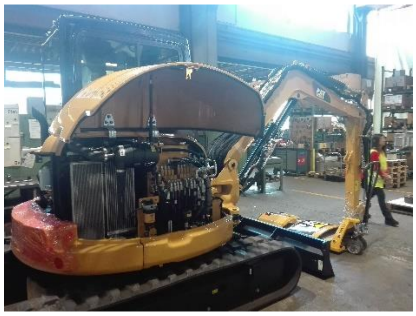
METHODOLOGICAL GUIDE

CALAC+

Programa Clima y Aire limpio
en Ciudades de América Latina

METHODOLOGICAL GUIDE FOR DEVELOPING "SOOT-FREE" POLICIES FOR NON-ROAD MOBILE MACHINERY



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Methodological guide for developing "soot-free" policies for non-road mobile machinery

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Cover photo:

TECSUP headquarters in Lima, Peru; AVESCO Langenthal Switzerland (below); Skid-steer loader on public roads in Lima, Peru (above)

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The Climate and Clean Air project in Latin American Cities Plus (CALAC+) pursues a vision of healthier cities that seek to reduce their emissions of pollutants and greenhouse gases (GHGs) by encouraging a shift to soot-free, low-carbon city buses and non-road mobile machinery.

This guide is part of a series of 7 technical documents developed by CALAC+ to promote knowledge and environmental management of machinery emissions reduction in Latin America. The topics covered include the generation of inventories, estimation of pollutants, emission control systems, regulatory standards policies and monitoring of measures adopted.

The *Methodological guide for developing "soot-free" policies for non-road mobile machinery* aims at taking the opportunity to implement policies and regulatory measures. These measures should prioritise a significant reduction of soot in diesel emissions, given its toxicity and climate change impact.

Content

1. INTRODUCTION

Contrary to what has happened with on-road vehicles, emissions from non-road mobile machinery have not been sufficiently quantified[1] in Latin America, although international experience shows this sector to be an important contributor to air pollution[2].

This has delayed the implementation of emission reduction policies such as emission standards for new engines or the retrofitting of used engines with aftertreatment systems. Therefore, there is an opportunity to significantly reduce emissions from these sources through the implementation of policies and regulatory measures in a largely unregulated sector.

In order to successfully address the design of such policies, consideration must be given to the major responsibility that diesel engines have in the total emissions from this sector[3]. In this discussion the soot content in diesel emissions becomes a priority, due to their toxicity and climate change impact. Given this background, the policies and measures analysed are geared towards technologies that allow soot-free machinery.

2. SOOT IN DIESEL EMISSIONS: HEALTH IMPACT AND CLIMATE CHANGE

Several pollutants coexist in non-road diesel engine emissions[4] that are regulated in European and US legislation because of their impact on human health. Among these pollutants are Nitrogen Oxides, Unburned Hydrocarbons, Carbon Monoxide and Particulate Matter. Of these, the main focus is on the reduction of Nitrogen Oxides (NOx) and Particulate Matter (PM), because of their toxicity and high emissions from these engines.

According to international legislation, PM of diesel engines is defined as the mass of all substances emitted from the exhaust which are captured by a sampling and dilution procedure on a filter at 52° Celsius. Based on this technical definition, the PM of a diesel engine may contain the following substances:

- **Soot:** Small solid carbon particles (20-30 nm) that are formed in the combustion process and then agglomerate into larger particles (~100 nm). It is part of the insoluble fraction of PM.
- **Volatiles:** Liquid-phase substances resulting from the condensation of unburned hydrocarbons (part of the soluble organic fraction) and sulphates produced from the sulphur content of the fuel (part of the water-soluble fraction).
- **Ashes and others:** Solid particles formed by metal oxides (ashes), from the lubricant or other fuel additives, and by the engine's abrasion particles (pistons). Like soot, they are part of the insoluble fraction.

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[1] For the purposes of this document, non-road mobile machinery does not include locomotives, aircrafts or ships.
[2] Non-road machinery accounts for 39% and 25% of total PM emissions from mobile sources in the US and the EU, respectively (higher share than heavy-duty vehicles in both cases). [ICCT2016]
[3] As an example, 87% of NOx emissions and 94% of PM emissions come from machinery in the construction, industry, forestry and agriculture sectors, which are all sectors where diesel engines are prevalent [ICCT 2016].
[4] Hereinafter, a non-road engine is defined as one installed in non-road mobile machinery..

Figure 1: Substances comprising the PM measured in mass according to their legal definition (based on a heavy-duty diesel engine)

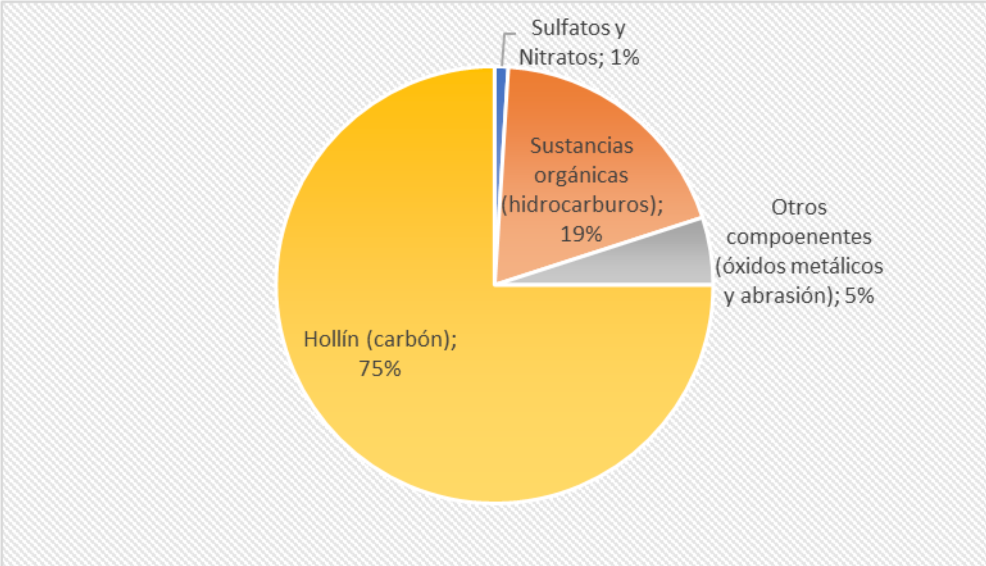


Figure Translation: Sulfatos y nitratos: Sulphates and nitrates/ Sustancias orgánicas (hidrocarburos): Organic substances (hydrocarbons)/ Otros componentes (óxidos metálicos y abrasión): Other components (metal oxides and abrasión)/ Hollín (carbon): Soot (coal)

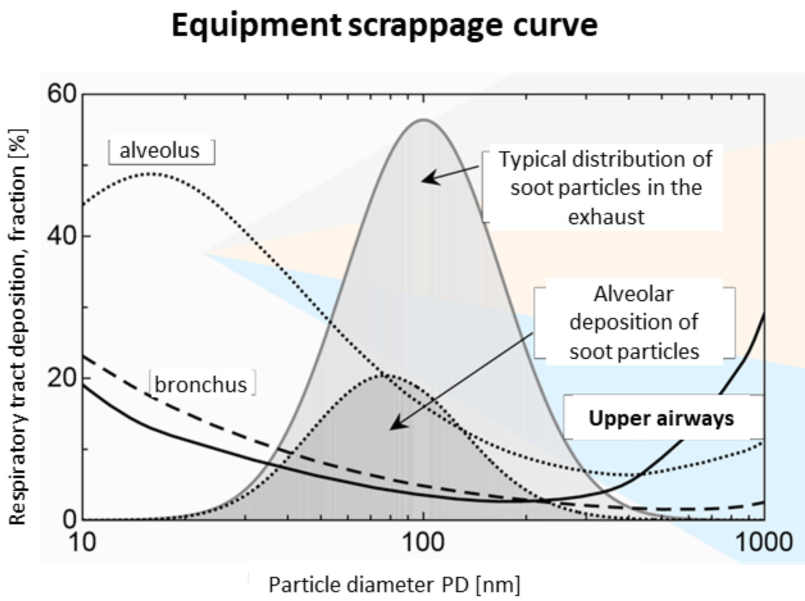
Source: Prepared by the authors from [VAASA 187].

The epidemiological and toxicological effects[5] of diesel PM have placed this pollutant at the forefront of attention. Among the most relevant epidemiological effects studied is the WHO classification of diesel emissions as carcinogenic to humans (Grade 1)[6].

Toxicological studies have paid special attention to soot, as it is the insoluble and persistent fraction of PM. Also, in terms of size distribution, these particles are found to be in the range of highest penetration into the respiratory tract.

[5] Toxicology studies the effects of pollutants on the human body, while epidemiology studies the effects of pollutants on the human population.
[6] [WHO 2012]

Figure 2: Size distribution of soot particles and their deposition in the respiratory tract.

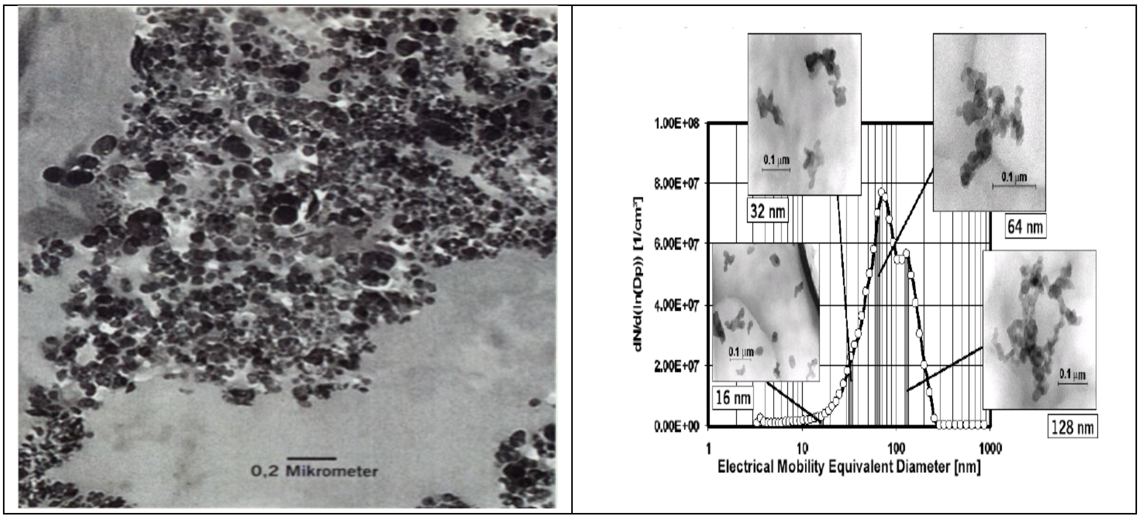


Source: Health Effects of Fine Airborne Particles - PhD. Markus Kasper, Matter Engineering. Presented in Santiago de Chile, May 2005.

From a toxicological perspective, soot particles have two properties that are critical to health: they are highly inhalable and they are inorganic and insoluble. In other words, they are particles that get deep into the lungs and cannot be destroyed by the body's defence mechanisms, nor are they diluted in the body's fluids. In addition, these particles of nanometric size, capable of penetrating the cell layer of the alveoli, can be transported through the bloodstream to other organs of the body[7].

[7] [ETH 2004]

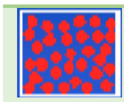
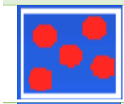
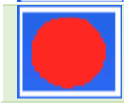
Figure 3: Deposition of soot particles into the lungs (left) and their size distribution (right).



Source: Health Effects of Fine Airborne Particles - PhD. Markus Kasper, Matter Engineering. Presented in Santiago de Chile, May 2005.

However, with regard to the metric for measuring soot, and diesel particles in general, a dilemma arises, as in the measurement of mass PM the largest particles have the greatest weight in the result, which is contrary to the rationale behind the health impact. For example, at a concentration of 10 [µg/m^3], depending on the size of the particles, the following quantities can be found:

Table 1: Relationship between particle size and quantity for equal mass concentration.

	Diameter	**Number [1/cm^3]**
	20 nm	2.400.000
	500 nm	153
	2.5 µm	1

Source: Institut für Epidemiologie – Oberdörster et al. - 1994

According to mass metrics it would be equivalent to emitting a single 2.5 µm particle as 2,400,000 20 nm particles, although from a health perspective the effects are very different.

In view of all this evidence, legislation in Europe has enhanced the regulation on non-road engine emissions; as a result of this, Stage V standard was implemented which includes the metric of the solid particle number in accordance with the previous soot present in these emissions. Thus, a new definition for measuring diesel particulates, i.e. the amount of solid particles above 23 nm and up to 2.5 µm, has been incorporated into European legislation.

In line with the latter definition and in addition to mass measurement, soot-free policies on non-road machinery must consider particle number metrics to adequately assess health impact.

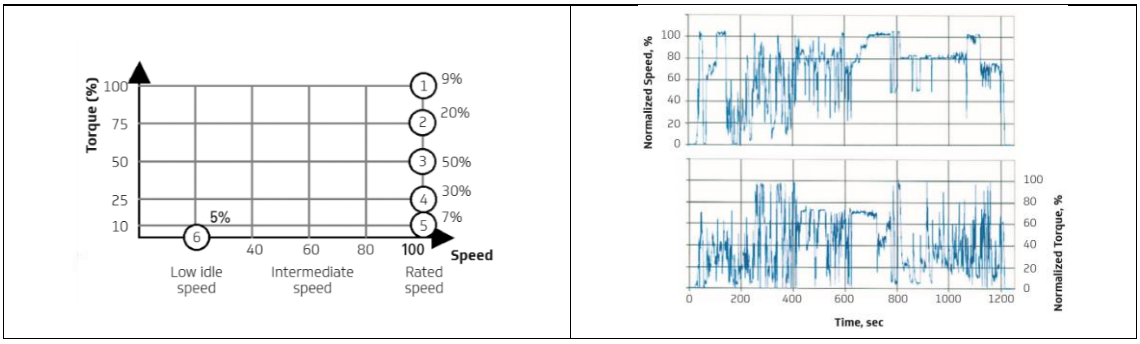
In relation to climate change effects, soot or black carbon influences the climate: 1) by directly absorbing sunlight, 2) by reducing the reflectivity of snow or ice by deposition. Soot plays a very important role in global warming, which is 460 to 1,500 times greater than CO_2 per unit of mass emitted[8].

3. EMISSIONS CERTIFICATION AND CONTROL TECHNOLOGIES FOR NON-ROAD DIESEL ENGINES

One of the first policies to mitigate emissions from non-road diesel engines is the regulation of emissions through type approval. This involves setting emission limits for new engines, defined by rated power ranges.

In the type certification, an engine representative of the units to be sold is tested using a typical operating cycle according to the operating conditions of the machinery. For this purpose, different points of engine torque and speed are defined. The cycle can be steady (constant speed at each point) or transient (variable speed). Figure 5 shows some examples of the cycle.

Figure 4: Operating cycles for measuring emissions in non-road engines. On the left a steady cycle (NRSC) and on the right a transient cycle (NRTC). For NRSC, emission results weighting percentages are used at each measurement point. The engine speed is given as a percentage of the rated speed. Torque is represented as a percentage of the maximum torque for each operating point.



Source: On and off-highway commercial vehicles, Worldwide emissions standards (2018-2019), Delphi Technologies.

The emission limits are defined according to the power range of the engine and in accordance with a series of increasingly demanding and chronologically arranged regulatory levels.

[8] https://ccacoalition.org/en/slcps/black-carbon

Figure 5: Implementation schedule of regulatory levels in the European Union and the United States.

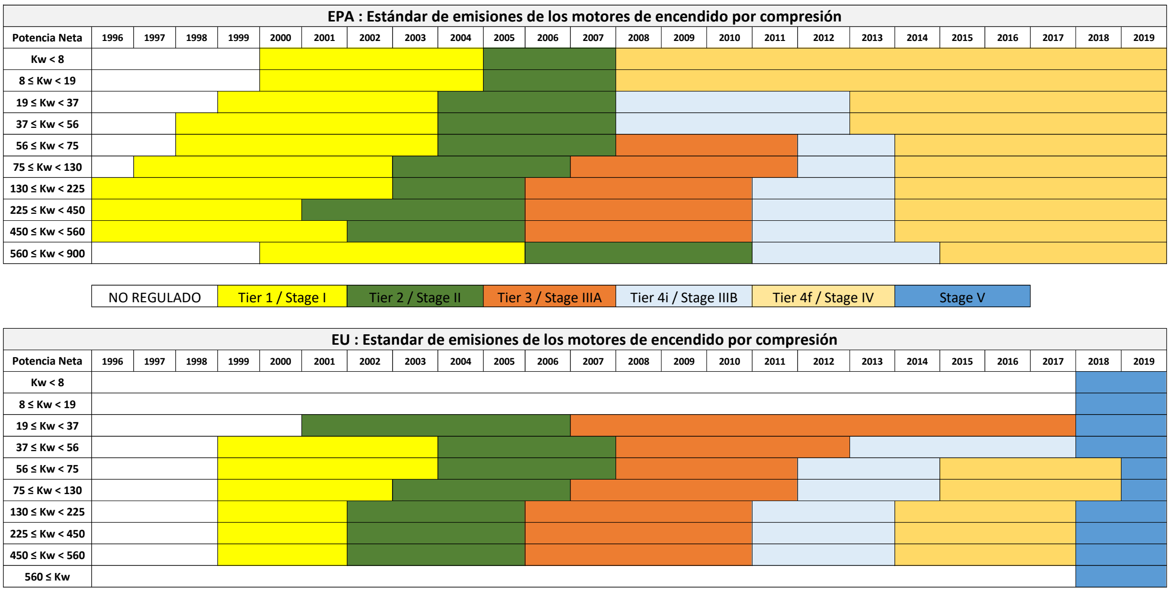
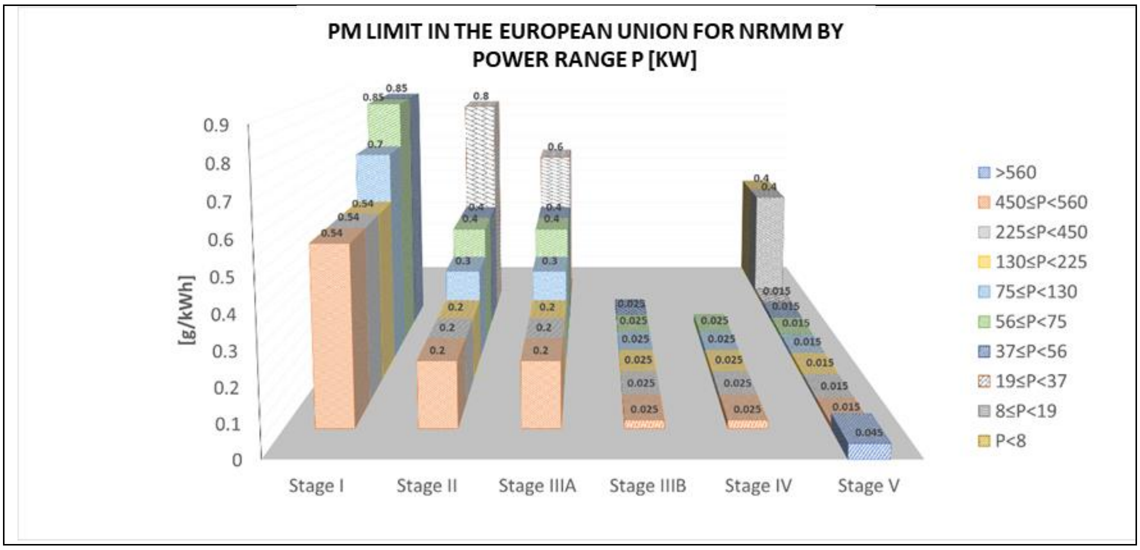
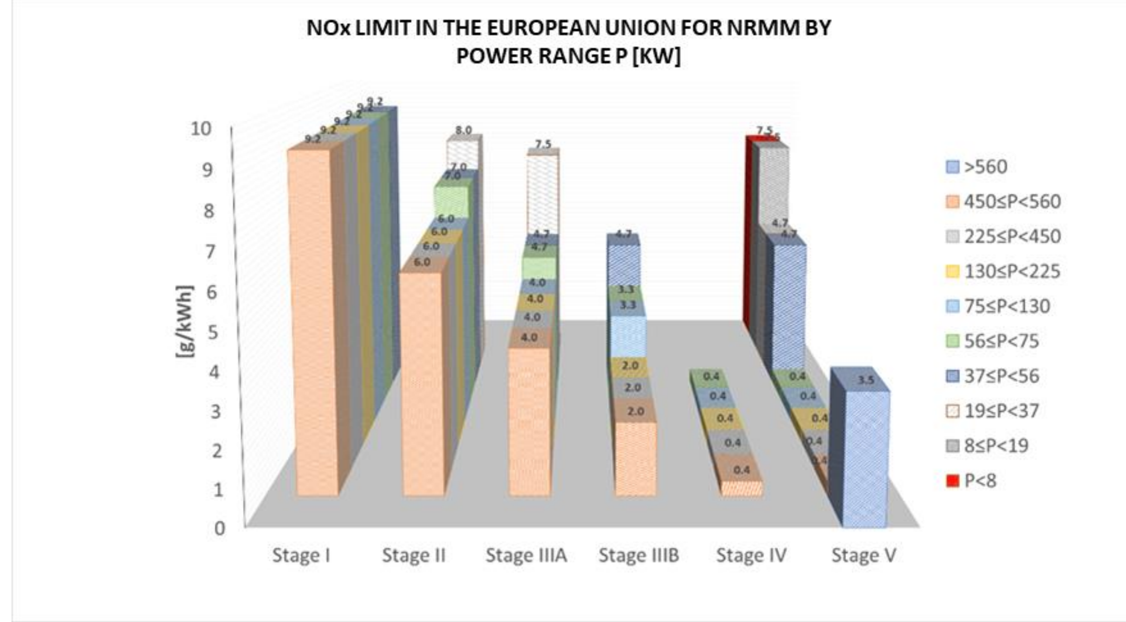


Figure translation: EPA: Estándar de emisiones de los motores de encendido por comprensión = EPA: Emission standard for compression-ignition engines/ Potencia neta: Net power/ NO REGULADO: UNREGULATED

Source: Updated from [Geasur 2013].

Figure 6: PM and NOx limits in European Union legislation for diesel engines, by power range.

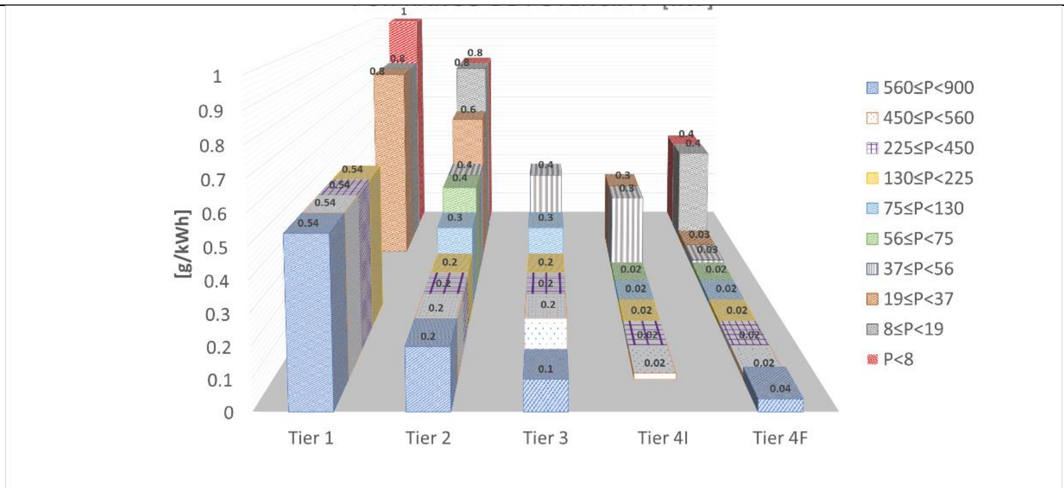




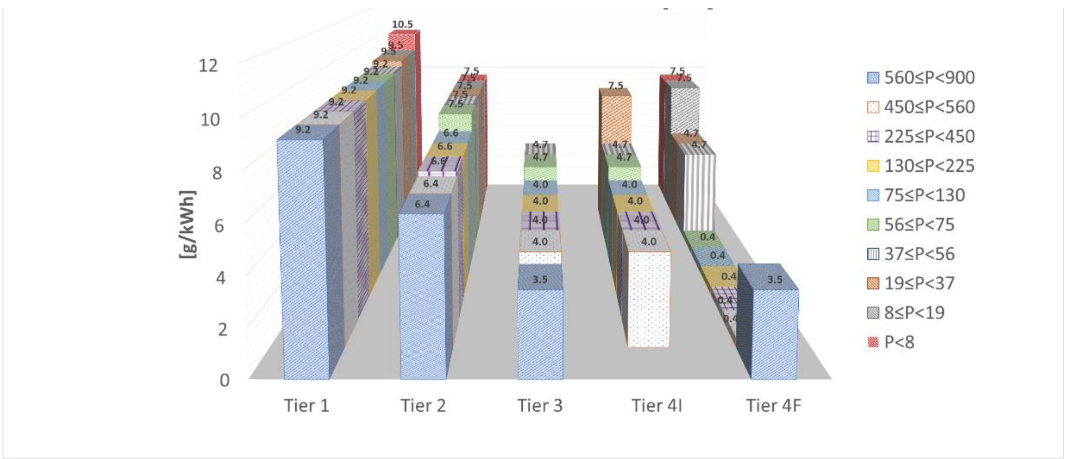
Note: For those phases (Stage) where the limit value for the category is omitted, the previous phase (Stage) still applies in that power range.

Source: Prepared by the author.

Figure 7: PM and NOx limits in EPA legislation for diesel engines, by power range



EPA NOx LIMIT FOR NRMM BY POWER RANGE P [KW]:



Note: For those phases (Stage) where the limit value for the category is omitted, the previous phase (Stage) still applies in that power range.
Source: Prepared by the author.

As can be seen, unlike the EPA regulation which regulates them from Tier 1, engines above 560 [kW] and below 19 [kW] were not regulated by European legislation until Stage V. With regard to the intermediate ranges (560<P≤19), the limit value tends to be inversely proportional to the size (power) of the engine. This is explained by the following:

- The cost impact, as a percentage of the price, of developing engines or aftertreatment systems for emission standards is greater the smaller the engine[9].
- The intensity of use and exhaust gas volume of small engines is lower.

The most significant reductions in PM and NOx values occur in Stage IIIB/Tier 4i and Stage IV/Tier 4f, respectively, with reductions close to 90% and 80%. The above is within the power ranges between 56-560 [kW], in the case of PM, and within the ranges 560-75 [kW], in the case of NOx.

Up to the Stage IIIA/Tier 3 regulatory level, emissions were controlled by the following technological strategies:

Injection system:

By using high-pressure injection and electronically controlled systems, better fuel atomisation can be achieved and dosage and injection times can be varied. This allows the air/fuel mixture to be improved and the formation of NOx and PM to be controlled. One example is Common Rail technology.

Turbocharger:

It allows the intake air to be increased by compression, improving the air/fuel ratio. The design of variable-geometry turbochargers allows better performance over the complete operating range of the engine. The addition of a compressed air cooler reduces combustion temperatures. It improves PM and NOx emissions.

[9] [ICCT 2018]

Exhaust Gas Recirculation (EGR):

Recirculation of a percentage of the exhaust gases to the engine, which reduces the combustion temperatures, thus decreasing NOx emissions. By means of a recirculated gas cooler, NOx reductions can be improved.

Engine modifications:

Modification of engine design parameters such as cylinder head and combustion chamber geometry, position of the injectors, number of valves, compression ratio, gas inlet and outlet geometry. Allows for reductions in PM and NOx.

Starting at the Stage IIIB/Tier 4i regulatory level, to obtain the most stringent PM limits, emission control on these engines required the use of aftertreatment systems such as those listed below:

Diesel Oxidation Converter (DOC)

Monolithic substrate that allows the flow of exhaust gases through open channels at both ends and is coated with precious metals that allow the oxidation of the soluble organic fraction of PM. This allows reductions of PM mass of up to 20%, but no reduction in PN.

Diesel Particulate Filter (DPF):

Filtering substrate, highly efficient in retaining solid particles (>97%), through which all exhaust gases flow and which has a regeneration system to burn off (oxidize) the retained soot.

Selective Catalytic Reduction (SCR):

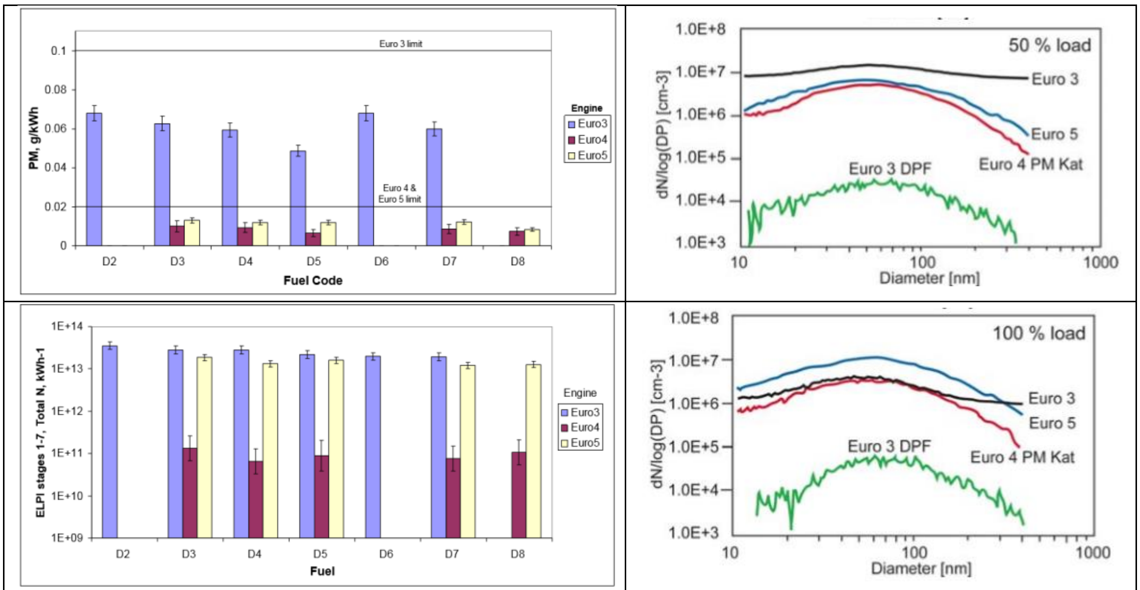
Catalyst that uses ammonium as an agent to reduce NO and NO_2 to N_2 and H_2O. Its reduction efficiency varies strongly with temperature. Ammonium is generated from a solution of urea that is injected into the exhaust gases. Depending on the exhaust gas temperatures its efficiency can reach 90%.

Choosing a combination of aftertreatment systems depends on the air/fuel ratio of the engine. When the air/fuel ratio is low, there is a trade-off between improving fuel economy and lowering PM emissions, but increasing combustion temperatures and thus NOx. Compliance with the Stage IIIB/Tier 4i standard is possible by reducing excess NOx with an SCR system. Conversely, if the engine air-fuel ratio is high, meeting the standard is possible by lowering engine NOx emissions, but reducing excess PM using a combination of EGR+DOC+DPF. This reduces excess PM mainly in the DPF. However, as can be seen in Figure 8, which shows various measurements made on diesel engines, for different aftertreatment system configurations and regulatory levels, using the DPF alone allows PN reductions of at least two orders of magnitude.

The following regulatory step, Stage IV/Tier 4f, essentially involves a significant reduction of NOx, but without modifying the PM, so it is possible to achieve these levels by incorporating an SCR to the EGR+DOC+DPF combination, or by adding an EGR system to the SCR already installed in the previous phase to obtain an additional reduction of this pollutant (EGR+SCR) and eventually a DOC (EGR+DOC+SCR).

In practice, less than 50% of Stage III/Tier 4i or Stage IV/Tier 4f non-road engines are fitted with DPFs[10]. This means that the health benefits of reducing the mass standard are partial in that it does not guarantee a significant reduction in PN. Therefore, for the Stage V standard the European Union legislation incorporated the PN limit ≤ $1*10^{12}$, for power ranges between 19 ≤ P ≤ 560. This standard does ensure the use of DPFs in emissions aftertreatment and the associated health and climate change benefits.

Figure 8: Comparison of emissions results measured in PN and PM for different diesel emission control technologies.



Diesel engine particulate emissions measured in mass (PM, top chart) and number (Total N, bottom chart), for steady-state cycle (ESC), Euro 3 engine, Euro 4 engine (with DPF), Euro 5 engine (with SCR), with different fuel specifications (D2 to D8) Source: [CONCAWE 2005]	Diesel particulate emissions in number (PN), for Euro 3 diesel engines, Euro 3 with DPF, Euro 4 with PM Kat (partial filter), Euro 5 (with SCR), in two load levels (50% and 100%). Source: [SAE 2007]

10 [ICCT 2018]

4. EMISSIONS REDUCTION PROGRAMMES FOR CONSTRUCTION MACHINERY: SOME EXAMPLES

Considering the long lifetime of non-road mobile machinery[11], many countries have adopted policies to advance the benefits of control technologies. Two types of programme that have proved successful in Europe are explained below.

DPF retrofit program

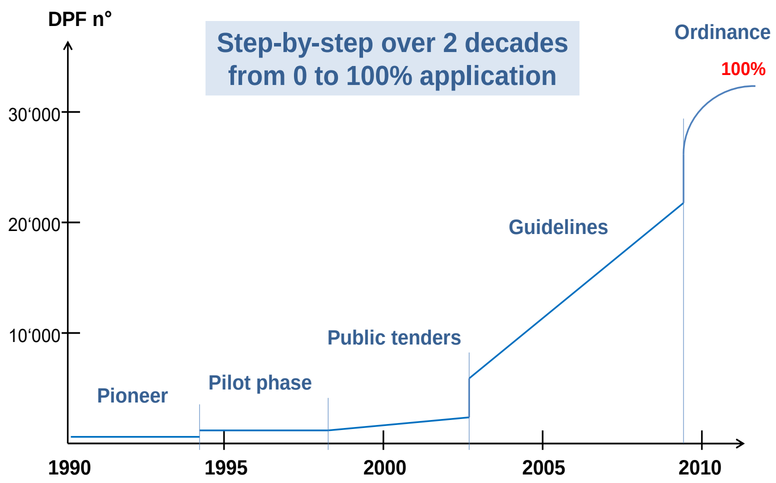
As we have seen, the particulate filter has proved to be the only aftertreatment technology that allows the soot to be virtually eliminated from diesel engine emissions. The retrofitting of these engines consists of installing a DPF device at the exhaust gas outlet, usually in place of the muffler, to clean the emissions, retaining the particulate material generated in the combustion in the engine.

One of the most important experiences with DPF retrofit of non-road mobile machinery is in Switzerland, where a pilot retrofit programme was initiated in 1990 for the construction of the 57 km long Gotthard Tunnel, to reduce diesel particulate concentrations in the working environment. By 1998, a DPF retrofit certification programme was in place, which considered a minimum efficiency of 97% measured in PN. In 2002, machinery retrofit with a particulate filter in underground construction was made mandatory by the SUVA[12], and the Federal Office for the Environment (FOEN) provides a guide with recommendations for large surface construction sites.

In 2009, the FOEN issued an ordinance that makes retrofit mandatory for all construction machines with a diesel engine over 37 kW[13].

[11] For example, the European Environment Agency considers the lifespan of tractors and harvesters to be 10 years for a front loader and 14 years for a skid-steer loader (EMEP/EEA air pollutant emission inventory guidebook 2016).
[12] The Swiss National Accident Insurance Fund regulates environmental conditions at work.
[13] For engines between 18 and 37 kW the ordinance mandates the use of new machinery with DPF.

Figure 9: DPF retrofit of construction machinery in Switzerland.



Source: Construction machines with DPF – Experience in Switzerland. PhD. Gerhard Leutert. Presented in Chile, July 2015.

The Air Pollution Control Ordinance (OAPC), in addition to used machinery retrofitting, considered that new machinery should comply with the European engine emission standard, in addition to meeting an PN emission limit of $1*10^{12}$ or using a FOEN certified DPF for PN efficiency greater than 97%. This was even before the Stage V standard with the PN limit came into force.

As a result, FOEN authorised 84 engine families, with 500 different engine types, for construction machinery, which met the standard and 44 different types of DPFs, applicable to used or new engines.

In any case the success of a retrofit program has to do with the implementation of a series of good practices such as:

- Engine maintenance conditions.
- Use of filters certified for efficiency and endurance[14].
- Proper selection of the DPF system.
- Verification and monitoring of installations.

The maintenance and verification and monitoring conditions are very relevant since the loss of efficiency is proportional to the percentage of the DPF surface that is damaged[15].

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[14] The UN ECE R132 Regulation provides requirements for type certification of emission control devices for retrofitting non-road mobile machinery.

[15] A study by Yamada et al (NTSEL-2015) showed that with 0.5% damage to the DPF surface, the emissions from a Euro VI engine with DPF can exceed the Particulate Number (PN) emission limit. With 100% damage to the DPF the emissions exceeded the PN limit by 40,000 times.

Low Emission Zones

Low Emission Zones (LEZs) correspond to a widespread experience in European cities that establishes a specific area in which the circulation of vehicles and/or the use of construction machinery is limited according to their environmental performance. This is done by requiring compliance with an environmental type approval standard (Stage for construction machinery), or by retrofitting with aftertreatment systems such as the DPF.

Although there is no common scheme in the LEZs, it is possible to identify the variables or attributes to be considered in their definition:

- **Regulated fleet:** Mobile sources and construction machinery are regulated. For machinery, the same power classification established in the emission standards is generally used.
- **Emissions requirement:** The reduction of PM and NOx is prioritized, which is why it focuses on diesel vehicles, establishing emission limits according to type approval standards (Stage IIIA, Stage IIIB, Stage IV or Stage V).
- **Regulated area:** It can cover large urban areas (London) or small central areas of the city (Sweden).
- **Retrofitting:** In general, retrofitting is allowed or encouraged with aftertreatment systems, for which certification requirements and minimum efficiencies are established.
- **Gradual implementation:** In general, LEZs schemes consider gradual implementation where the initial phase provides for less stringent requirements in order to achieve the objectives in the final phase (London 2008/2010/2012, Netherlands 2008/2010/2013, Denmark 2008/2010).

COUNTRY	REGION	REQUIREMENT
Austria	Vienna	• Stage IIIA or higher for all construction machinery. • Stage IIIB or higher for new machinery.
Denmark	Copenhagen	• Within a low emission zone, it must approve the installation of a DPF.
Sweden	Gothenburg, Malmö and Stockholm.	• Stage IIIA, exemptions allowed on request.
United Kingdom	London	Power between 37-560 kW: • Major construction sites in the Greater London area: Stage IIIA. • Any construction site in central areas: Stage IIIB.
Germany	Berlin	• Stage IIIB, all construction machinery. • Stage IIIA for machinery <37 kW. • Previous machinery must be equipped with DPF.
	Mainz	• Construction machinery for procurement of construction works must be fitted with DPF.
	Bremen	Emission requirements for construction machinery under public tenders: • 19 to 37 kW Stage IIIA, otherwise retrofitted with DPF. • 37 to 560 kW Stage IIIB, otherwise retrofitted with DPF • When retrofitting is not technically feasible, the equipment is exempted.

	Baden-Württemberg	• 19 to 37 kW:
		  ◦ 2017: Stage IIIA or DPF.
		  ◦ 2019: Stage IIIA and DPF
		• 37 to 56 kW:
		  ◦ 2017: Stage IIIB or DPF.
		• 56 to 560 kW:
		  ◦ Stage IV or DPF.

Source: https://urbanaccessregulations.eu/

5. ALTERNATIVE FUELS AND TECHNOLOGIES

CNG/LNG

Among the most recurrent alternative fuels to replace diesel engines is the Compressed Natural Gas (CNG) or Liquefied Natural Gas (LNG). This fuel can be used in spark-ignition engines, also called Positive Ignition (PI). Historically, spark-ignition engines have presented lower particle emissions than a diesel engine, so its control has not been required. However, the high retention efficiency of diesel filters has made their particulate emissions comparable to those of diesel engines with filters (see Figure 10).

However, a CNG or LNG vehicle, operating with direct injection, has a combustion process very similar to diesel and is capable of emitting as many particles as a diesel engine, unless it also has a particulate filter (GPF). For this reason, European Union legislation has incorporated the PN limit in non-road engines with spark ignition (PI) into the Stage V standard.

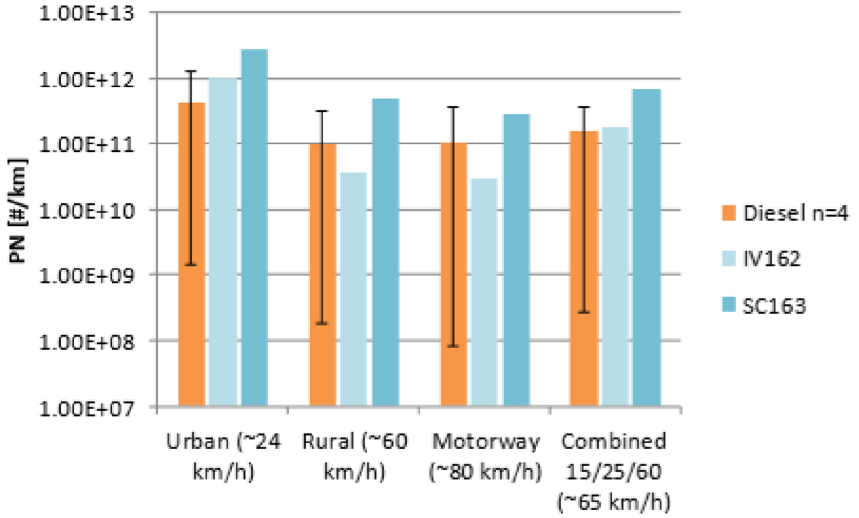
Electrification

Full or hybrid electrification of the propulsion and mechanical work of non-road machinery is very attractive from the environmental and occupational health perspective as they have no exhaust emissions. This technology is also interesting from the energy efficiency standpoint, considering that the maximum efficiency of a diesel engine is 35% versus 90% for an electric engine.

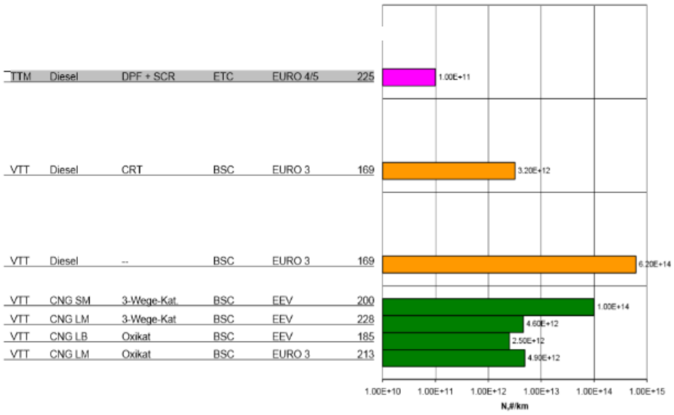
However, electrification in this sector must overcome some challenges such as the greater complexity of hybrid drives and more aggressive environmental conditions due to the high temperatures, vibrations and dust that this kind of machinery is often exposed to. As a result, it is more difficult to guarantee the required reliability and lifetime.

In Europe and the USA, hybrid drives are expected to account for 10 to 20 percent of sales in all three categories of machines in the 56 to 150 kW power class by 2030. In Europe and the USA, purely electric drives hardly play a role. In China, electric drives are expected to account for up to 8% of the two categories of construction machinery studied. In China, the power supply for these drives is often provided by cable, which shows considerable economic advantages compared to installing a battery in a vehicle.

Figure 10: Top chart: PN emissions measured en route (PEMS) of four Euro VI diesel engines (with DPF), compared with two Euro VI LNG engines (IV162 and SC163). Figure below: Three diesel engines with different emission standards compared to PN with CNG engines.



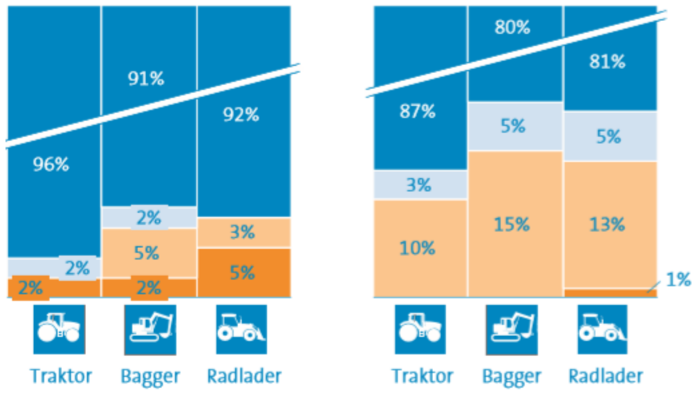
Source: TNO 2017



Source: [TTM 2005-2]

In the power class 19 to 56 kW, the three markets considered are expected to account for up to 5% of electric drive sales in 2030. The regional differences are less significant, with the exception that in China a cable is used for power supply in construction machinery. The first machines from the small tractor and small construction machinery area are already available from several manufacturers. For the user, very individual machine requirements are decisive for the purchase. These can be, for example, noise emissions or emission-free local operation.

Figure 11: Projected electrification of construction machinery in 2030. Left 19 to 56 [kW], right 56 to 150 [kW].



Source: VDMA 2018

In terms of hybrid solutions, some technologies are already on the market that allow energy to be recovered while, for example, lowering a load, so that it can be accumulated and used when an excess demand for energy is required, supporting the work of the hydraulic system in lifting, reducing fuel consumption, and allowing the diesel engine to operate more efficiently. However, in order to be soot-free solutions, these hybrid technologies will require the use of a diesel engine with DPF.

In 2015 a joint effort began between Volvo Construction Equipment, together with Skanska Sweden, several Swedish universities and the Swedish Energy Agency to implement a fully electrified quarry site. Depending on the use of different types of machinery, several electrification solutions were considered. Excavators and crushers, which stay at one site for a long time, were connected to the electricity grid by a cable. While dumpers and loaders were electrified by means of batteries. Along with eliminating exhaust emissions, the experience showed a 70% reduction in energy costs and a 25% reduction in operating costs.

6. CONCLUSIONS

- The correct metric for assessing soot-free technologies is the particulate number (PN) measurement, as this has sufficient instrument sensitivity and is best linked to health effects.
- The implementation of type approval standards in non-road engines will only gradually improve emissions, considering that the renewal of the non-road machinery fleet is even slower than the road vehicle fleet. Therefore, policy and regulatory approaches to improving emissions from the existing fleet are required.
- Within the European and US standards for new engines, only Stage IIIA/Tier 4i represents a significant reduction in mass PM and therefore mass soot. However, it does not necessarily represent a significant reduction in PN, as this depends on the aftertreatment device selected by the manufacturer. In practice less than 50% of engines with such standards incorporate DPFs.
- Within the aftertreatment systems developed for compliance with type approval standards, only DPF guarantees a significant reduction of PN.
- There are at least two alternatives used mainly in Europe as strategies to accelerate reductions in soot from non-road machinery: DPF retrofit and Low Emission Zones.
- DPF retrofit can immediately reduce emissions from the entire fleet but requires a set of good practices in terms of technology and fleet selection to ensure long-term sustainability.
- Low Emission Zones will accelerate the renewal of the fleet to cleaner technologies with type approval standards, but whether or not health and climate change benefits are guaranteed will depend on the metrics of the requirement; if this is in PN, it will involve the incorporation of DPF or Stage V technology with DPF.
- Regarding CNG/LPG fuel, the fuel itself does not ensure significant reductions in PN, unless associated with a Stage V standard, which includes a PN limit even for spark ignition (PI) engines, which use CNG.
- Total and partial electrification (hybridization) of non-road machinery is a concept that is being incorporated into the industry and solutions are already available. However, this has to overcome some important challenges regarding the working conditions of this machinery type and its energy-intensive use. Nevertheless, there are projections of 4% to 20% penetration by 2030 between hybrid and electric, depending on the machinery type and its power range. Of these percentages, between 1% and 5% are expected to be fully electric.

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