 months thereafter by equal annual percentages to reach 0 % by 1 January 2010	1 January 2010
Calendar year	40 µg/m³	50 % on 19 July 1999, decreasing on 1 January 2001 and every 12 months thereafter by equal annual percentages to reach 0 % by 1 January 2010	1 January 2010
Benzene			
Calendar year	5 µg/m³	5 µg/m³ (100 %) on 13 December 2000, decreasing on 1 January 2006 and every 12 months thereafter by 1 µg/m³ to reach 0 % by 1 January 2010	1 January 2010
Carbon monoxide			
maximum daily eight hour mean (²)	10 mg/m³	60 %	— (¹)
Lead			
Calendar year	0,5 µg/m³ (³)	100 %	— (³)
PM_{10}			
One day	50 µg/m³, not to be exceeded more than 35 times a calendar year	50 %	— (¹)
Calendar year	40 µg/m³	20 %	— (¹)

(¹) Already in force since 1 January 2005

(²) The maximum daily eight hour mean concentration will be selected by examining eight hour running averages, calculated from hourly data and updated each hour. Each eight hour average so calculated will be assigned to the day on which it ends i.e. the first calculation period for any one day will be the period from 17:00 on the previous day to 01:00 on that day; the last calculation period for any one day will be the period from 16:00 to 24:00 on that day.

(³) Already in force since 1 January 2005. Limit value to be met only by 1 January 2010 in the immediate vicinity of the specific industrial sources situated on sites contaminated by decades of industrial activities. In such cases, the limit value until 1 January 2010 will be 1,0 µg/m³. The area in which higher limit values apply must not extend further than 1 000 m from such specific sources.

Source: EC, 2008

21. Specific to diesel-powered vehicles, Canada regulates new on-road light passenger cars and trucks, as well as on-road heavy-duty trucks and off-road machinery. Most recently, Canada aligned with the Tier 4 air pollutant standards of the United States of America for off-road diesel engines used in mining, agricultural and construction sectors. Canada has also implemented regulations to reduce the maximum allowable content of sulphur diesel fuel to 15 part per million (ppm) in order to

ensure the effective operation of exhaust after-treatment systems used on diesel engines to meet increasingly stringent emission standards.

22. Similarly, the European Union (EU) set up a number of instruments aiming to avoid, prevent or reduce harmful effects on human health and the environment as a whole. The policies in place limit the emissions of air pollutants, and/or establish objectives for ambient air quality. Key legislative EU instruments include the following:

(a). In 2001, the EU Directive on National Emission Ceilings[1] for certain pollutants (NEC Directive) (EC, 2001), setting upper limits for each Member State for the total emissions in 2010 (and beyond) of the four pollutants responsible for acidification, eutrophication and ground-level ozone pollution: sulphur dioxide (SO_2), nitrogen oxides (NO_X), volatile organic compounds (VOC) and ammonia (NH_3). The NEC Directive left to the EU Member States the decision on which measures to take in order to comply, but it included the requirement to develop (in 2002, with a second round foreseen for 2006) national programmes for the attainment of the targets. These programmes have been analyzed and evaluated.

(b). In 2002, the Sixth Environment Action Programme (6EAP) set long-term objective of achieving levels of air quality that do not give rise to significant negative impacts on, and risks to, human health and the environment.

(c). In 2005, the Thematic Strategy on Air Pollution (EC, 2005) identified a number of key measures to be taken to help meeting the 2020 interim objectives for human health and the environment. The revision of the NEC Directive, now under preparation, was identified as one of the key measures in this strategy.

(d). In 2008, the Air Quality Directive (EC, 2008) merged most of the previous legislation on air quality (i.e. legislation targeting the ambient concentration of pollutants, with the exception of target values for the concentration of arsenic, cadmium, nickel and benzo(a)pyrene in ambient air) into a single directive, with no change to pre-existing air quality objectives. The Air Quality Directive also introduced new air quality objectives for PM2.5 (fine particles), the possibility to discount natural sources of pollution when assessing compliance against limit values, and the possibility for time extensions of three years (PM10) or up to five years (NO2, benzene) for complying with limit values, based on conditions and the assessment by the European Commission. The limit values for the protection of human health included in the Air Quality Directive are reported in Table 1.

23. According to the final assessment on the 6EAP, the review of the European air quality policy is expected by 2013 (EC, 2011). The review of the NEC Directive is expected to set emission ceilings for the four already regulated substances (SO_2, NO_x, volatile organic compounds and ammonia), as well as the primary emissions (i.e. the fraction of emissions that is emitted directly into the atmosphere, rather than following the oxidation and transformation of precursor gases) of fine particulate matter (PM2.5) (EC, 2012a).

24. Parallel to the development of the EU NEC Directive, the EU Member States together with Central and Eastern European countries, the United States of America and Canada have negotiated the "multi-pollutant" protocol (the so-called Gothenburg Protocol, agreed in November 1999 (UNECE, 1999)) under the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP)

[1] Later amended as part of the accession of new Member States.

(UNECE, 1979). The Gothenburg Protocol also includes emission ceilings for nitrogen oxides (NO_X), sulphur dioxide (SO_2), ammonia (NH_3) and non-methane volatile organic compounds (NMVOCs). The emission ceilings in the protocol are equal or less ambitious than those in the NEC Directive (EC, 2012b).

25. In early May 2012, Parties of CLRTAP reached a consensus to revise the Gothenburg Protocol. The revised Protocol (not in force yet) sets new emission ceilings for NO_X, SO_2, NH_3 and NMVOCs for the year 2020 and beyond. It also introduces emission ceilings for fine particular matter (PM2.5).

V. Emissions of the main air pollutants

V.I Emissions trends

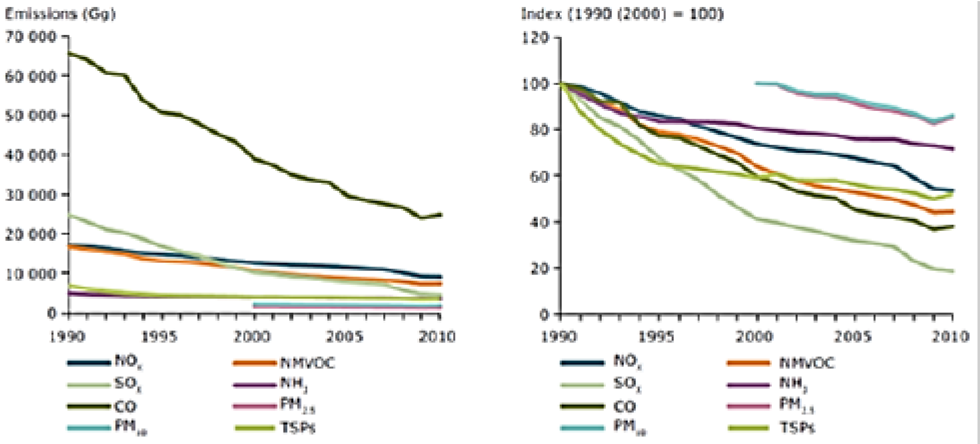
26. A number of modeling instruments have been developed for the estimation of the emissions of air pollutants over time and their attribution to different driving sources. According to the EEA (which builds on the results obtained with these modeling instruments), air pollutant emissions in Europe (including EEA Member States and Countries of the Western Balkans) have decreased since 1990. In 2010 (EEA, 2012a):

(a). SO_X emissions were 82 % lower than in 1990;

(b). emissions of the other main air pollutants have dropped significantly since 1990, including emissions of the three air pollutants primarily responsible for the formation of ground-level ozone: CO (62 % reduction), NMVOC (56 % reduction) and NO_X (47 % reduction);

(c). Total Suspended Particles (TSP) have seen a reduction of 48 % from 1990. For PM10 and PM2.5, the aggregated EU-27 emission reduction achieved since 2000 is 14 % and 15 %, respectively.

Figure 1. EU-27 emission trends for the main air pollutants and for particulate matter



Source: EEA, 2012a

27. Canada's regulatory approach has been effective at reducing harmful emissions from diesel heavy-duty and light duty vehicles. For example, PM2.5 emissions from the diesel powered on-road fleet have been reduced 75% between 1985 and 2010. Also, NO_X emissions from the diesel heavy-duty and light-duty fleet have gone down 40% in 2010 from 1998 peak values. It is important to

note that these reductions have occurred despite an increase in the total annual vehicle kilometers travelled by diesel vehicles.

V.2 The role of different economic sectors

28. In addition to total emissions, the EEA estimated the role of different economic sectors with respect to the emissions of different pollutants. Figure 2 and Table 2 show that energy, transport (distinguishing between road and non-road transport), industrial processes, the use of solvents and other similar products, as well as the commercial and household sectors have emerged as the key sources of emissions a wide range of air pollutants, including NO_X, SO_X, NMVOC, CO, and PM (EEA, 2012a). In particular, the EEA (EEA, 2010 and EEA, 2012a) points out that:

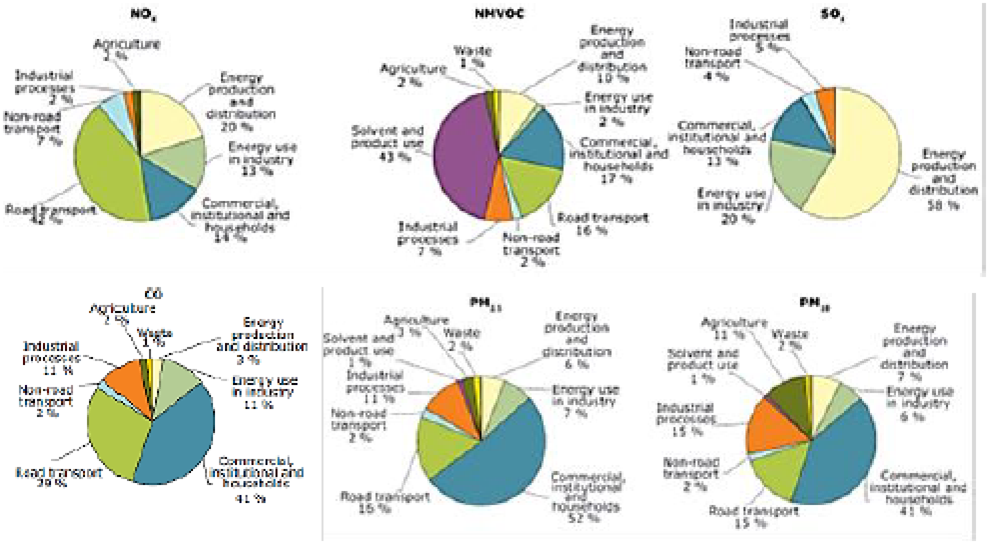
(a). The energy sector accounts for around three quarters of Europe's sulphur oxides (SO_X) emissions and about 20 % of NO_X output;

(b). Transport (namely road transport) vehicles are important emitters of NO_X, carbon monoxide (CO), PM and NMVOCs. Road transport is the biggest emitting economic sector only for NO_X;

(c). Energy combustion from households and commercial/institutional buildings - burning fuels such as wood and coal - is the main source of directly emitted PM (especially primary PM2.5);

(d). Agriculture accounts for most (about 95 %) of Europe's NH_3 emissions (not shown in Figure 2).

Figure 2. Share of EU-27 emissions of the main pollutants by sector group



Source: EEA, 2012a

29. The EEA report shows that a number of key source categories were identified as being key categories for more than one of the 15 pollutants assessed (Table 3). These key categories are defined as the individual sources that overall contributed most to 2010 emissions of pollutants, determined by a level assessment for each of the main air pollutants, PM, heavy metals (HMs) and persistent organic pollutants (POPs). From a total of 109 source categories, 49 source categories

were identified as being key categories for at least 1 pollutant. A number of source categories were identified as being key categories for more than 1 of the 15 pollutants assessed.

Table 3. Most relevant key categories for air emissions

Name of key category	Number of occurrences as key category
1 A 4 b i Residential: stationary plants	13 times: NO_x, SO_x, CO, NMVOC, Cd, Hg, Pb, POPs including hexachlorobenzene (HCB) and polychlorinated dibenzodioxins/ dibenzofurans (PCDD/Fs), PM10, PM2.5 Pb, PCBs, polycyclic aromatic hydrocarbons (PAH)
1 A 1 a Public electricity and heat production	11 times: NO_x, SO_x, CO, Cd, Hg, HCB, PCDD/Fs, PM10, PM2.5, Pb, polychlorinated biphenyls (PCBs)
1 A 2 Stationary combustion in manufacturing industries and construction (includes 1 A 2 a — 1 A 2 f)	10 times: NO_x, SO_x, CO, Hg, Pb, Cd, PCDD/Fs, PAHs, PM10, PM2.5
2 C 1 Iron and steel production	10 times: CO, Cd, Hg, Pb, HCB, PCDD/Fs, PM10, PM2.5, PCBs, PAHs
1 A 3 b Road transport (includes 1 A 3 b i — 1 A 3 b vii)	6 times: NO_x, CO, NMVOC, Pb, PM10, PM2.5

30. The major source category for NO_x this is road transport (Table 2). Similarly, energy production is the main source for SO_x; agriculture for NH_3; solvent and product use for NMVOC; and the commercial, institutional and household sector for CO. NO_x emissions from the road transport sector have decreased by 46 % since 1990, mainly as a result of the introduction of three-way catalytic converters on passenger cars and stricter regulation of emissions from heavy-duty vehicles across Europe.

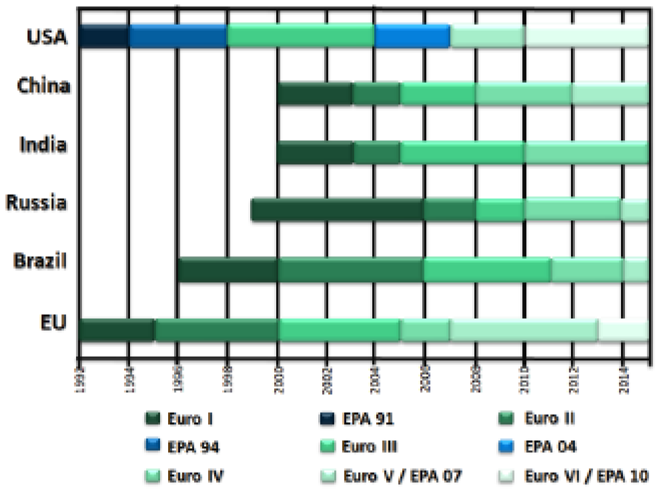
Table 2. Share of EU-27 emissions of the main pollutants by sector group

Pollutants	Sector with highest share per pollutant		Road Transport	Non Road Transport
	Sector	Share		
NO_x	Road Transport	42%	-	7%
NMVOC	Solvent and product use	43%	16%	2%
SO_x	Energy production and distribution	58%	0%	4%
NH_3	Agriculture	94%	2%	0%
PM2.5	Commercial, institutional and households	52%	16%	2%
PM10	Commercial, institutional and households	41%	15%	2%
CO	Commercial, institutional and households	41%	29%	2%
Pb	Energy use in industry	36%	10%	1%
Cd	Commercial, institutional and households	39%	3%	1%
Hg	Energy production and distribution	41%	0%	4%
PCDD/Fs	Commercial, institutional and households	37%	1%	1%
Total PAHs	Commercial, institutional and households	59%	2%	0%
HCB	Industrial processes	70%	2%	0%
HCH	Industrial processes	66%	0%	0%
PCBs	Waste	35%	4%	0%

Source: EEA, 2012a

31. Among the top five key categories, the highest relative reductions in emissions between 1990 and 2010 were achieved for passenger cars (-82.9 %), largely reflecting the successful introduction of vehicle emission standards and use of vehicle exhaust catalytic converters (Figure 3).

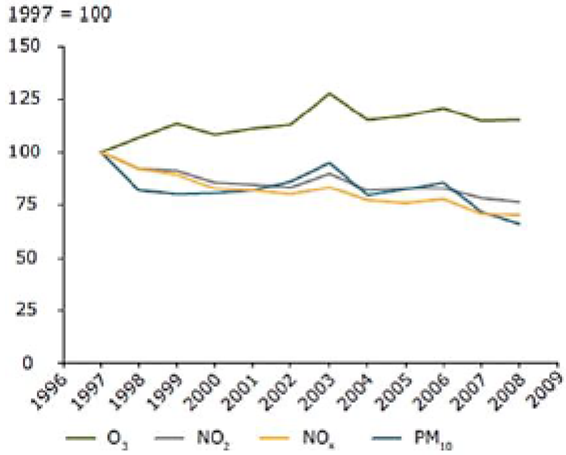
Figure 4.Regulatory instruments affecting pollutant emission of heavy duty vehicles



Source: IRU (2012)

VI. Compliance with existing international agreements and regional legal obligations

Figure 4. Indexed trends in air quality



Source: EEA, 2010

32. As already pointed out in Section III, changes in the emissions of air pollutants and their precursors do not necessarily lead to corresponding changes in the concentrations of health- and environment-relevant air pollutants. This is confirmed by the fact, reported by the EEA (EEA, 2010) and illustrated here in Figure 4, that the emission reductions documented in Section V were not

necessarily coupled with a corresponding improvement in the atmospheric concentration of related air pollutants.

33. In the case of PM10, the EEA points out that the majority of EU Member States have not attained the limit values required by the Air Quality Directive by 2005 (EEA, 2010). In particular, the exceedance of the daily mean PM10 limit is considered by the EEA as the biggest PM compliance problem in most urban environments (EEA, 2010).

34. Critical issues also emerge looking at the emission of air pollutants with respect to the limits included in the relevant European and international legislation.

Table 4. Distance of 2010 NO_x emissions (reported in 2012) to the Gothenburg Protocol ceilings

NO_x	2010 emission [Gg]	GP ceilings [Gg]	Distance to target	Compliance
Belgium	221	181	22%	No
Bulgaria	115	266	-57%	Yes
Croatia	71	87	-19%	Yes
Cyprus	18	23	-22%	Yes
Czech Republic	239	286	-16%	Yes
Denmark	129	127	1%	No
Finland	167	170	-2%	Yes
France	1080	860	26%	No
Germany	1323	1081	22%	No
Hungary	162	198	-18%	Yes
Latvia	34	84	-60%	Yes
Lithuania	58	110	-47%	Yes
Luxembourg	46	11	320%	No
Netherlands	276	266	4%	No
Norway	184	156	18%	No
Portugal	186	260	-28%	Yes
Romania	272	437	-38%	Yes
Slovakia	89	130	-32%	Yes
Slovenia	45	45	0%	Yes
Spain	890	847	5%	No
Sweden	161	148	9%	No
Switzerland	79	79	0%	Yes
United Kingdom	1106	1181	-6%	Yes
United States of America		6897	-	-
EU-15	7219	6671	8%	No

35. According to the recently reported data (CEIP, 2012) nine Parties to the CLRTAP, including eight EU Member States, failed to reduce their nitrogen oxides emissions below the 2010 national ceilings (Table 4) set in the Gothenburg Protocol. On the same issue, EEA announced that eleven Member States failed to reduce their air pollutant emissions set in the NEC Directive (EEA, 2012b). A few EU-15 "old" Member States also missed their targets for the other pollutants included in the Gothenburg Protocol. On the other hand, all new EU Member States (EU-12) have met their emission ceilings for all pollutants covered in it.

36. The tenth Party that missed its NO_x target is the EU-15 that itself is a Party to the Gothenburg Protocol. Moreover, Austria and Ireland that - up till now - have not ratified the Protocol and therefore are not listed in Table 6, also missed their 2010 NO_x ceilings by 76 and 15%,

respectively. The two Parties provided their respective ceilings (107 and 65 Gg) when signing the Gothenburg Protocol (GP) in 1999.

37. The figures for EU-15, ten EU Member States, and Norway that missed their GP ceilings for NO_x in 2010 are shown in decreasing order in Table 5. The ten EU Member States listed in Table 7 made up a 49% share of the EU-27 NO_x emissions in 2010 (EEA, 2012a).

Table 5. Distance to target of 2010 NO_x emissions in the Gothenburg Protocol in deceasing order

NO_x	*2010 emission [Gg]*	*GP ceilings [Gg]*	*Distance to target*
Luxembourg	46	11	320%
Austria	*189*	*107*	*76%*
France	1080	860	26%
Germany	1323	1081	22%
Belgium	221	181	22%
Norway	184	156	18%
Ireland	*75*	*65*	*15%*
Sweden	161	148	9%
EU-15	7219	6671	8%
Spain	890	847	5%
Netherlands	276	266	4%
Denmark	129	127	1%

Parties in italics have not ratified the Gothenburg Protocol.

VII. Interactions between sectoral emission sources and exposure to air pollution

VII.1 Exposure to air pollution

38. The EEA warned that, notwithstanding clear progress made across Europe in reducing anthropogenic emissions of the main air pollutants over recent decades, poor air quality remains an important public health issue (EEA, 2010). In particular, the Agency identifies airborne particulate matter (PM), tropospheric (ground-level) ozone (O_3) and nitrogen dioxide (NO_2) as Europe's most problematic pollutants in terms of harm to health.

39. The EEA results are confirmed by the following observations:

(a). A significant proportion of Europe's population lives in urban areas;

(b). Cities are the areas with the highest exposure to air pollution because most exceed the air quality reference levels occur (e.g. EU (EC, 2008) and WHO (WHO, 2011));

(c). For PM2.5, 16 to 30% of the urban population in the EU countries was exposed (in the period 2008-2010) to air pollutant concentrations above the EU reference levels (the percentages increase to 90-95% for WHO reference levels). Similarly, exposure estimates for ozone are 15-17% (EU) and >97% (WHO), respectively (EEA, 2012).

40. As pointed out in Section V, emissions from buildings used for households and commercial/institutional activities are the most important contributors to ozone and PM ambient concentrations levels. Other important sources include industrial processes and road transport. The latter is the main sector responsible for NO_x emissions, followed by the energy and household/commercial sector.

VII.2 Measures aimed to reduce the emissions of air pollutants

41. Addressing the issues associated with the most problematic pollutants in Europe (PM, ground-level ozone, and NO_X) is likely to require further legislative action aiming at the reduction of the emissions of air pollutants. Actions contributing to this target should take into account of the following elements:

(a). The nature of the pollutants concerned, including information on the geographical scale that they are likely to affect (e.g. because of local meteorological characteristics, the chemical properties of the pollutant such as its average lifetime in different ambient conditions, etc.);

(b). The sectors bearing most of the responsibility for their emissions in the atmosphere (likely to be targeted with higher priority, unless high costs justify taking action elsewhere), taking into account their importance in the areas characterized by the highest exposure levels.

42. In order to maximize their efficacy, it is widely recognized that all actions should make sure that they are maximizing social benefits while minimizing social costs.

43. Even if the definition of specific strategies will need to take into account local characteristics, a qualitative analysis indicates that higher priorities are more likely to target:

(a). The urban fractions of the household and commercial/institutional sector;

(b). Urban road mobility;

(c). Industrial activities and energy transformation plants located close to urbanized regions.

44. In order to avoid further efforts in case of inefficient solutions, e.g. generating uneven costs (for comparable benefits) across different economic sectors, the same strategies will also need to consider the actions that have already been undertaken to date.

45. A complex task such as the abatement of harmful air pollutants in the ambient air is unlikely to be feasible using a single policy interventions or measures that are limited to specific sectors. This is especially true when polices do not only address air pollution, but also congestion, noise and CO_2 emission abatement. An effective strategy should include the adoption of a package of instruments, often comprising a range of different types of policies reinforcing the impact (and offsetting the disadvantages) of others (ADB, 2009).

46. The instruments available to get to this objective typically include economic measures, regulatory approaches and participatory initiatives. Economic measures comprise taxes, subsidies, the exemptions from levies and other financial incentives, or the combination of these instruments. Command and control (or regulatory) policies can be easier to implement than economic instruments, but they are not immune from inefficiencies such as the obligation to face different marginal costs for different users. They are best suited for a number of specific situations: emergencies, interventions targeting specific fields and cases when the optimum is very close to a condition that can be easily and precisely defined (e.g. zero emissions of a given pollutant, when even a small release of this pollutant would lead to high social and environmental losses). Participatory instruments are concerned with the direct involvement of consumers and businesses. They encompass awareness-raising campaigns, instruments capable to improve consumer information (e.g. labelling schemes or the dissemination of best practices) and the negotiation of voluntary agreements between the industry and regulators. They can be combined with economic instruments (e.g. reducing the cost of training programs through fiscal incentives, or using taxation in combination with labelling) and regulatory approaches (e.g. the progressive phase-out of obsolete and underperforming options, combined with labelling and awareness-raising initiatives).

47. The reduction of air pollution has been most frequently tackled with regulatory instruments. Economic instruments such as differentiated taxation on fuels (e.g. on natural gas for transport and residential/commercial heating) also exist. In most cases, however, they have been enforced to pursue primarily other policy objectives, such as energy diversification. Typical examples of regulatory policy interventions were mentioned in section IV. They include mandatory fuel quality specifications and standards limiting pollution levels (e.g. for noxious pollutants released by the combustion of fuels). In transport, other regulatory instruments can also target the access to different part of the infrastructures of the transportation network (e.g. city centers), speed limits, as well as decisions on land-use planning, e.g. influence the development of urban areas along transit axes and to promote modal shifts in a way that favors less polluting options, like public transportation.

48. When looking at regulatory measures adopted in recent years, it is important to underline that:

(a). The same EEA report (EEA, 2010) identifying airborne particulate matter (PM), tropospheric (ground-level) ozone (O_3) and nitrogen dioxide (NO_2) as Europe's most problematic pollutants also openly recognizes that regulatory action such as the Euro vehicle emission regulations and EU directives on large combustion plants have considerably reduced emissions of PM, NMVOCs, NO_x and SO_2;

(b). Recent EU legislations, like the Euro 5 and Euro 6 regulations for light road transport vehicle and the EURO VI regulation, concerning the pollutant emissions from engines used on heavy duty vehicles - recently introduced through UN Regulations No. 83 (UNECE, 2010) and No. 49 (UNECE, 2012) by the UNECE World Forum for Harmonization of Vehicle Regulations (WP.29) - have further strengthened the action being taken on road transport vehicles[2]. Similar legislative initiatives have been enforced in North America (US EPA, 2000) and are being progressively considered in countries with rapidly increasing motorization rates;

(c). For non-road transport modes, as well as other sectors, such as the household and commercial/institutional sector, legislative initiatives have been undertaken with less frequency and with lower ambitions than in road transport. One of the few examples of legislative action in the residential and commercial area is available in Germany, where new small firing installations, such as stoves, are subject to regulatory requirements, and where the same legislative framework also requires the modernization of existing installations of the same kind (BMU, 2010).

VIII. Diesel exhaust emissions

49. Internal combustion engines powered by diesel fuel oil tend to offer better performances in terms of fuel consumption (also associated with lower greenhouse gas emissions) with respect to comparable gasoline engines. Even if diesel ICEs cost more than their gasoline equivalents, the fuel savings they generate tend to exceed the incremental investment cost gap they require for their purchase. Since savings are larger in applications that require an intensive use of the ICE, diesel ICEs

[2] In the case of road transport, the scale and relevance of the action already taken in recent years (in relation to measures addressing other sectors) is further confirmed by the explicit reference to Euro 5/6 and EURO VI regulation amongst the key examples to take into account in the proposals for the forthcoming revision of the NEC Directive (EC, 2012a).

are the main technology of choice in heavy-duty stationary and mobile applications. This is the case for a wide range of economic and industrial sectors, including for instance goods movement, public transportation, construction and agriculture.

50. Transport applications are highly dependent on liquid fuels and strongly coupled with internal combustion engine (ICE) technologies. Within transport, heavy duty transport modes (including road, rail, maritime and air transport) are those with the strongest association with diesel ICEs, contrary to residential, industry, mining and energy sectors with a wide range of applications of diesel fuel (such as heating and power generation plants), not only with ICEs.

VIII.1 International Agency on Research on Cancer (IARC) decision on the carcinogenicity of diesel engine exhaust

51. In June 2012, the World Health Organization's International Agency on Research on Cancer (IARC)[3] concluded that diesel engine exhaust is carcinogenic to humans based on sufficient evidence that exposure is associated with an increased risk for lung cancer (IARC, 2012). IARC thereby changed its finding from 1988, when it classified diesel exhaust as probably being carcinogenic to humans. The finding from a previous evaluation in 1989, that gasoline exhaust is possibly carcinogenic to humans, remained unchanged.

52. It is noteworthy that the IARC decision was unanimous and was based on "compelling" scientific evidence. It urged people worldwide to reduce their exposure to diesel fumes as much as possible. Large populations are exposed to diesel exhaust in everyday life, whether through their occupation or through the ambient air. People are exposed not only to motor vehicle exhausts but also to exhausts from other diesel engines, including from other modes of transport (e.g. diesel trains and ships) and stationary sources (e.g. power and motion generators used in the energy and in the industrial sectors).

53. However, the mounting concern about the cancer-causing potential of diesel exhaust was based on findings in epidemiological studies of workers exposed in various settings. This was re-emphasized by the publication in March 2012 of the results of a US National Cancer Institute/National Institute for Occupational Safety and Health study of occupational exposure to such emissions in underground miners, which showed an increased risk of death from lung cancer in exposed workers (IARC, 2012).

54. Dr. Kurt Striaf, Head of the IARC Monographs Program, indicated that "the main studies that led to the above mentioned conclusion were in highly exposed workers (mines) and that they came up to this conclusion based on other carcinogens, such as radon, that initial studies showing a risk in heavily occupational groups were followed by positive finding for the general population" (IARC, 2012).

55. Dr. Christopher Wild, IARC Director, answering the question if the new diesel engines are so clean that the findings from this Monograph meeting are no longer relevant to today´s situation[4],

[3] IARC is a specialized agency of WHO. It produces evidence-based science to be translated into public health policies and actions by national or international public health authorities such as WHO. IARC defines potential cancer risks to humans, but it does not recommend legislation or regulation. The IARC evaluation is designed to assist national and international health authorities in making their risk assessments and taking preventive action.

replied: "the new diesel engines contain far fewer particles and chemicals compared to the older technology engines. In addition to that there are also qualitative changes, so the composition of the mixture in the exhaust is different. However, what we do not know at this stage is if this composition and the decreased levels of these components translated to a different healthy fact in exposed people and here we should encourage further research in the future. The second point is that in many developing countries the transition from the old technology to the new one will take time and therefore, for many people in the world, the exposures are still from the diesel engines" (Wild, 2012).

56. The US EPA considers that the health effects of diesel emissions are well studied, but complex (US EPA, 2002). Even if the level and duration of exposure that causes harm varies from one substance to the next, the EPA has designated diesel exhaust as a likely carcinogen to humans by inhalation at environmentally adequate exposures (US EPA, 2002). In the United States, a number of other agencies (National Institute for Occupational Safety and Health, the International Agency for Research on Cancer, the World Health Organization, California EPA, and US Department of Health and Human Services) have made similar classifications.

VIII.2 Measures aimed to reduce the emissions of air pollutants from diesel ICEs

57. The importance of the health risks pointed out by the IARC and other authoritative sources calls for continued action aiming at the limitation of emission of air pollutants characterizing diesel exhaust and, more broadly, to reduce human exposure to them.

58. To date, the legislation targeting the emissions of air pollutants was the main contributor to the achievement of major reductions of air pollutant emissions that also address diesel combustion.

59. The strong relationship between transport and ICEs was such that legislative actions were aimed primarily to limit pollution generated in road transport applications. In Europe and other highly motorized countries, recent policy measures that impose stricter pollutant emission limits for the construction of new road transport vehicles (through the Euro 5/6 and EURO VI regulations), extend into the forthcoming years the achievement of substantial impacts in terms of abating the emissions from diesel exhaust emissions. Given their characteristics, they do so in a way that attempts to target primarily NO_x, i.e. the only pollutant whose emissions are primarily imputable to transportation. These considerations highlight that, to date, road transport played the most prominent role in the limitation of health and environmental effects due to ICEs, including in those powered by diesel fuel oil.

60. The efficacy of the regulations limiting the emissions of air pollutants from diesel ICEs used in road transport application is confirmed by the recognition that new diesel engines used on road vehicles contain far fewer particles and chemicals compared to older diesel ICEs, notwithstanding qualitative changes that require further research.

61. Some of the opportunities to further reduce emissions are available on stationary engines and the in-use mobile fleet, since older in-use diesel engines and vehicles can remain in operation for over 20 years. Such measures include retrofitting or removing the older in-use fleet off the road to ensure that newer engines and vehicles, which are compliant with newer more recent air pollutant regulations, have a chance to lead to improved health and environmental outcomes. Some initiatives in this area have already been undertaken by a number of governments. In particular, the Government of Canada is the co-chair of a pan-Canadian working group which holds discussions on reducing emissions from the in-use fleet. The working group has identified off- and

on-road diesel emissions as a concern and is now looking at discrete initiatives to achieve reductions in this area over the next 3 years.

62. In some high exposure areas, there might be the need to set up policy measures aimed at replacing vehicles equipped with older engine technologies with new vehicles complying with the new regulations or to retrofit the engines with appropriate emission control devices. In this respect, countries like Canada and the United States of America are looking at initiatives aimed at exploring the financing options which can help support heavy-duty fleets to further reduce GHG and air pollutant emissions by making the purchase of emission reduction technologies for their in-use fleets more feasible and affordable.

63. As pointed out in section VII, regulatory measures aiming to limit pollution from road transport applications were not frequently mirrored by comparable measures in other transport areas and in other economic domains, such as residential and commercial/institutional sector. This is especially relevant when looking at pollutants associated with diesel exhausts (namely PM and NO_X), since substantial amounts of diesel and residual fuel oil are combusted in applications widely employed in the energy, industry and residential/commercial sector, and since a significant fraction of these emissions (namely those originating in the residential and commercial sector, which is responsible for the largest fraction of PM emissions) is likely to insist on urban agglomerations, i.e. the areas subject to the largest exposure to air pollution.

64. Considering the existing and forthcoming legislative measures, action limiting the exposure to air pollution due to diesel exhausts is likely to be most urgently needed in economic sectors and applications that have not yet been targeted, such as residential diesel-powered heating plants. Even if road transport is not amongst these priorities, the rapid motorization taking place in urban areas of emerging economies and developing countries, as well as the high motorization rate characterizing cities in developed regions are both likely to remain associated with high exposure to air pollution. This is likely to call for regulatory measures capable to promote a swifter evolution towards the adoption of advanced pollutant emission control technologies. The strong efforts already undertaken to reduce emissions of road vehicles for personal and collective use, as well as the contextual difficulties encountered in improving air quality to date, also encourage the adoption of measures that favor selection of transport modes that are characterized by lower emissions of pollutants. Finally, whenever their contribution to the concentration of air pollution in high exposure areas like cities is relevant, the example set by the pollutant emission regulation in road transport should also be extended (with greater ambition in comparison with current practice) to other transport modes.

VIII.3 UNECE activities on technologies reducing harmful effects of diesel ICEs

65. UNECE Working Party 29 on Vehicles Regulations has already done extensive work in this field, with major achievements towards reducing PM emissions of all motor vehicles engines (diesel and petrol).

Figure 5. $PM_{2.5}$ emissions in the EU-27 share of emissions by sector group, 2010

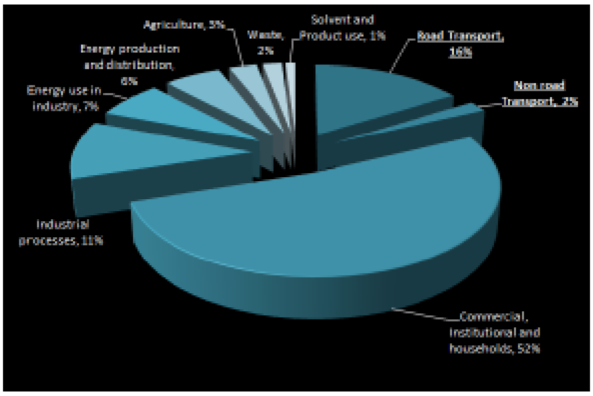
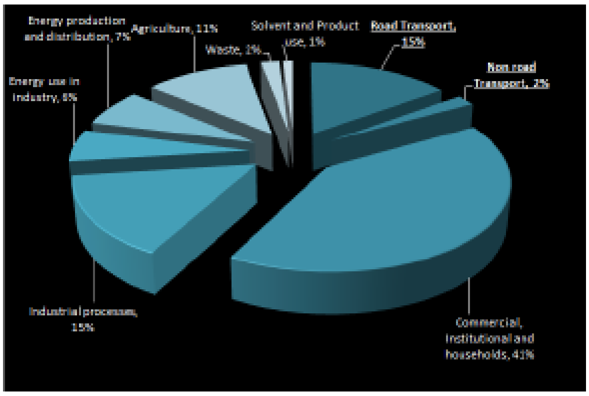


Figure 6. PM_{10} emissions in the EU-27 share of emissions by sector group, 2010



66. In 2001, WP.29/GRPE established an informal expert group on the Particle Measurement Programme (PMP). The main focus of this group is, and has been, the development of standardized methodologies to test emissions from vehicles and engines. This has been instrumental for the development of regulatory instruments targeting the emissions of pollutants, including particulate matter. In 2008, WP.29 adopted the new particle number measurement method for light vehicles (UN Regulation No. 83), including new limit values (Euro 5 level) that have to be fulfilled by petrol and diesel engines. In 2010, WP.29 adopted the new particle number measurement method for heavy duty vehicles (UN Regulation No. 49).

67. Today, PMP is still an active group dealing with calibration issues. The measurement limit of today's particle measuring devices is about 23 nm. GRPE agreed to resume, at its next session in January 2013, discussions on the possible need for measurements of sub 23 nm particles (for future diesel and petrol engines).

68. UN Regulations Nos. 49 (heavy duty vehicles) and 83 (light vehicles) specify limit values for emissions of particulate matter (expressed both in terms of particulate mass and particle number). These values are reported in the figures below. The evolution of regulatory instruments on emissions of local pollutants led to limit values for PM emissions of light vehicles that are today more than 30 times lower than 2 decades ago.

69. Similar limit values for PM have been enforced for engines of non-road mobile machinery (UN Regulation No. 96), i.e. engine fitted to self-propelled machinery including agricultural/forestry tractors, construction site engines, locomotives, navigation vessels, etc. The current limit values are for non-road mobile machinery depend on the net power of the engine and range between 0.025 g/kWh (large engines) and 0.8 g/kWh (small ones).

Figure 7. PM emission limits for light vehicles

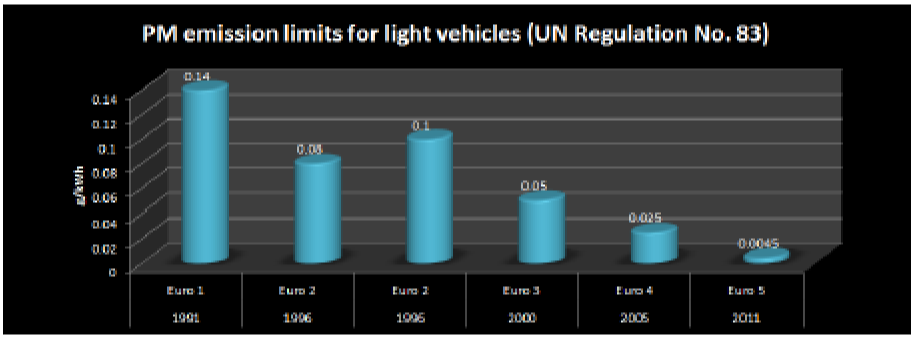


Figure 8. PM emission limits for heavy duty vehicles

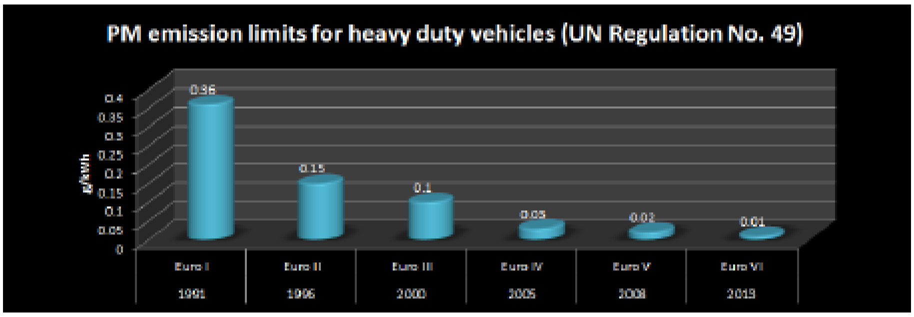
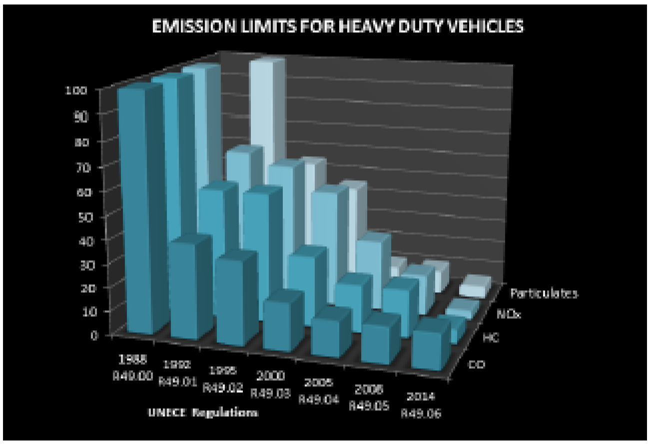


Figure 9. Emmission limits for heavy duty vehicles (CO, HC, NO, PM)



70. The World Forum considered at its Round Table on Climate Change and Transport (ECE/TRANS/WP.29/1070, para. 77) that a possible strategy for the automotive sector to contribute to the abatement of the emissions of greenhouse gases and air pollutants was to pursue:

a) improved energy efficiency and the use of sustainable biofuels as a short-term objective (2015);

b) the development and introduction into the market of plug-in hybrid vehicles as a mid-term objective (2015-2025); and

c) the development and introduction into the market of electric vehicles as a long-term objective (2025- 2040).

This strategy would shift the automotive sector from the use of fossil energy to the use of hydrogen and electric energy. To be effective, this strategy would need to rely on the sustainable production of electricity and hydrogen, a crucial policy issue identified for future discussions on global warming and the reduction of air pollutants and CO_2 emissions.

IX. Conclusions and recommendations.

71. The conclusions and recommendations will be drafted following the discussions of the Working Party.

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