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In-service monitoring for small utility engines

Pilot programme for procedure development

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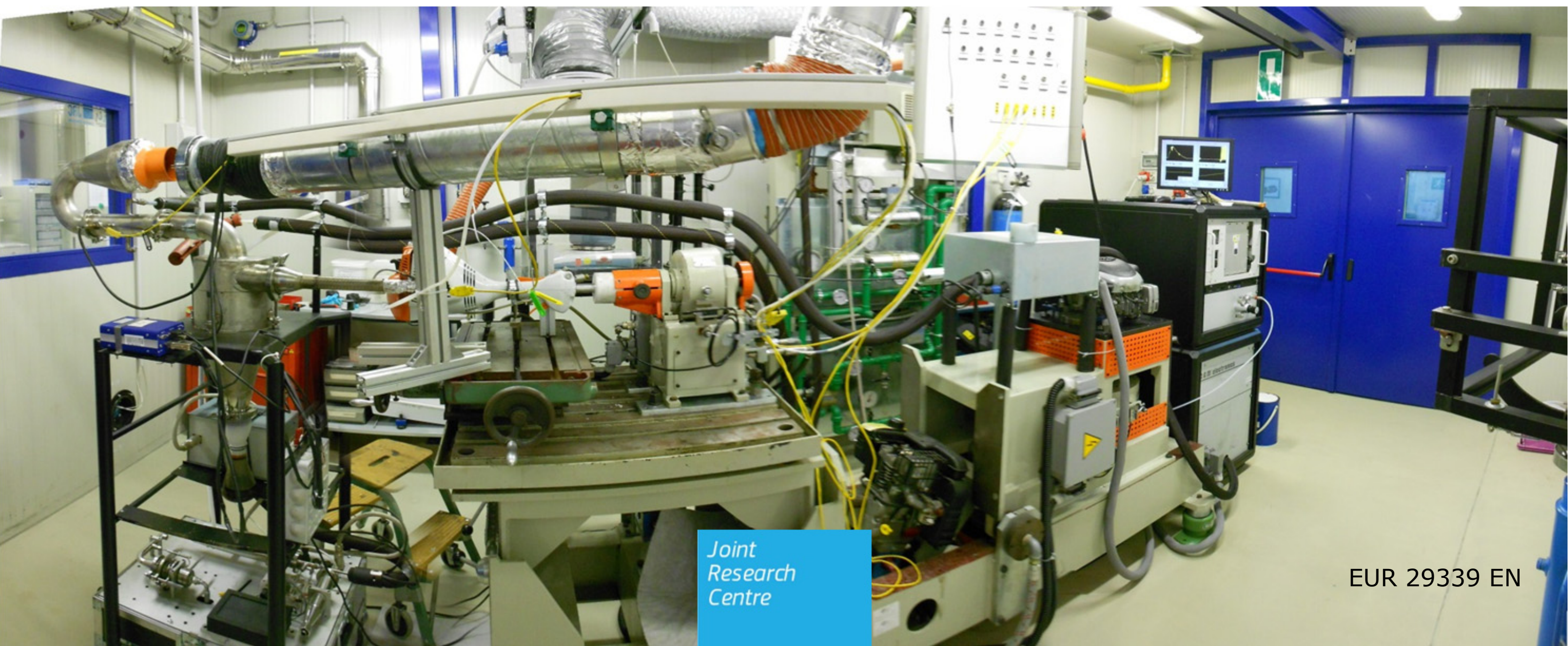

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In-service monitoring for small utility engines: Pilot programme for procedure development

In-service monitoring procedure should not be applied to hand-held engine of categories NRSh-v-1a, NRSh-v-1b and NRS-vr-1a, as a result of comparing their ageing in a test bench with their operation in the field. Equivalent field vs bench ageing should be demonstrated at type-approval of new models. It is also recommended further reduction of the emission limits for total hydrocarbons, carbon monoxide and nitrogen oxides for these categories of NRMM engines.

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Executive summary

Policy context

The European Union legislation on Non-Road Mobile Machinery (NRMM [1]) has been for some time under revision. The recently approved Regulation (EU) 2016/1628 ([2]), which repeals Directive 97/68/EC ([3]), lays down gaseous and particulate emission limits and type-approval requirements for internal combustion engines installed in such NRMM. In particular, it lays down the provisions for small hand-held and non-hand-held machines (NRSh and NRS category, respectively) mounting internal combustion engines with rated power below 19 kW, such as those used in gardening and forestry operation (e.g., chainsaws, brush cutters, blowers and lawn mowers).

The new emissions limits, referred to as "Stage V", are one of the measures designed to reduce the current emissions of air pollutants, such as particulate pollutants, as well as ozone precursors such as nitrogen oxides (NOx) and hydrocarbons (HC). Compared to Directive 97/68/EC and limited to the engine classes studied in this Report, the changes in the following Table 1 were introduced.

Table 1. Comparison between Directive 97/68/EC (Stage II) and Regulation (EU) 2016/1628 (Stage V) relevant for the test engines in the present Report (type-approved under Stage II).

Stage II			**Stage V**		
Class	**Swept Volume (SV) [cm3]**	**HC+NOx Limit [g/kWh]**	**Class**	**Swept Volume [cm3]**	**HC+NOx Limit [g/kWh]**
SH:2	20 ≤ SV < 50	50	NRSh-v1a	SV < 50	50
SH:3	SV ≥ 50	72	NRSh-v1b	SV ≥ 50	72
SN:3	100 ≤ SV < 225	16.1	NRS-vr-1a	80 ≤ SV < 225	10

Source: Directive 97/68/EC and Regulation (EU) 2016/1628.

In particular, Regulation (EU) 2016/1628 prescribes for the first time that the Commission shall conduct monitoring of emissions of in-service engines ([4]). It also empowers the Commission "to conduct pilot programmes with a view to developing appropriate test procedures for those engines categories and sub-categories in respect of which such test procedures are not in place". In-service Monitoring procedure prescriptions for engines in the categories NRE-v-5 and NRE-v-6 (variable speed engines with power in the 56 to 560 kW range) are given by Regulation (EU) 2017/655 ([5]) and

([1]) 'Non-Road Mobile Machinery' means any mobile machine, transportable equipment or vehicle with or without bodywork or wheels, not intended for the transport of passengers or goods on roads, and includes machinery installed on the chassis of vehicles intended for the transport of passengers or goods on roads.

([2]) REGULATION (EU) 2016/1628 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 September 2016 on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery, amending Regulations (EU) No 1024/2012 and (EU) No 167/2013, and amending and repealing Directive 97/68/EC. Official Journal L 252/53. Available at: http://eur-lex.europa.eu

([3]) DIRECTIVE 97/68/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 1997 on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery, Official Journal L 59. Available at: http://eur-lex.europa.eu

([4]) 'In-service engine' means an engine that is operated in non-road mobile machinery over its normal operating patterns, conditions and payloads, and is used to perform the emission monitoring tests.

([5]) COMMISSION DELEGATED REGULATION (EU) 2017/655 of 19 December 2016 supplementing Regulation (EU) 2016/1628 of the European Parliament and of the Council with regard to monitoring of gaseous they are based on the use of Portable Emissions Measurement Systems (PEMS). Given their typical size and weight, PEMS do not seem appropriate for the NRSh category. For these engines, full emission durability period (EDP) testing is performed as part of the type-approval process and therefore there is a guarantee that their emissions will remain within the prescribed limits over the full useful life of this engine category. However, the equivalence between the ageing processes these engines undergo in the approval procedure (on the engine test bench) and the real ageing in normal use in the field needs to be confirmed. To investigate whether the above approach related to EDP and deterioration factors are suitable for small engines DG-GROW ([6]) commissioned to the European Commission - Joint Research Centre (JRC) an *In-service Monitoring (ISM) programme,* in the framework of the Administrative Agreement N° SI2.784345 - JRC.35074 .

The present report describes the outcome of the ISM pilot programme carried out by the JRC during which 22 small engines provided by original equipment manufacturers (OEMs) on a volunteer basis were subject to emission testing at the start, middle and end of their EDP, as prescribed in Annex V of Regulation (EU) 2016/1628, by ageing the engines at the test bench or in the field. This issue is even more relevant when a pollution control device is present, as engine-out emissions deteriorate generally slower than those after a pollution control device.

Main findings

Based on emission tests performed at JRC and OEMs facility (repeated and confirmed by a certification agency, TÜV Nord, Germany), and based on additional data provided by the European Engines Manufacturer Association (EUROMOT), the results of the ISM programme can be summarized as follows.

<u>Compliance with emission limit values during EDP</u>

All engines complied with prescribed emission limit values at beginning, middle and end of their applicable EDP.

<u>Field vs Robot (bench) ageing</u>

We could not discriminate clearly between the severity ([7]) of field ageing against that of the bench ageing procedure (also referred to as "robot ageing" or "automated ageing procedure"). Moreover, the results were compound and facility dependent.

Based on emission testing of 4 engines carried out at JRC, the field ageing procedure (carried out by the engine manufacturer) was more severe than robot ageing considering both HC+NOx and CO emission levels over the EDP. Emission testing performed at OEMs facilities showed equivalent field and robot ageing in terms of HC+NOx emissions, while more severity could be linked to robot ageing when considering CO.

All in all, field and robot ageing seemed very similar in terms of severity, with a light unbalance toward more severe ageing in the field. We can therefore conclude that field and robot ageing may for now be considered equivalent procedures. Note that the whole ageing activity was performed by OEMs with no involvement of JRC.

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pollutant emissions from in-service internal combustion engines installed in non-road mobile machinery. Available at: http://eur-lex.europa.eu

([6]) Directorate General Internal Market, Industry, Entrepreneurship and SMEs. http://ec.europa.eu/growth/index_en

([7]) Severity is expressed as the ratio between emission factors at the end of the EDP period and the emission factors at the beginning of the EDP, see paragraph 3.7.2.

Emission reduction

Our conservative approach based on maximum emission values identified potential emission reductions (as percentage of the correspondent limit value) for each chemical component.

- HC+NOx: 10% reduction based on both JRC and OEM results;
- CO: 30% reduction based on both JRC and OEM results;
- NOx: from 40% (JRC) up to 60% reduction (OEMs)

Quick guide

Exhaust emissions from engines for type-approval purposes (homologation) are typically measured on engine test beds equipped with a dynamometer, a device for measuring the engine torque (or power), during simulated engine loading points (corresponding to specific amounts of delivered work). For instance the G3 test cycle (Regulation EU 2016/1628) is made of 2 loading points, one at engine full load and one at engine idle. When the mechanical/thermal conditions are stabilized at the prescribed load point, the measurements take place for an interval of time (typically 3 minutes) and then are averaged. Two types of measurements are allowed, directly at the tailpipe like in the present study or after gas dilution in a tunnel. For small gasoline engines, only gaseous (and not particulate) emissions are measured and then reported in units of mass diveded by energy (grams/kilowatt hour). The results must be compared to the limit values laid down in Regulation (EU) 2016/1628 for type-approval. This study focuses on the durability of the emissions, i.e., the capability of the engines to produce emission below the limit values for a prescribed period of time called Emission Durability Period (EDP). The EDP depends on the engine class and it is for instance equal to 300 hours for professional engines such as chainsaws.

1 Introduction

This European Commission - Joint Research Centre (JRC) Science for Policy Report presents the results of an experimental study on the exhaust emissions of petrol fuelled, small utility machines such as chainsaws, string trimmers, lawn mowers and leaf blowers.

Scope

The experimental study, called In-service Monitoring programme (ISM), was commissioned by the European Commission - Directorate General Internal Market, Industry, Entrepreneurship and SMEs (DG-GROW) with the scope of developing a procedure for the monitoring of in-service exhaust emissions of some classes of Non-Road Mobile Machinery (NRMM) such as small hand-held engines (NRSh class of engines, as per Regulation (EU) 2016/1628) and small non-hand-held NRMM like lawn mowers (NRS class).

Engines normally age with use and this is reflected in an increase of their exhaust emissions. Therefore, it is necessary to guarantee that the exhaust emissions are durable, i.e. remain below legislated limit values during their full useful life and under normal conditions of use, i.e. those for which the engine was type-approved.

Regulation (EU) 2016/1628, amending and repealing Directive 97/68/EC introduces emission durability requirements for the small engines in this study and sets the emission durability period (EDP) during which the emissions should remain below the limit values. The EDP is used to determine the deterioration factors (DFs), i.e. the set of factors that indicate the relationship between emissions at the start and end of the EDP (Regulation (EU) 2016/1628, Annex V).

This study investigates whether the provisions related to EDP and deterioration factors guarantee that their emissions will remain within the prescribed limits in the regulation over the full useful life of this engine category. At present, small non-road gasoline engines (rated power < 19 kW) available on the market were type-approved under Stage I (Directive 97/68/EC) or Stage II (Directive 2012/46/EU) without the in-service testing provisions included in Stage V (Regulation (EU) 2016/1628) which became mandatory in the European Union (EU) from January 2018 for type-approval of small engines and will be mandatory from January 2019 for the placement in the market of new small engines.

The ISM study was performed on a group of 22 engines provided on a volunteer basis by original equipment manufacturers (OEMs): 12 chainsaws, 2 string trimmers, 4 pedestrian controlled (walk-behind) lawn mowers and 4 blowers. The regulated chemical components total hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NOx) were monitored in the engine raw exhaust at beginning, middle and end of the engine EDP (EDP =0%, 50%, 100%) and critically compared for engines aged on the test bench or during normal service in the field.

The objectives of the experimental campaign were:

- Verify the compliance with limit values of the exhaust emissions from small gasoline engines in terms of hydrocarbons, carbon monoxide, and nitrogen oxides during the whole durability period;
- Compare the severity of 2 different ageing procedures: ageing in the test cell with an automated procedure (robot ageing) and ageing directly in the field during normal service.

Additional outputs related to the main objectives were:

— Compare the emission data provided by the OEM with emissions produced at JRC;
— Compare the raw exhaust analysis method (JRC) with diluted exhaust analysis method (OEMs);
— Assess a potential emission reduction of regulated pollutants.

2 Experiments and method

2.1 Test facility

The In-service Monitoring (ISM) programme was carried out at the Vehicles Emissions Laboratory (VELA) of the Sustainable Transport Unit, Directorate for Energy, Transport and Climate, European Commission – Joint Research Centre (Italy).

The VELA-6 test cell for small engines (see Figure 1 and Table 2) is capable to perform raw exhaust emission tests in accordance with Directive 97/68/EC and Regulation (EU) 2016/1628 and it is suitable for small engines with rated power < 19kW such as chainsaws, string trimmers, blowers and lawn mowers; see technical specifications in section 2.2. The 75 m^3 climatized test cell is equipped with the following:

— Remotely controlled engine bench test bed;

— Eddy current dynamometer brake (API-COM FR6);

— Air and Fuel system for external delivery of the test fuel and of the temperature- and humidity- controlled intake air with embedded:
    - Intake air mass flow meter (Emerson 30595MA);
    - Fuel mass flow meter (Emerson Micro Motion CMF010);

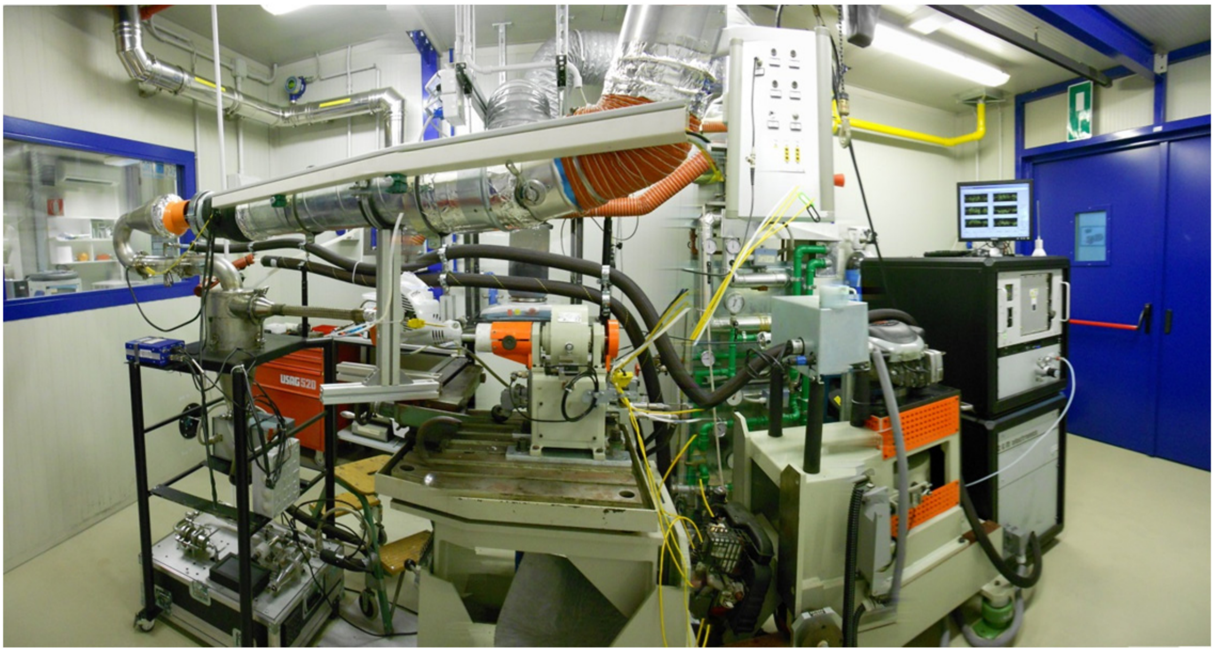
— Exhaust gas analysers (N200, Rosemount Analytical) for measuring:
    - Total Hydrocarbons (HC, also referred to as THC);
    - Carbon monoxide (CO) and carbon dioxide (CO_2)
    - Oxides of nitrogen (NOx)
    - Oxygen (O_2)

— Oxygen sensor (Lambda sensor) for measurement of the air fuel ratio;

— Temperature monitor of the engine spark, engine-out emissions and exhaust;

— Meteorological station for ambient temperature, humidity, and pressure.

Figure 1. Panoramic picture of the VELA-6 test cell for small engines.



Source: JRC.

Table 2. Technical specifications of the VELA-6 test cell.

Equipment	Parameter	Model
Dynamometer	Engine power: 0-6 kW Engine speed: 0-15000 rpm	API-COM FR6
Exhaust gas analyser	THC: flame ionisation detector CO, CO_2: non-dispersive infrared NOx: chemi-luminescence detector O2: electrochemical cell	N200, Rosemount Analytical
Air mass flow meter	Air mass flow	Emerson 30595MA
Fuel mass flow	Fuel mass flow (Coriolis)	Emerson Micro Motion CMF010
Oxygen sensor	Lambda	ETAS-LA4-E
Thermocouples	Spark, engine-out and exhaust temperatures	K-thermocouples
Meteorological station	Ambient temperature and humidity, barometric pressure	

Source: JRC.

2.2 Engines and fuel

Original equipment manufacturers (OEMs) provided the engines on a volunteer basis, assisted during installation and attended the test programme in the VELA-6 laboratory.

We received from 4 OEMs a total of 16 spark-ignited small engines of the type commonly used in gardening and forestry operations: 8 chainsaws, 2 string trimmers (also known as strimmers), 4 lawn mowers and 2 blowers.

Table 3 summarizes the basic engine technical specifications, type-approval details, applicable Emission Durability Period (EDP) and emission limit values. All engines had been type-approved under Stage II according to Directive 97/68/EC and following amendments, and belong to the following classes:

— SH:2, S = small engine with net power ≤ 19kW, H = hand-held (i.e. designed to be held by hands), the number 2 defines the second segment of engine capacity, i.e. between 20 cc and 50 cc;

— SH:3, the number 3 refers to the third segment of engine capacity, i.e. above 50 cc;

— SN:3, N = non-hand-held engine with capacity between 100 cc and 225 cc.

The correspondent classes defined by the new Regulation (EU) 2016/1628 are reported in Table 3. Compared to Directive 97/68/EC and limited to the engine classes studied in this Report, the changes highlighted in Table 4 were introduced. Small engines of class SH:2 and SH:3 were only subject to an engine reclassification (NRSh-v1a and NRSh-v1b, respectively), while tailpipe emission limits remained those of Directive 97/68/EC. Engines of class SN:3 were subject to reclassification (NRS-vr-1a) and emission limit reduction of HC+NOx from 16.1 g/kWh down to 10 g/kWh.

The environmental performance requirements for type-approval of these engines include tailpipe emission limits for three gaseous compounds: hydrocarbons plus nitrogen oxides (HC+NOx), carbon monoxide (CO) and nitrogen oxides alone (NOx), see Table 3. The column EDP of Table 3 reports the emission durability period related to each engine class. Besides the engine class, the final application of the engine was taken into account to define the EDP, which is shorter for engines intended for hobby use (Eng5 to Eng8 and Eng17 to Eng20) and longer for professional use engines. Eng5 to Eng8 were equipped with a 2-way oxidation catalyst, while the remaining engines did not feature pollution control devices.

Table 5 summarizes the specifications of (i) the reference test fuel F1 (CEC LEGIS.FUEL RF-02-99) chosen for the ISM programme and complying with the requirements set in Directive 97/68/EC, Annex V, and (ii) the alkylate fuel F2 with only trace content of aromatic compounds. The fuels were analysed by a specialized external company. In addition for the 2-stroke engines, the OEMs recommendations on the type and amount of lubricant oil were followed: Husqvarna LS+ for Eng1 and Eng2, and Stihl HP-ultra for the remaining 2-strokers (see specifications in Table 6).

Table 3. Engine technical specifications.

Engine	OEM	Type	Capacity	Stroke	Fuel[(1)]	Rated Power	Rotation	Class[(2)]	Stage	EDP	Stage V[(3)] Class	Cat[(4)]	Family Emission Limits [g/kWh]		
			[cm^3]			[kW]	[min^{-1}]			[hours]			HC+NOx	CO	NOx
Eng1	1	Strimmer	45.7	2	F1-L1	2.1	9000	SH:2	II	0-150-300	NRSh-v-1a	No	50	805	10
Eng2	1	Strimmer	45.7	2	F1-L1	2.1	9000	SH:2	II	0-150-300	NRSh-v-1a	No	50	805	10
Eng3	2	Chainsaw	50.2	2	F1-L2	2.8	10000	SH:3	II	0-150-300	NRSh-v-1b	No	72	603	10
Eng4	2	Chainsaw	50.2	2	F1-L2	2.8	10000	SH:3	II	0-150-300	NRSh-v-1b	No	72	603	10
Eng5	3	Chainsaw	32	2	F1-L2	1.35	10000	SH:2	II	0-25-50	NRSh-v-1a	Yes	50	805	10
Eng6	3	Chainsaw	32	2	F1-L2	1.35	10000	SH:2	II	0-25-50	NRSh-v-1a	Yes	50	805	10
Eng7	3	Chainsaw	32	2	F1-L2	1.35	10000	SH:2	II	0-25-50	NRSh-v-1a	Yes	50	805	10
Eng8	3	Chainsaw	32	2	F1-L2	1.35	10000	SH:2	II	0-25-50	NRSh-v-1a	Yes	50	805	10
Eng9	4	Lawn Mower	190	4	F1	NA [(5)]	2600	SN:3	II	0-125-250	NRS-vr-1a	No	16.1	610	10
Eng10	4	Lawn Mower	190	4	F1	NA	2600	SN:3	II	0-125-250	NRS-vr-1a	No	16.1	610	10
Eng11	4	Lawn Mower	190	4	F1	NA	2600	SN:3	II	0-125-250	NRS-vr-1a	No	16.1	610	10
Eng12	4	Lawn Mower	190	4	F1	NA	2600	SN:3	II	0-125-250	NRS-vr-1a	No	16.1	610	10
Eng13	2	Blower	27	2	F1-L2	0.6	7500	SH:2	II	0-25-50	NRSh-v-1a	Yes	50	805	10

Engine	OEM	Type	Capacity	Stroke	Fuel(1)	Rated Power	Rotation	Class(2)	Stage	EDP	Stage V(3) Class	Cat(4)	Family Emission Limits [g/kWh]		
Eng14	2	Blower	27	2	F1-L2	0.6	7500	SH:2	II	0-25-50	NRSh-v-1a	Yes	50	805	10
Eng15	2	Blower	27	2	F1-L2	0.6	7500	SH:2	II	0-25-50	NRSh-v-1a	Yes	50	805	10
Eng16	2	Blower	27	2	F1-L2	0.6	7500	SH:2	II	0-25-50	NRSh-v-1a	Yes	50	805	10
Eng17	3	Chainsaw	32	2	F1-L2	1.35	10000	SH:2	II	0-25-50	NRSh-v-1a	Yes	50	805	10
Eng18	3	Chainsaw	32	2	F1-L2	1.35	10000	SH:2	II	0-25-50	NRSh-v-1a	Yes	50	805	10
Eng19	3	Chainsaw	32	2	F1-L2	1.35	10000	SH:2	II	0-25-50	NRSh-v-1a	Yes	50	805	10
Eng20	3	Chainsaw	32	2	F1-L2	1.35	10000	SH:2	II	0-25-50	NRSh-v-1a	Yes	50	805	10
Eng21	2	Chainsaw	50.2	2	F1-L2	2.8	10000	SH:3	II	0-150-300	NRSh-v-1b	No	72	603	10
Eng22	2	Chainsaw	50.2	2	F1-L2	2.8	10000	SH:3	II	0-150-300	NRSh-v-1b	No	72	603	10

(1) F1 = reference fuel, see Table 5; F2 = alkylate fuel; L1 = *Husqvarna L+* lubricant oil; L2 = *Stihl HP Ultra* lubricant oil, see Table 6
(2) Engine class as per type-approval under Directive 97/68/EC and Directive 2012/46/EU.
(3) Correspondent engine classes under Regulation (EU) 2016/1628.
(4) Catalyst used as after-treatment device.
(5) Constant speed engine, the max torque is reported instead of power.

Source: JRC and OEMs.

Table 4. Comparison between Directive 97/68/EC (Stage II) and Regulation (EU) 2016/1628 (Stage V) relevant for the test engines in the present Report (Stage II).

Stage II			Stage V		
Class	**Swept Volume [cm^3]**	**HC+NOx limit [g/kWh]**	**Class**	**Swept Volume [cm^3]**	**HC+NOx limit [g/kWh]**
SH:2	20 ≤ SV < 50	50	NRSh-v1a	SV < 50	50
SH:3	SV ≥ 50	72	NRSh-v1b	SV ≥ 50	72
SN:3	100 ≤ SV < 225	16.1	NRS-vr-1a	80 ≤ SV < 225	10

Source: JRC.

Table 5. Parameters of the reference (F1) and alkylate (F2) fuels used in the ISM programme fulfilling the requirements laid down in Annex V of Directive 97/68/EC.

Parameter	Unit	Fuel F1 (standard)	Fuel F2 (alkylate)	Method
Trade name		RF-02-99	Stihl Motomix	
RON(1)		100	94	EN ISO 5164
MON(2)		87.6	92.4	EN ISO 5163
Density	kg/m^3	752.5	692.4	ISO 3675
DVPE	kPa	58.6	54.5	EN13016-1
Olefins	% volume	8	0.1	ASTM D1319
Aromatics	% volume	34.1	0.4	ASTM D1319
Benzene	% volume	0.21	< 0.01	EN 12177
Saturates	% volume	57.9	NA	ASTM D1319
Oxygen content	% weight	< 0.1	< 0.1	EN 1601
Sulfur	mg/kg	10	< 3	EN ISO 14596
Carbon	% weight	87.03	84.5	ASTM D3343
Hydrogen	% weight	12.97	15.5	ASTM D3343

Source: JRC and external reference laboratory.

Table 6. Parameters of the 2-strokers engine lubricant oils.

Parameter	Unit	Oil L1	Oil L2	Method
Trade name		Husqvarna LS+	Stihl HP-ultra	
Density	kg/m^3	872	935.8	UNI EN ISO 12185
Viscosity	mm^2/s	53	49.78	UNI EN ISO 3104
Sulfur	% weight	0.007	< 0.06	ASTM D1572
Ash	% weight	0.054	0.005	UNI EN ISO 6245
Fuel/Oil mix	vol/vol	50:1	50:1	-
Destination		Eng1, Eng2	Eng3 to Eng8	-

Source: JRC.

2.3 Test procedure and data handling

After engines were installed at EDP = 0% (beginning of service) on the VELA-6 testbed in the presence of the OEMs and following their recommendations, a series of emissions tests were performed during legislated steady-state cycles, see Table 7 and Table 8, following the prescriptions of Directive 97/68/EC. The G3 non-road steady test cycle was used for all OEMs except for OEM 4 which used a modified D cycle, see Table 8. The simple G3 cycle consists of 2 loading points (modes), one at 100% nominal torque (mode 1) and one at idle operation (mode 2), while the modified D cycle is made of 5 modes of decreasing load from 100% to 10%. According to the legislation, during each mode the emissions were sampled for at least 180 seconds and averaged for the last 120 seconds providing that mechanical and thermal parameters were constant within 5%.

Figure 2 displays an example of the signals recorded during a modified D steady cycle: mechanical parameters (torque, power, engine speed), thermal parameters (spark and oil temperature) and gaseous raw exhaust concentrations of the chemical components (HC, CO, CO_2, O_2) were acquired and used for emissions calculations.

After emissions in mass/time units were obtained for each mode as described in Directive 97/68/EC, a weighted average was calculated with the indicated weighting factors to obtain the emissions in mass/energy units (grams per kilowatt-hour):

$$EF[g/kWh] = \frac{\sum_i EF_i\,[g/h] * WF_i}{\sum_i P_i\,[kW] * WF_i},$$

where EF_i , WF_i , and P_i are the emission, the weighting factors and the engine power of the i-mode, respectively. In the context of emission tests on engine benches, EF[g/h] and EF[g/kWh] are often called "mass emissions" and "brake-specific emissions", respectively. Tests were performed in minimum 3 repetitions, unless differently agreed with the OEM.

After testing at EDP = 0%, the engines were returned to OEMs for the ageing task performed either on a testbed or in the field during real service. When EDP = 50% was reached, engines were tested again at JRC to compare the emissions with those at EDP = 0%. The same procedure was followed after reaching EDP = 100%.

Eng3 and Eng4 were tested also with the alkylate fuel (see technical specifications in paragraph 2.2 and results in Appendix 4) following the same protocol as described above for the reference fuel. The engines and fuel systems were washed accurately before and after each fuel change and the engine preconditioned with multiple G3 tests.

Table 7. G3 test cycle applicable to all engines except for Eng9 to Eng12.

G3 cycle		
Mode number	1	2
Engine Speed	Rated	Low-idle
Load (1) %	100	0
Weighting factor	0.85	0.15

(1) The load figures are percentage values of the torque corresponding to the prime power rating defined as the maximum power available.

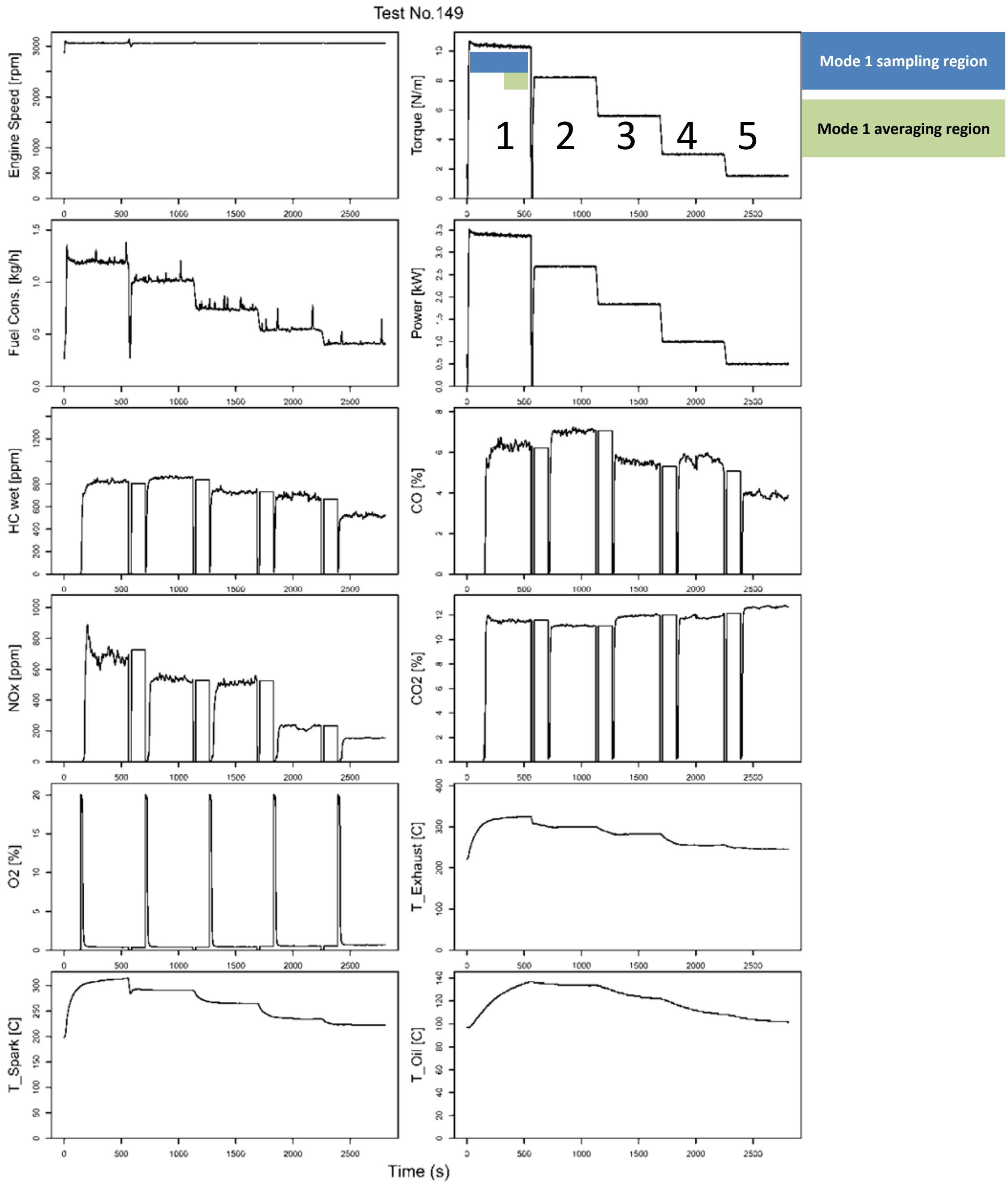
Source: Directive 97/68/EC.

Table 8. Modified D test cycle applicable to Eng9 to Eng12.

Modified D cycle					
Mode number	1	2	3	4	5
Engine Speed	Rated	Rated	Rated	Rated	Rated
Load %	100	75	50	25	10
Weighting factor	0.09	0.21	0.31	0.32	0.07

Source: Directive 97/68/EC.

Figure 2. Example of signals acquired during a non-road steady cycle type D made of 5 modes (1 to 5 in the figure). Highlighted for mode 1 are the sampling and the averaging time windows. The G3 cycle (not shown here) is instead made up of mode 1 at 100% load and mode 2 at 0% load (idle).



Source: JRC

3 Results and discussion

3.1 Overview of the accomplished programme

During the In-service Monitoring programme a total of 22 small utility engines were emission-tested at specific steps of their emission durability period (EDP), see Table 9. Of the 22 engines, 16 were emission tested at JRC.

Engines can be divided in three groups based on the JRC testing coverage:

- Engines tested at JRC covering the full EDP matrix: EDP=0%, EDP=50%, EDP=100% (Eng1, Eng2 and Eng3). These engines were also tested by the OEMs prior to JRC testing;
- Engines tested at JRC only at 1 EDP step (Eng9 to Eng12, Eng13, Eng15, Eng21, Eng22);
- Engines not tested at JRC, but tested by the OEMs in parallel to the ISM Programme (Eng17 to Eng20).

Eng4 was withdrawn by OEM-2 due to piston seizure. Therefore, Eng21 and Eng22 were added by the OEM to the test matrix in order to compensate. Both engines were tested at JRC at the end of their EDP.

Eng5 to Eng8 were withdrawn by OEM-3 due to catalyst contamination with Silicon (Si) and consequent emission increase above the limit values. An analysis of several fuel samples performed by a certified laboratory clarified that the fuel in the fuel line at JRC was contaminated by Silicon. The contamination source was eliminated after a full replacement of the fuel line and of the containers used to prepare the fuel-oil mix, as confirmed by the analysis performed after the replacement. Meanwhile, OEM-3 aged Eng17 to Eng20 which were tested at OEM's facility. Eng17 and Eng19 were also tested at OEM-2 facility witnessed by a member of JRC. Eng19 was also tested by a type-approval authority in the labs of OEM2.

Eng9 to Eng12 were pedestrian-controlled (also called walk-behind) lawn mowers of the same model provided to JRC by OEM-4 at EDP=0% or EDP=100%; no additional measurement at intermediate EDP was possible.

Leaf blowers Eng13 to Eng16 were added at a later stage by OEM-2 to increase the available information on emissions by a different type of engine/technology in class SH:2, namely stratified charge with catalyst and exhaust mixing chamber. Therefore, only the final EDP=100% testing was performed at JRC on Eng13 and Eng15, which were also tested at OEM's lab with a member of JRC as witness. Eng13 was also tested by a type-approval authority expressly for the ISM Programme. This demonstration exercise was in addition used to test the performance of raw exhaust emission sampling (JRC facility) against diluted emission sampling for this kind of engine and after/treatment technology; see section 3.7.

More emission data were made available by the engine manufacturers association EUROMOT. The data reported in Annex 3 are discussed in section 3.6.

Table 9. List of engines included in the In-service monitoring programme. Light green = only tested at OEM's facilities. Dark green = Tested also at JRC. Grey (np) = not planned.

Engine	OEM	Type	Class	EDP 0%	EDP 50%	EDP 100%	Witness (4)	Cert. (5)
Eng1	OEM1	Strimmer	SH:2	0h	150h	300	np	np
Eng2	OEM1	Strimmer	SH:2	0h	150h	300	np	np
Eng3	OEM2	Chainsaw	SH:3	0h	150h	300h	Yes	Yes
Eng4(1)	OEM2	Chainsaw	SH:3	0h	150h	withdrawn	np	np
Eng5(2)	OEM3	Chainsaw	SH:2	0h	withdrawn	withdrawn	np	np
Eng6(2)	OEM3	Chainsaw	SH:2	0h	withdrawn	withdrawn	np	np
Eng7(2)	OEM3	Chainsaw	SH:2	0h	25h	withdrawn	np	np
Eng8(2)	OEM3	Chainsaw	SH:2	0h	25h	withdrawn	np	np
Eng9	OEM4	Lawn Mower	SN:3	0h	np	np	np	np
Eng10	OEM4	Lawn Mower	SN:3	0h	125h	250h	np	np
Eng11	OEM4	Lawn Mower	SN:3	0h	125h	250h	np	np
Eng12	OEM4	Lawn Mower	SN:3	0h	np	np	np	np
Eng13	OEM2	Blower	SH:2	0h	np	50h	Yes	Yes
Eng14	OEM2	Blower	SH:2	0h	np	50h	np	np
Eng15	OEM2	Blower	SH:2	0h	np	50h	Yes	np
Eng16	OEM2	Blower	SH:2	0h	np	50h	np	np
Eng17	OEM3	Chainsaw	SH:2	0h	25h	50h	Yes	np
Eng18	OEM3	Chainsaw	SH:2	0h	25h	50h	np	np
Eng19	OEM3	Chainsaw	SH:2	0h	25h	50h	Yes	Yes
Eng20	OEM3	Chainsaw	SH:2	0h	25h	50h	np	np
Eng21(3)	OEM2	Chainsaw	SH:3	0h	150h	300h	Yes	np
Eng22	OEM2	Chainsaw	SH:3	0h	np	300h	np	np

(1) Piston seizure at OEM's facility.
(2) Contamination of the fuel line at JRC due to Silica.
(3) Replacement for Eng4.
(4) A member of the JRC team was present at OEM's facilities during additional testing.
(5) A certified body (TÜV Nord, Germany) performed and certified the testing at OEM-2 facility.

Source: JRC.

3.2 Tests on OEM-1 SH:2 string-trimmers

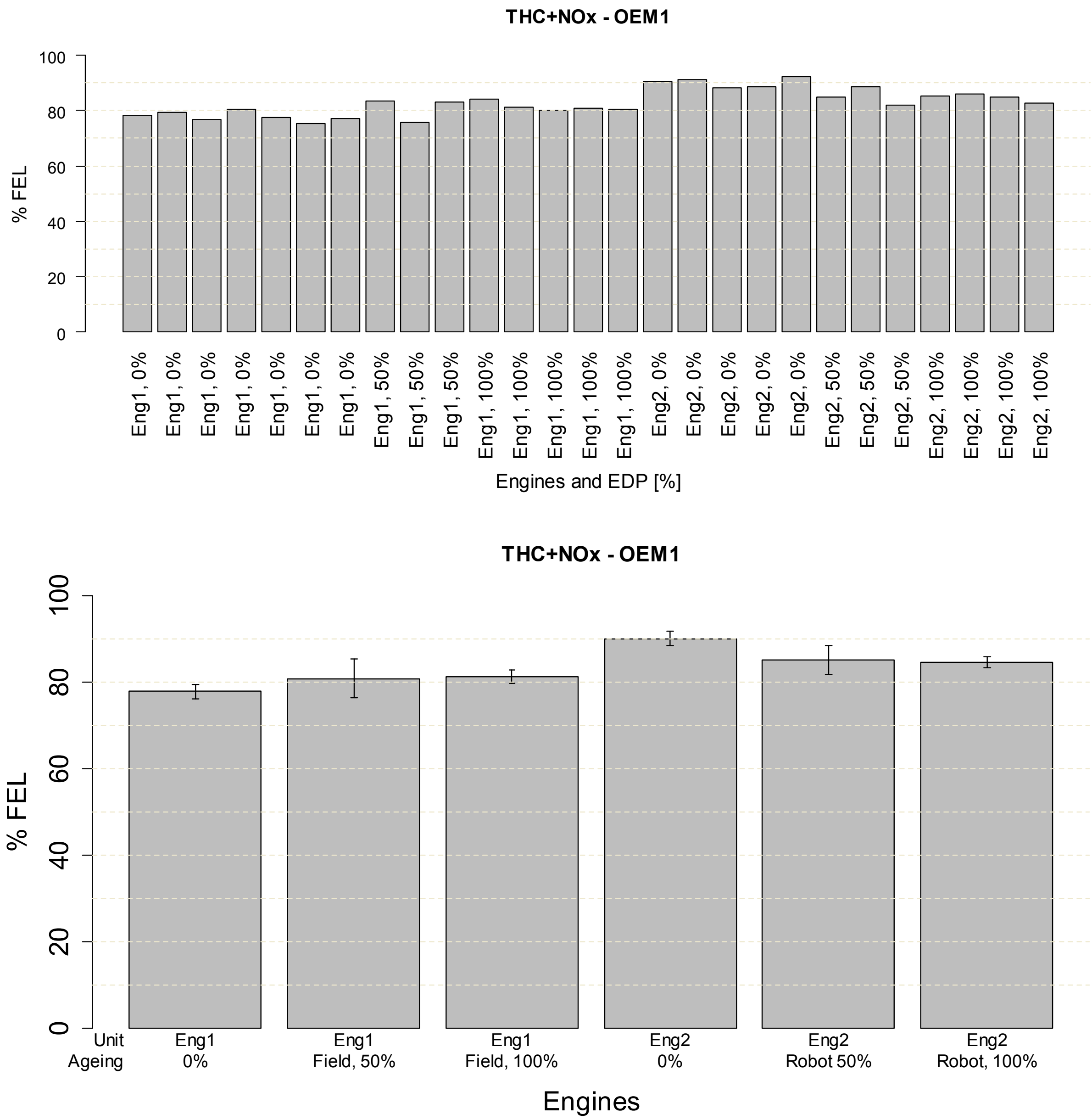
OEM-1 provided 2 non-catalysed string trimmers of category SH:2, see basic technical specifications in Table 3 and Table 10. Eng1 and Eng2 were aged in the field and with an automated procedure in the test cell of the OEM, respectively. They were tested as planned at JRC at EDP= 0%, 50%, and 100%, corresponding to 0 hours, 150 h, and 300 h, respectively. Emission data from JRC and OEM test results are reported in Table 19 and Table 22, respectively. Figure 3 to Figure 5 display the JRC results for pollutants regulated by the legislation. All engines emitted below the emission limits at any of the EDPs. As ageing in the field led to larger emission increase than ageing with the automated procedure in the test cell, field ageing was considered more severe than robot ageing in terms of HC+NOx and CO emissions measured at JRC. On the contrary a slightly more severe ageing was observed using the bench procedure by the OEM. NOx results were more prone to variability due to the very low values that typically characterize 2-stroke technology of small engines. While Eng1 exhibited increased or unaffected emissions with ageing, Eng2 was characterized by decreasing emissions with ageing. The comparison with OEM results in Figure 6 to Figure 8 partially confirms this behaviour, with 50% EDP results unaffected or decreasing and a final increase at 100% EDP. The largest emission of HC+NOx and CO came from Eng2 at 0% EDP during JRC testing, while the OEM data showed the largest emission for Eng2 at 100% EDP. For both JRC and OEM measurements, CO and NOx emissions were well below the limit values (55%-60%).

Table 10. OEM-1 engines tested at JRC.

Engine	**Type**	**Ageing Type**	**EDP**	**Displacement**	**Class**	**Stage**	**Catalyst**	**Limit**		
								HC+NOx	**CO**	**NOx**
			[%]	**[cm^3]**				**[g/kWh]**		
Eng1	String trimmer	Field	0,50, 100	46	SH:2	II	No	50	805	10
Eng2	String trimmer	Robot	0,50, 100	46	SH:2	II	No	50	805	10

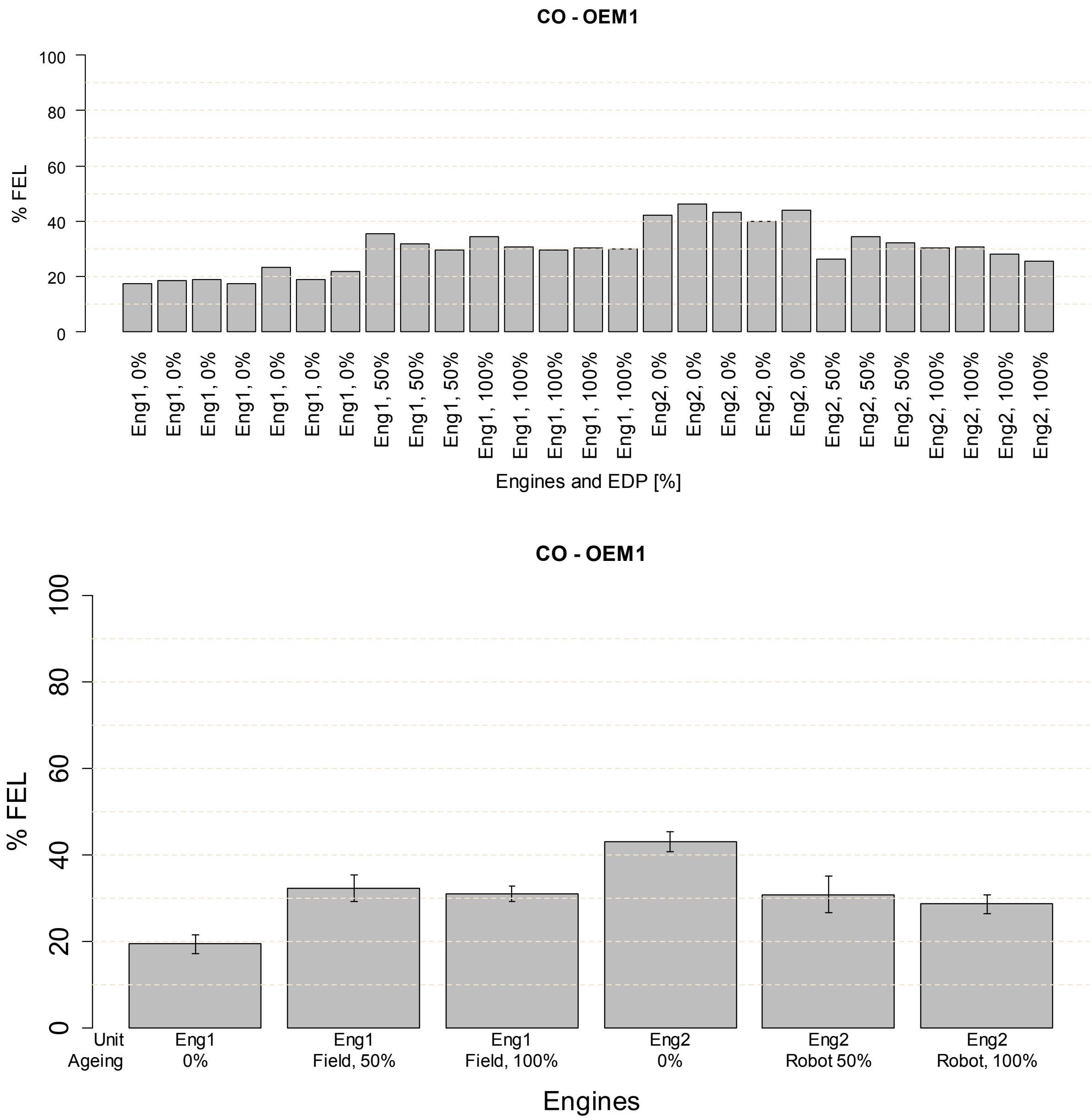
Source: OEM.

Figure 3. Emission data as percentage of the family emission limit for this class of engines. Upper panel: per-test results. Lower panel: engine-aggregated results (error bars = 1x standard deviation). THC = total hydrocarbons.



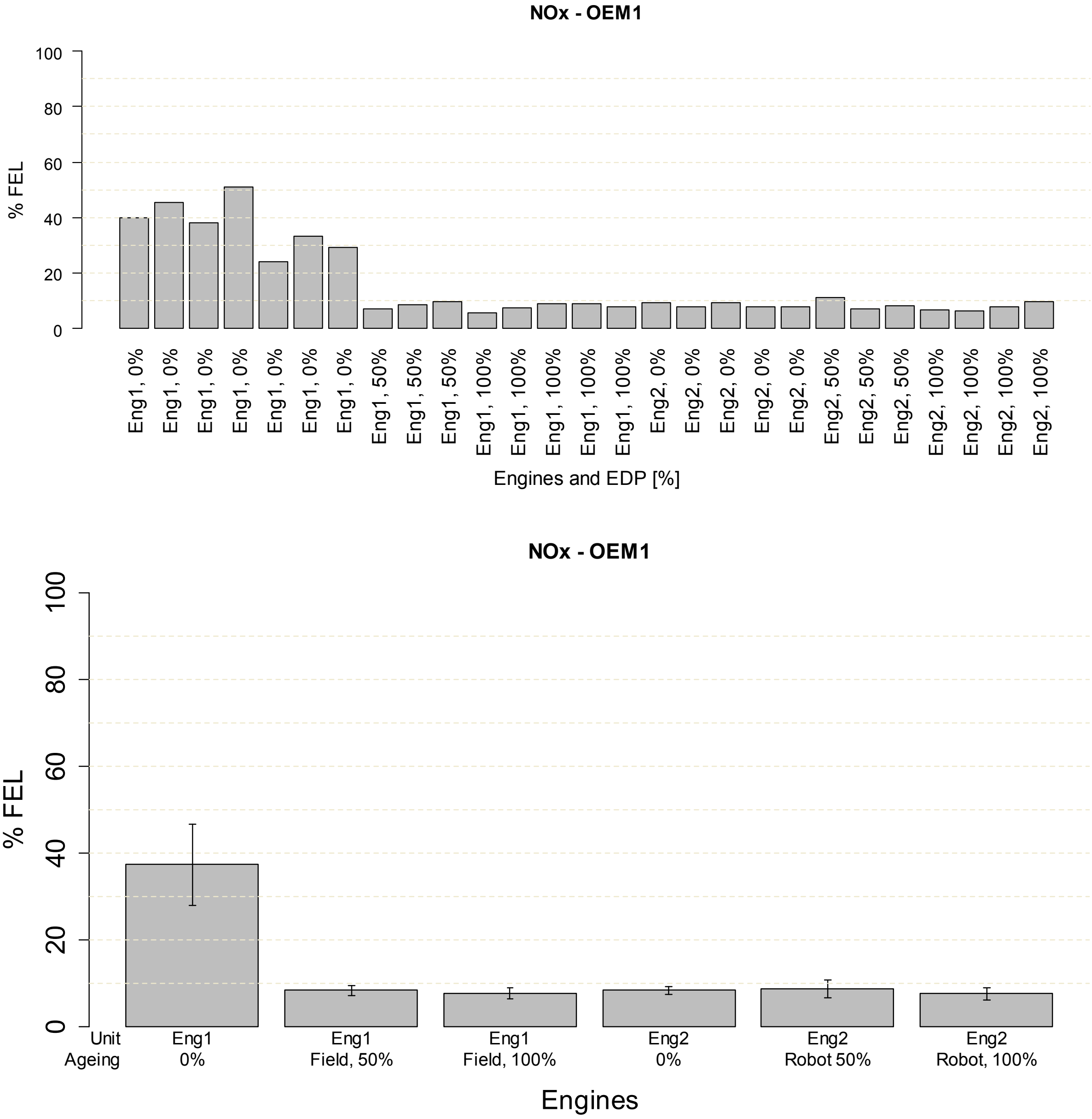
Source: JRC.

Figure 4. Emission data as percentage of the family emission limit for this class of engines. Upper panel: per-test results. Lower panel: engine-aggregated results.



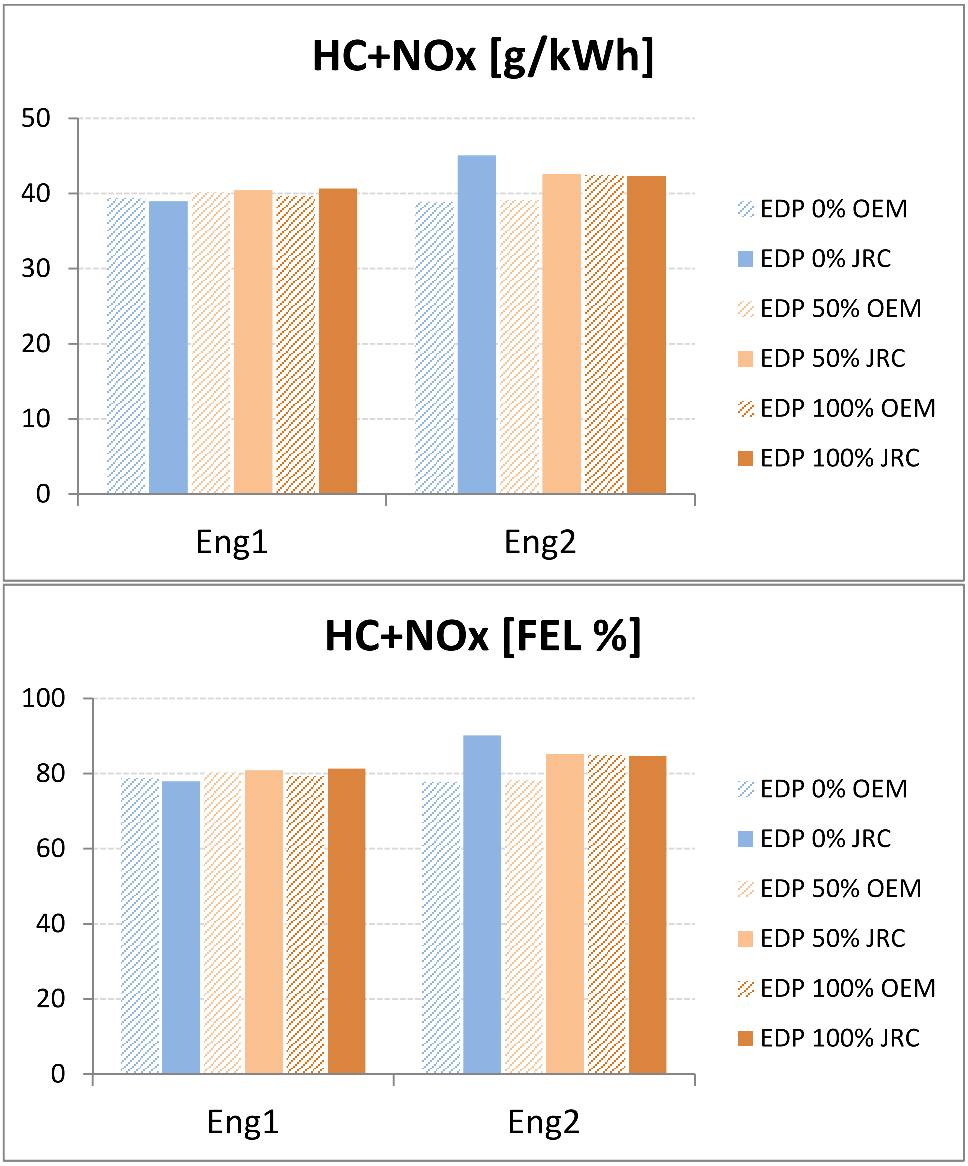
Source: JRC.

Figure 5. Emission data as percentage of the family emission limit for this class of engines. Upper panel: per-test results. Lower panel: engine-aggregated results.



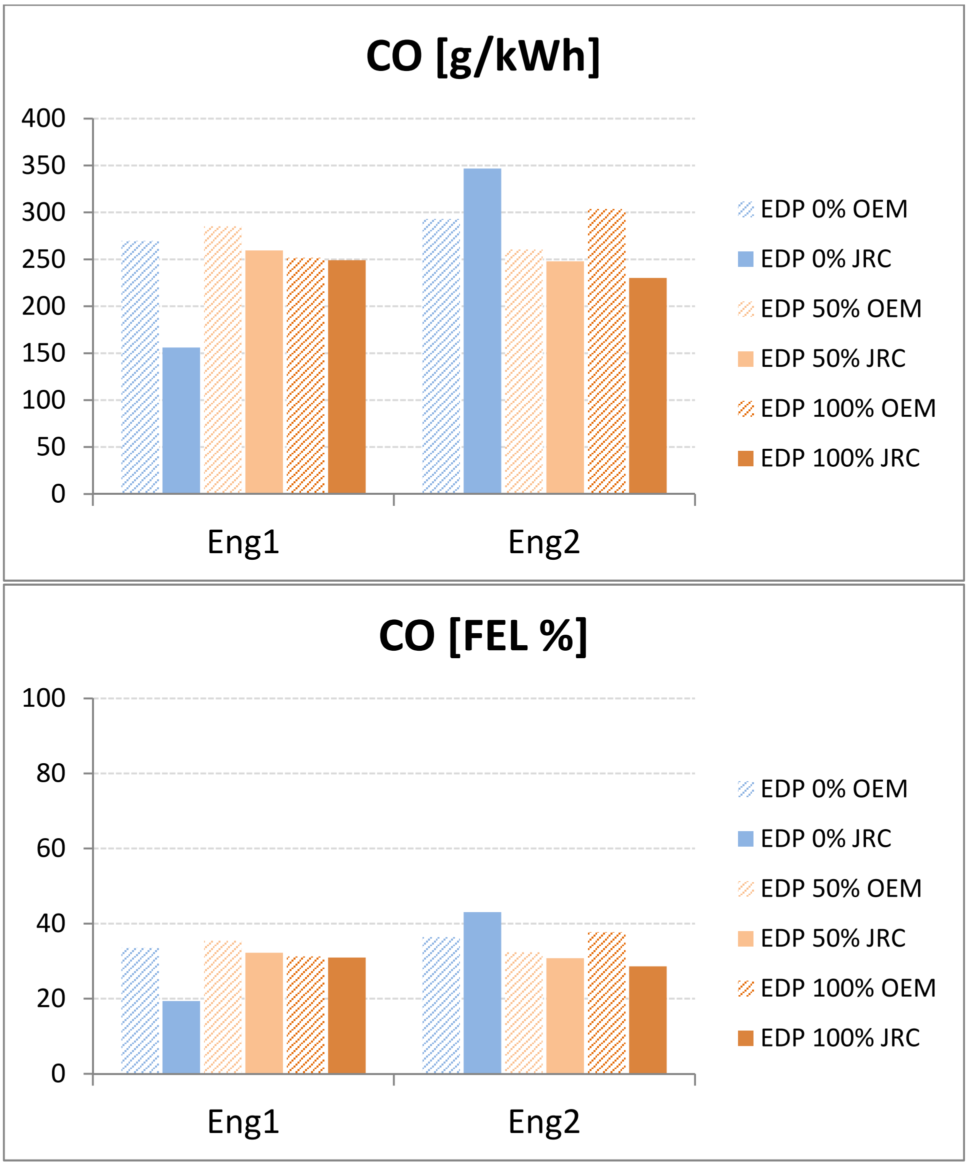
Source: JRC.

Figure 6. Comparison of JRC and OEM-1 emission data.



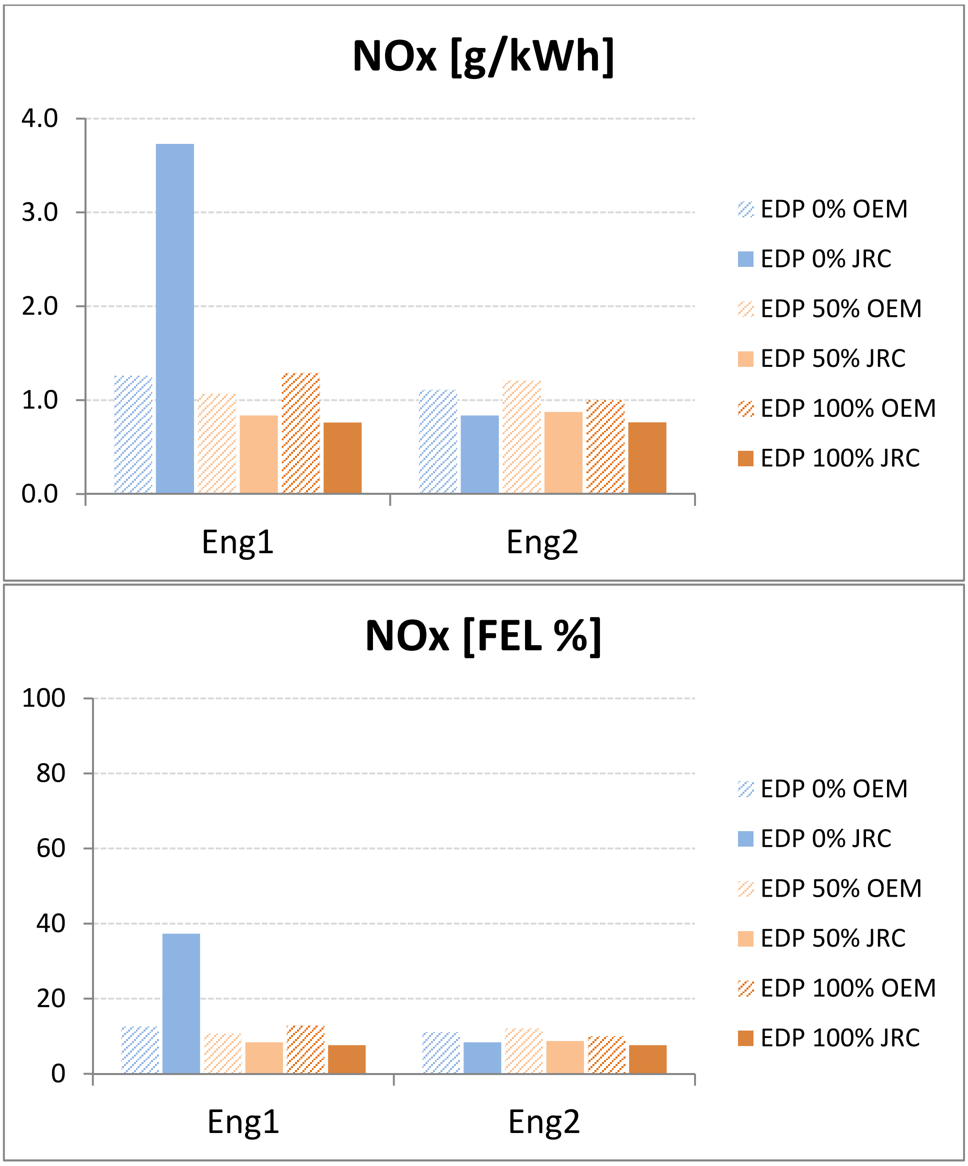
Source: JRC and OEM.

Figure 7. Comparison of JRC and OEM-1 emission data.



Source: JRC and OEM.

Figure 8. Comparison of JRC and OEM-1 emission data.



Source: JRC and OEM.

3.3 Tests on OEM-2 SH:3 chainsaws and SH:2 blowers

OEM-2 provided 4 non-catalysed chainsaws of category SH:3, and 2 stratified charge, catalysed blowers of category SH:2; see basic technical specifications in Table 3, and Table 11 below. Only for Eng3 it was possible to monitor the entire ageing procedure at JRC with EDP = 0%, 50% and 100%. Eng4 was withdrawn after 50% EDP due to piston seizure, while Eng13, Eng15, Eng21 and Eng22 were tested at JRC only at 100% EDP. Eng21 was meant as replacement for Eng4, while Eng22 was included as additional engine, not originally planned. The blowers featured an engine and after-treatment technology which in principle is not suitable for raw exhaust gas sampling (JRC) because of the partial mixing of the exhaust gases at the tailpipe that may result in untreated gas sampling and consequent large emission values. A cyclone designed to cut off large particles and oil droplets was included after the tailpipe acting as an additional mixing chamber allowing for testing at JRC. Results from blowers were included in the Report as an exercise in order to check the response of the raw gas sampling method for future applications. Emission testing of Eng3, Eng13, Eng15 and Eng21 were repeated at 100% EDP at the OEM facility with the presence of a member of the JRC in order to confirm the OEM results voluntarily provided. As an additional confirmation, supporting data from the OEM were provided for Eng3 (chainsaw) and Eng13 (blower) by testing the engines at the OEM facility replicating a type-approval procedure run by a certified body (TÜV Nord, Germany). All emission test results are included in Figure 12 to Figure 15.

Emission data from JRC and OEM test results are reported in Table 20 and Table 22, respectively. Figure 9 to Figure 11 display the JRC results for the chemical components regulated by the legislation. All engines emitted below the emission limits at each EDP step. The ageing procedure did not generally increase the emissions during JRC testing. Eng3 emitted less CO and more NOx at 100% EDP compared to previous ageing steps, suggesting a leaner air/fuel mix. However, the comparison with OEM data shown in Figure 12 to Figure 14 was in the opposite direction with increased CO. Except for this case, the 100% EDP data at JRC are within a 10-15% agreement with OEM data, see section 3.7. Based on JRC data, the comparison between field and robot ageing was not conclusive as no emission increase was observed for Eng3 and Eng4. The same comparison on OEM data was compound specific with increased HC+NOx emissions for Eng3 during ageing (decreased for Eng4), and increased CO emissions for Eng4, even though based only on the 50% EDP ageing (piston seizure).

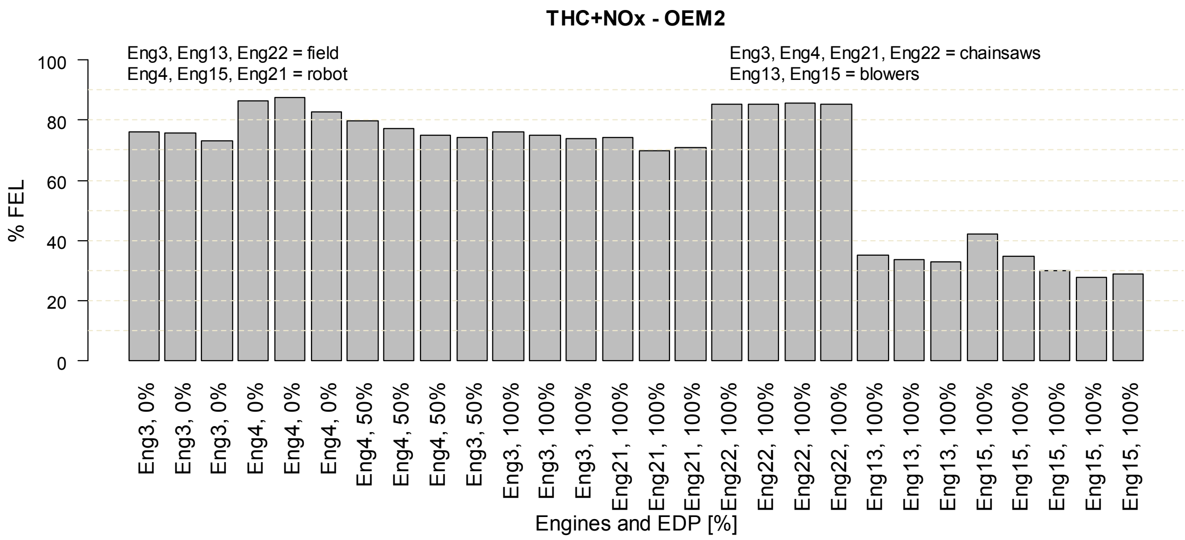
Figure 15 shows the emission results for the blowers indicating a discrepancy between JRC and OEM data, with JRC results systematically lower than OEM results. This is an indication that the raw gas sampling (JRC) does not overestimate the emissions from diluted gas sampling (OEM), even though a straightforward application of the raw gas sampling on this engine technology is not recommended.

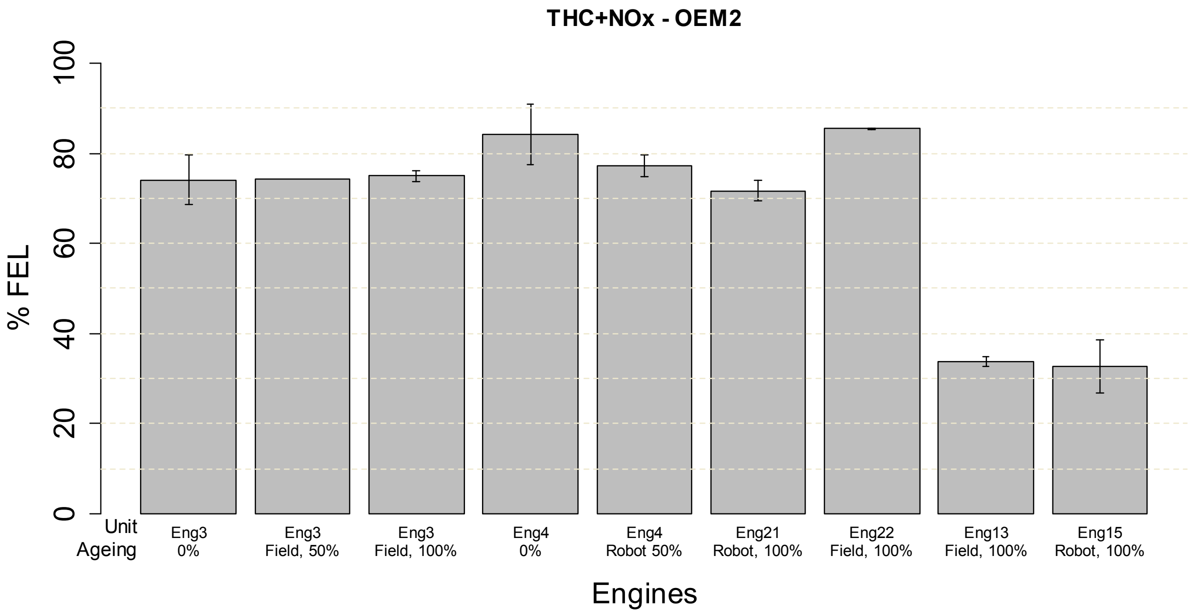
Table 11. OEM-2 engines tested at JRC.

Engine	Type	Ageing Type	EDP	Displace-ment	Class	Stage	Catalyst	Limit		
								HC+NOx	NOx	CO
			[%]	[cm^3]				[g/kWh]		
Eng3	Chainsaw	Field	0,50, 100	50.2	SH:3	II	NO	72	10	603
Eng4	Chainsaw	Robot	0,50	50.2	SH:3	II	NO	72	10	603
Eng13	Blower	Field	100	27.5	SH:2	II	YES	50	10	805
Eng15	Blower	Robot	100	27.5	SH:2	II	YES	50	10	805
Eng21	Chainsaw	Robot	100	50.2	SH:3	II	NO	72	10	603
Eng22	Chainsaw	Field	100	50.2	SH:3	II	NO	72	10	603

Source: OEM.

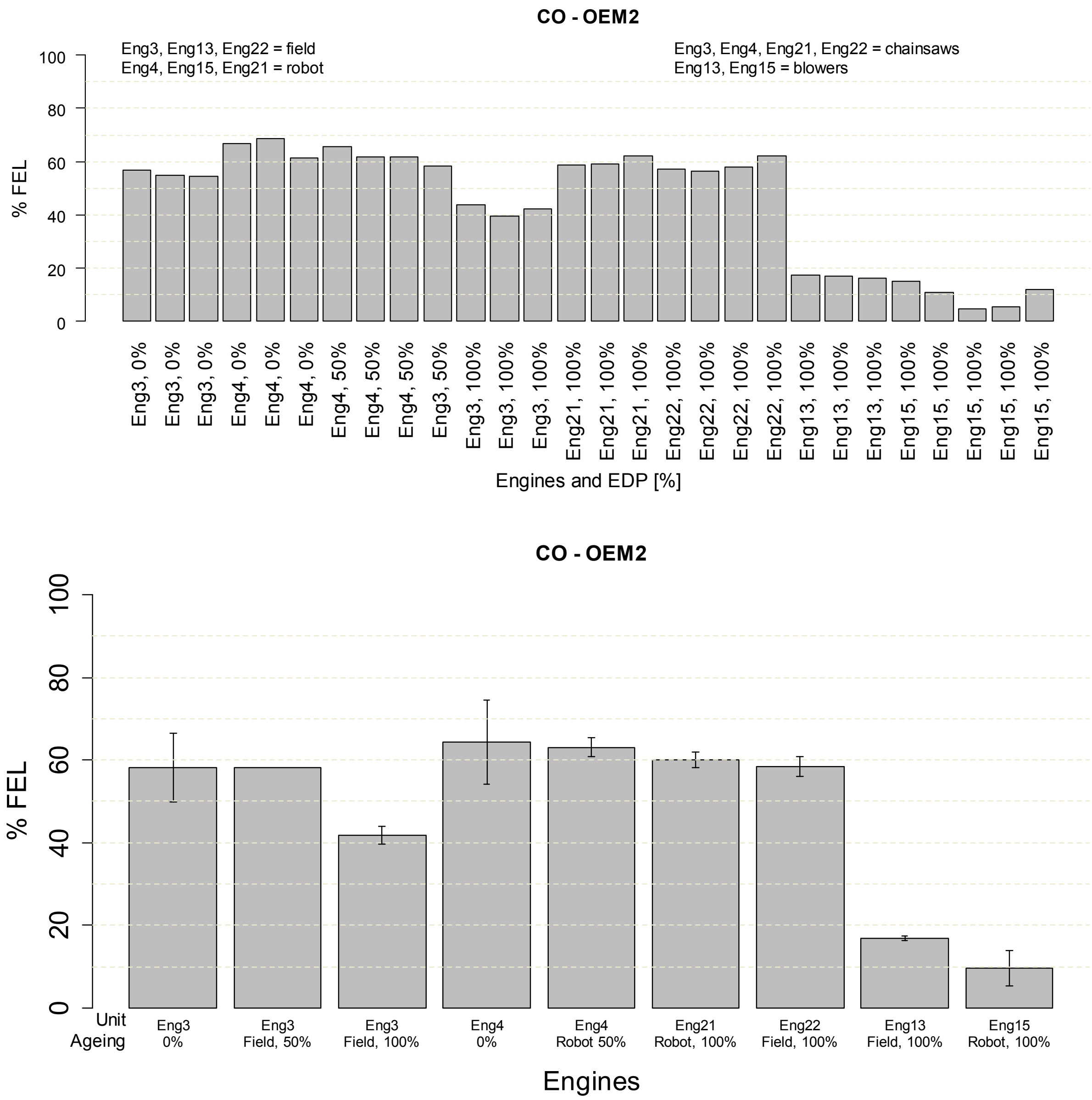
Figure 9. Emission data as percentage of the family emission limit for this class of engines. Upper panel: per-test results. Lower panel: engine-aggregated results.





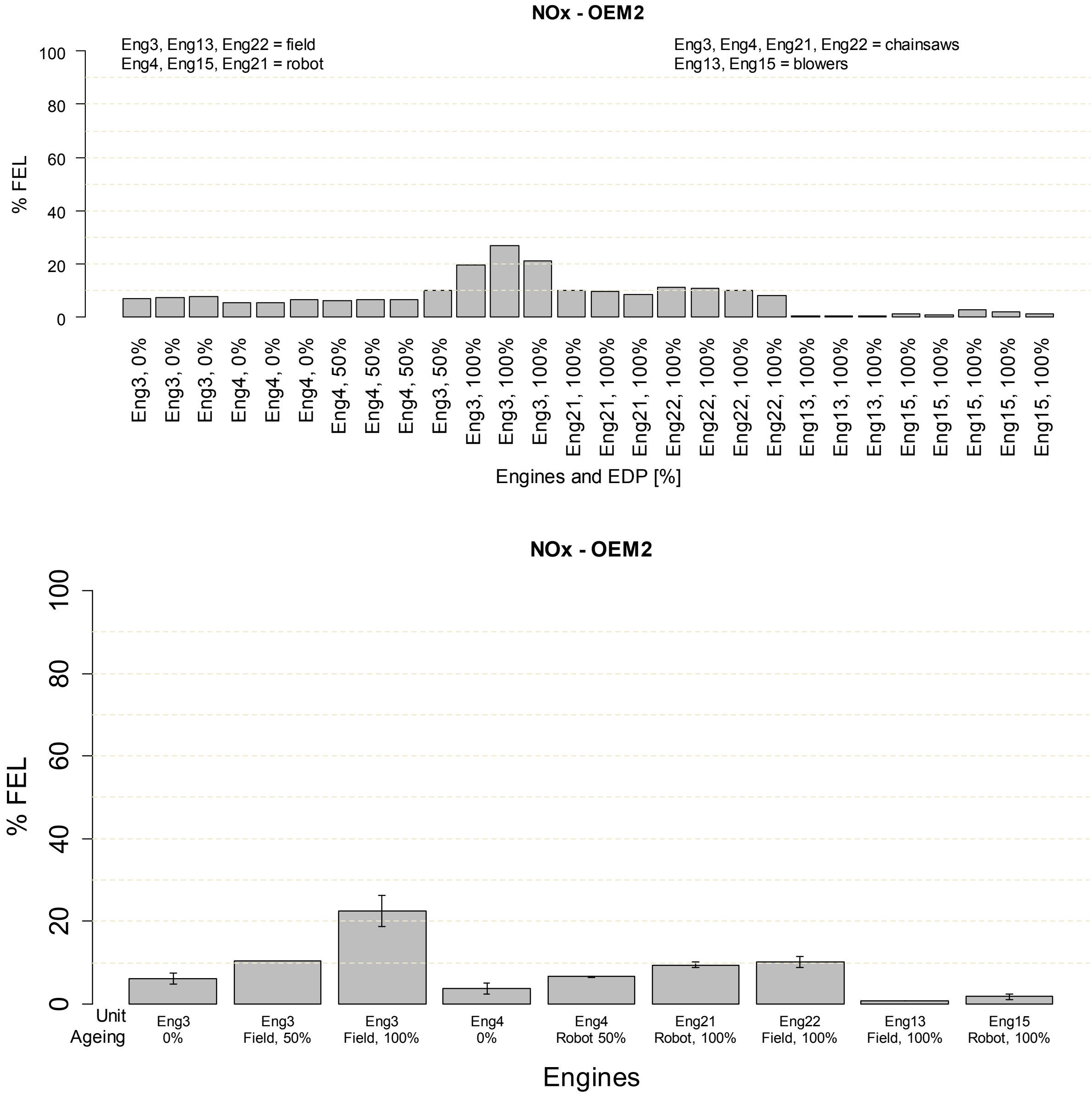
Source: JRC.

Figure 10. Emission data as percentage of the family emission limit for this class of engines. Upper panel: per-test results. Lower panel: engine-aggregated results.



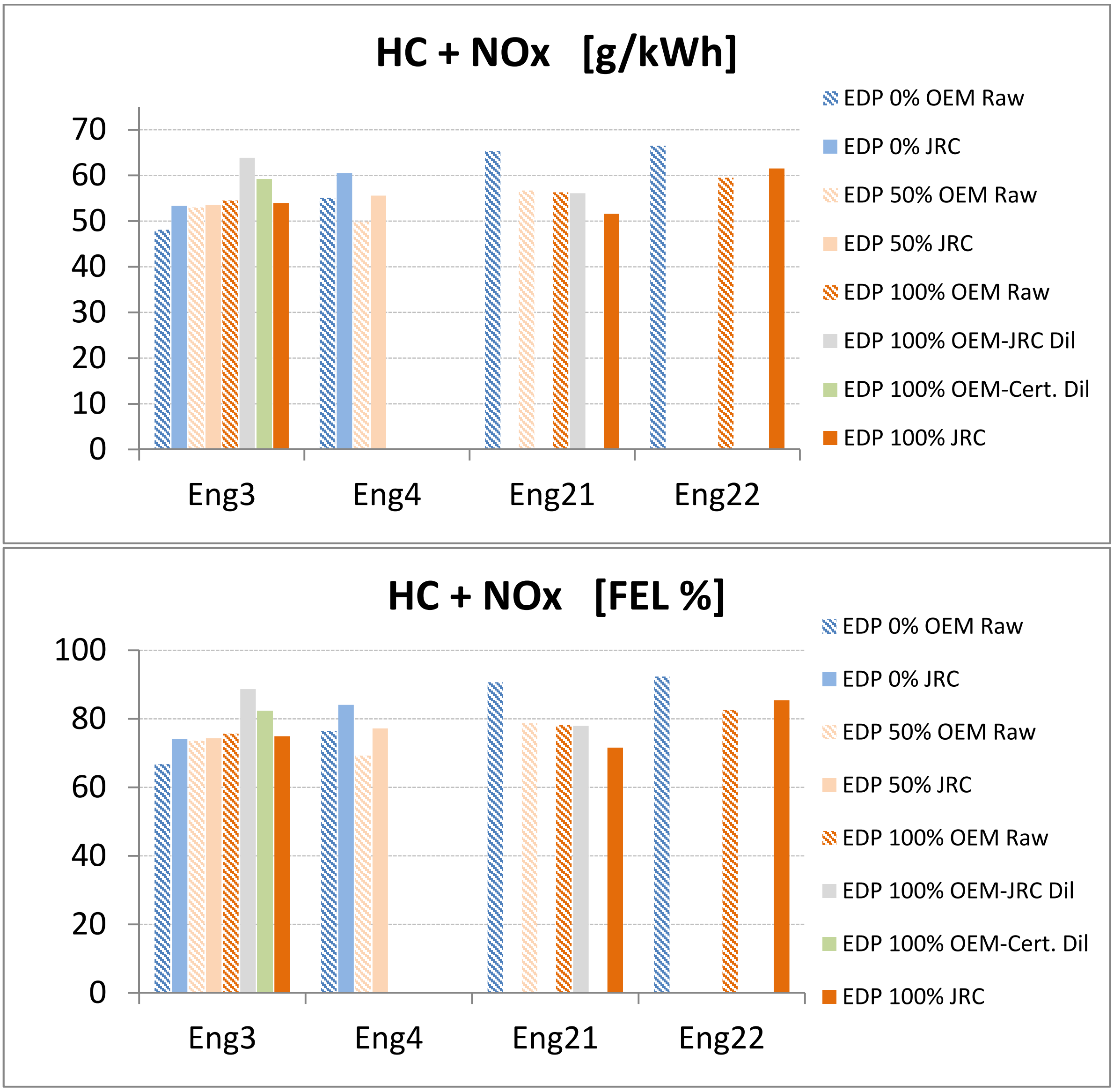
Source: JRC.

Figure 11. Emission data as percentage of the family emission limit for this class of engines. Upper panel: per-test results. Lower panel: engine-aggregated results.



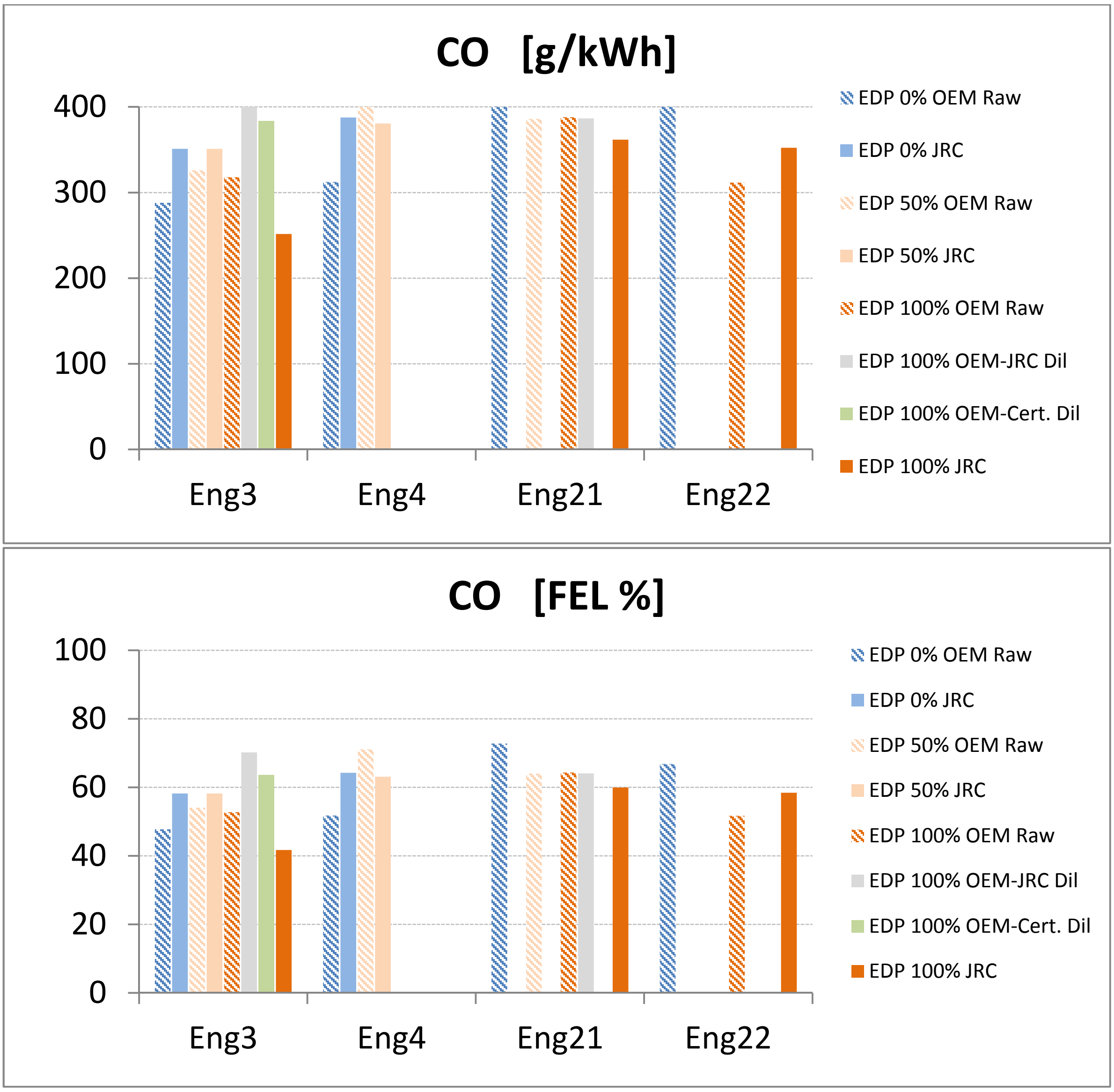
Source: JRC.

Figure 12. Comparison of JRC and OEM-2 emission data.



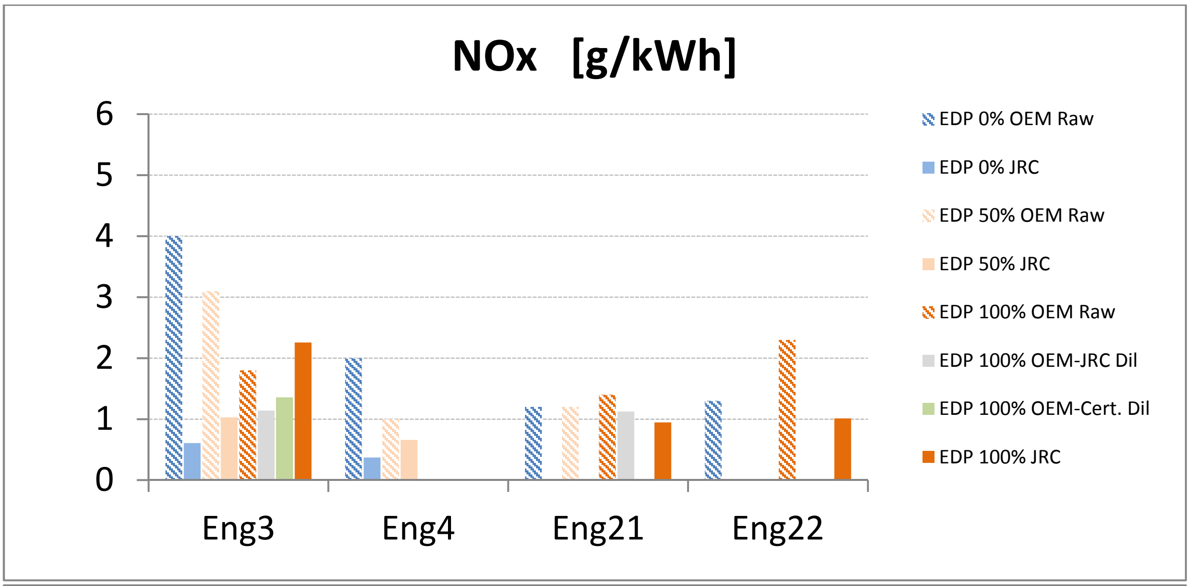
Source: JRC and OEM.

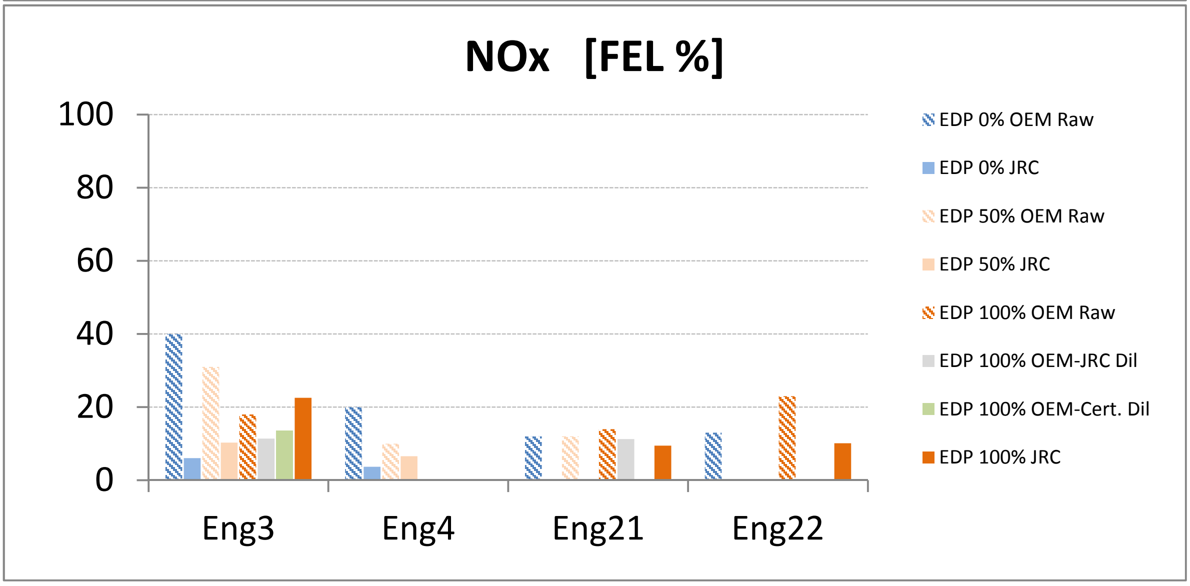
Figure 13. Comparison of JRC and OEM-2 emission data.



Source: JRC and OEM.

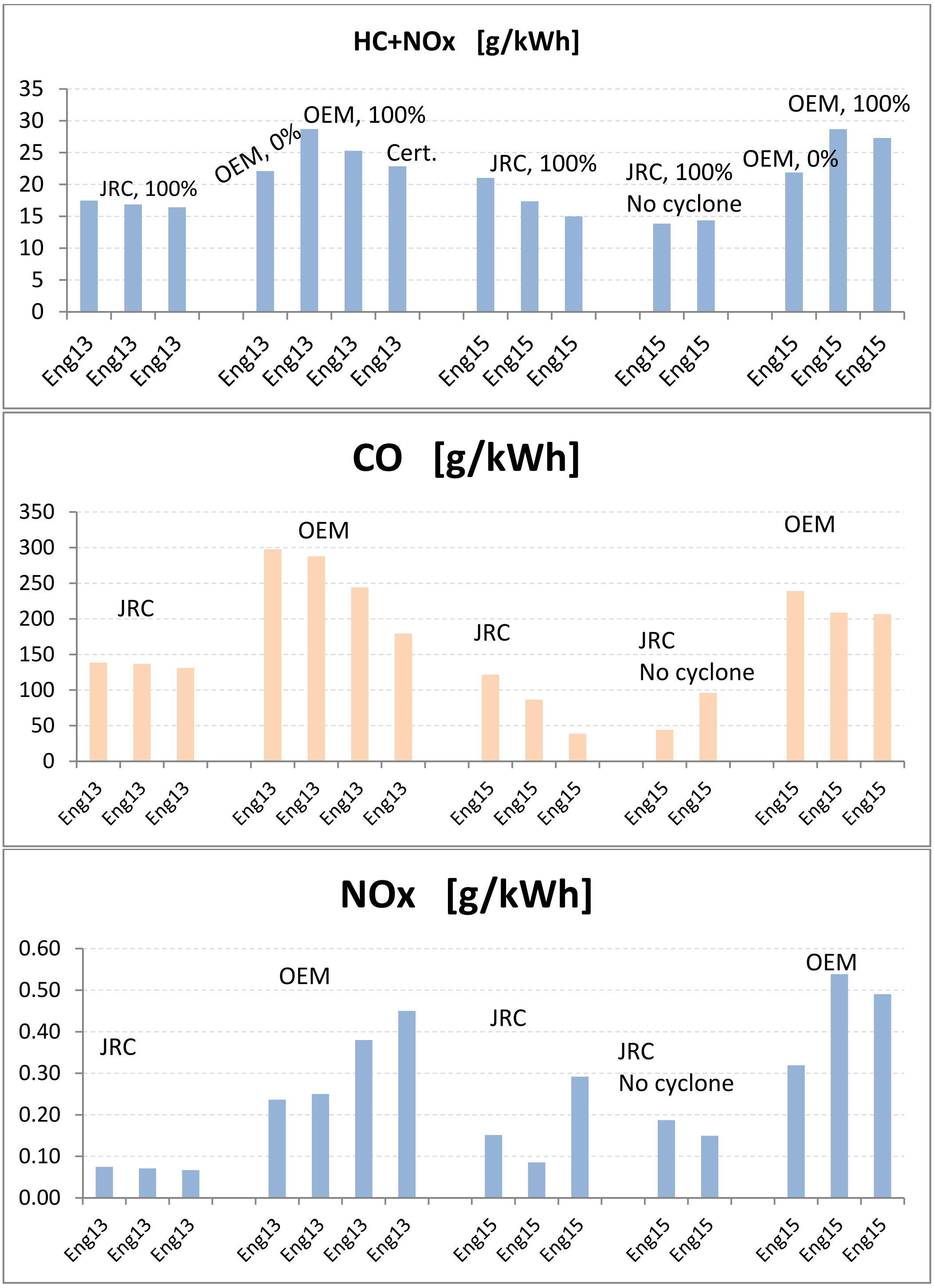
Figure 14. Comparison of JRC and OEM-2 emission data.





Source: JRC and OEM.

Figure 15. Comparison of JRC and OEM-2 emission data for blowers.



Source: JRC and OEM.

3.4 Tests on OEM-3 chainsaws

OEM-3 first provided 2 catalysed chainsaws of category SH:2 for hobby purposes (Eng5 and Eng6), see basic technical specifications in Table 3. During JRC testing, an anomalous deviation of the emissions was observed in comparison with original OEM data. HC+NOx emissions were largely exceeding the limit value. The same occurred after the OEM replaced the Eng5 and Eng6 with Eng7 and Eng8 of the same model. In order to investigate the cause of this behaviour the OEM performed an in-depth analysis of the catalyst after JRC testing and found high concentrations of Silicon (Si), very likely originated from interactions with contaminated fuel. Three fuel samples were therefore taken by JRC: 1) from the original fuel cylinder, 2) from the fuel tank at the beginning of the fuel line in the test cell, and 3) from the end of the fuel line, just before the engine intake and after 1 week of soaking time. The samples were sent to a certified laboratory for Si contamination analysis (EPA 6010C:2000) which confirmed that a Si contamination occurred during and after the preparation of the fuel/oil mix; see Table 12 (Samples 1 to 3). In order to remove any potential source of contamination, all parts of the fuel line and all tools used to prepare the fuel/oil mix were replaced and 2 additional samples were taken after 1 week soaking time in the new fuel line (Samples 4 and 5 in Table 12) and sent for Si concentration analysis. Results confirmed that the contamination had been removed. For this reason, no engine from OEM-3 was tested further at JRC facilities. However, 4 additional engines of the same model (Eng17 to Eng20) were included in this Report with emission data originated in the OEM facilities; see Table 13 and Table 22. One test on Eng17 and 1 test on Eng19 were witnessed by an JRC member and 1 test on Eng19 was performed by a certified body (TÜV Nord, Germany), in order to confirm the quality of the data provided by the OEM.

Emission results are summarized in Figure 16 and Figure 17. All engines and tests complied with the limit values. Remarkably, CO and NOx emissions were 60% and 90% below the limit values, respectively. As none of the engine was followed at JRC, it was not possible to discriminate between field and robot ageing based only on JRC data.

Table 12. Results of the analysis to investigate the fuel line contamination by Silicon. Method EPA 6010C:2000.

Sample	Type	Location	Si [mg/kg]	Result
1	Reference fuel	Original fuel tank	< 5	Clean
2	Fuel/Oil mix	Beginning of fuel line	72	Contaminated
3	Fuel/Oil mix	End of fuel line	411	Contaminated
4	Fuel/Oil mix	End of fuel line	< 5	Clean
5	Fuel/Oil mix	Beginning of fuel line	< 5	Clean

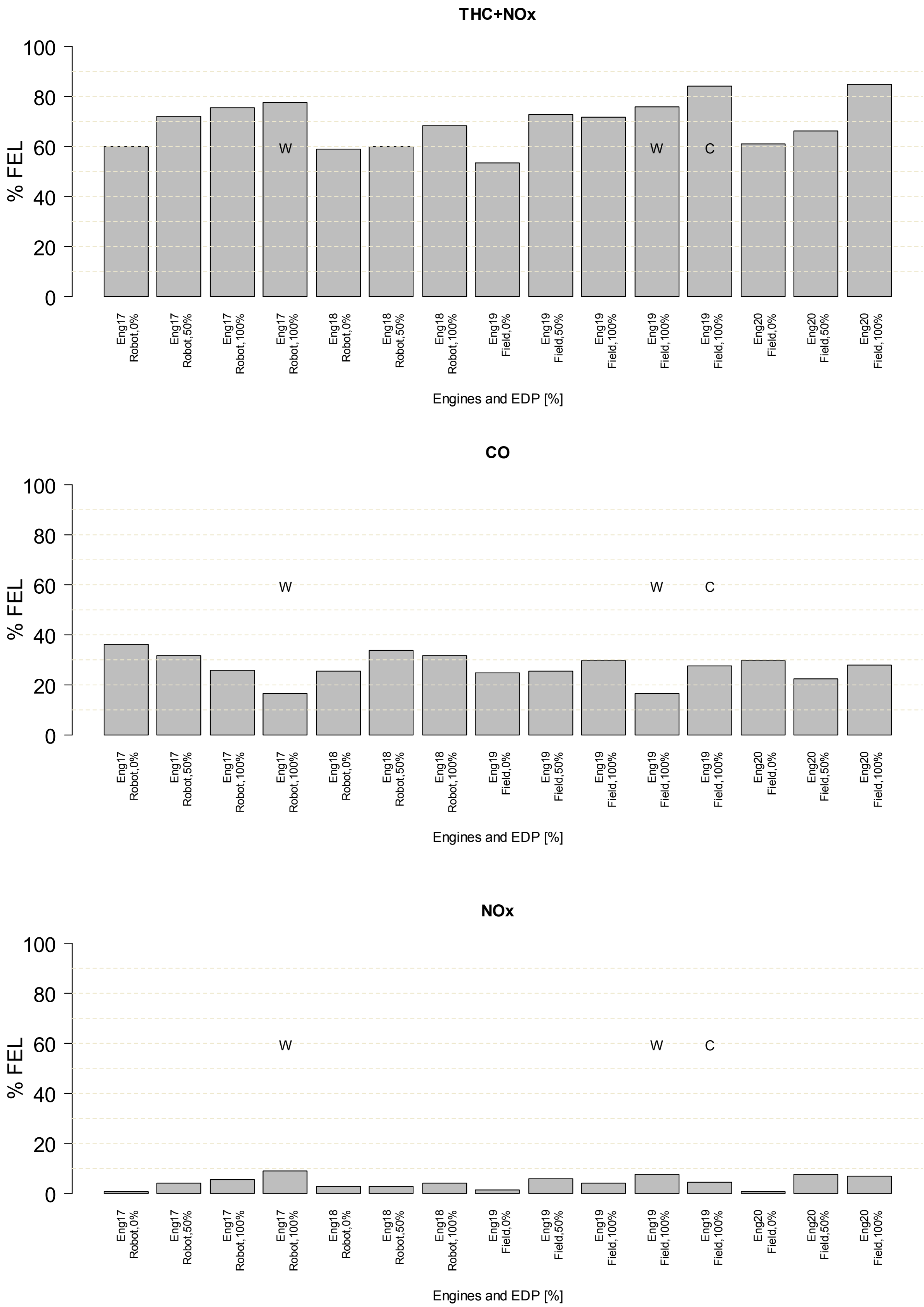
Source: JRC.

Table 13. OEM-3 engines tested at OEM facilities.

Engine	Type	Ageing Type	EDP	Displace-ment	Class	Stage	Cata-lyst	Limit		
								HC+NOx	CO	NOx
			[%]	[cm^3]				[g/kWh]		
Eng17	Chain-saw	Robot	0,50, 100	32	SH:2	II	Yes	50	805	10
Eng18	Chain-saw	Robot	0,50, 100	32	SH:2	II	Yes	50	805	10
Eng19	Chain-saw	Field	0,50, 100	32	SH:2	II	Yes	50	805	10
Eng20	Chain-saw	Field	0,50, 100	32	SH:2	II	Yes	50	805	10

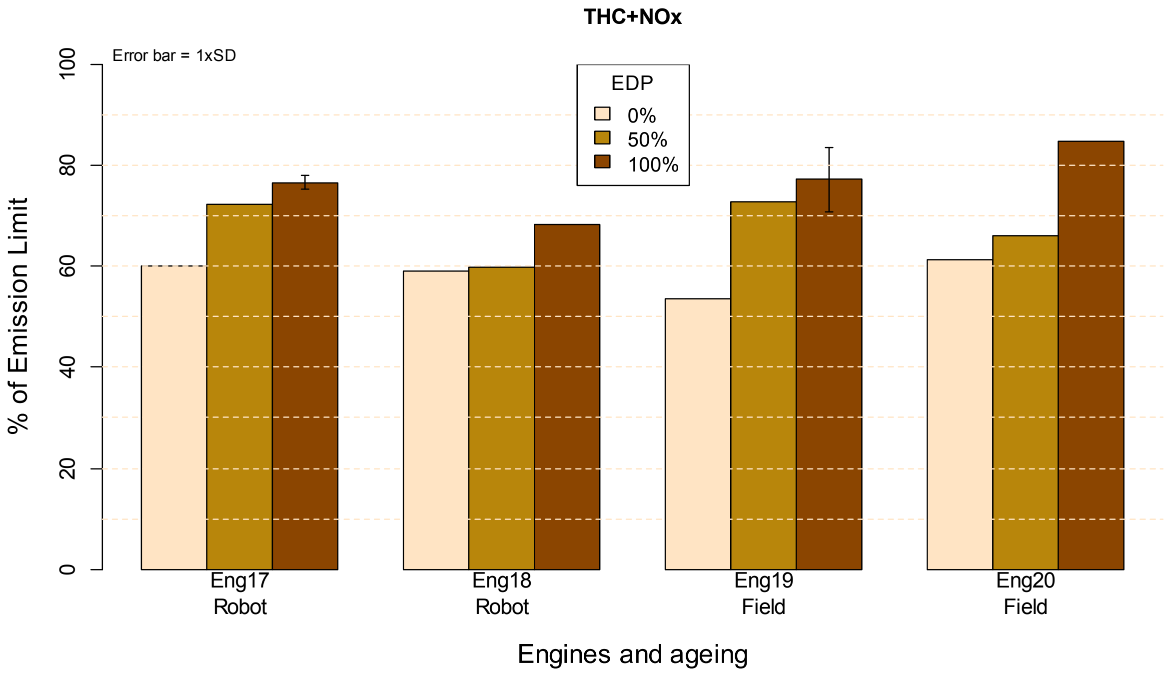
Source: OEM.

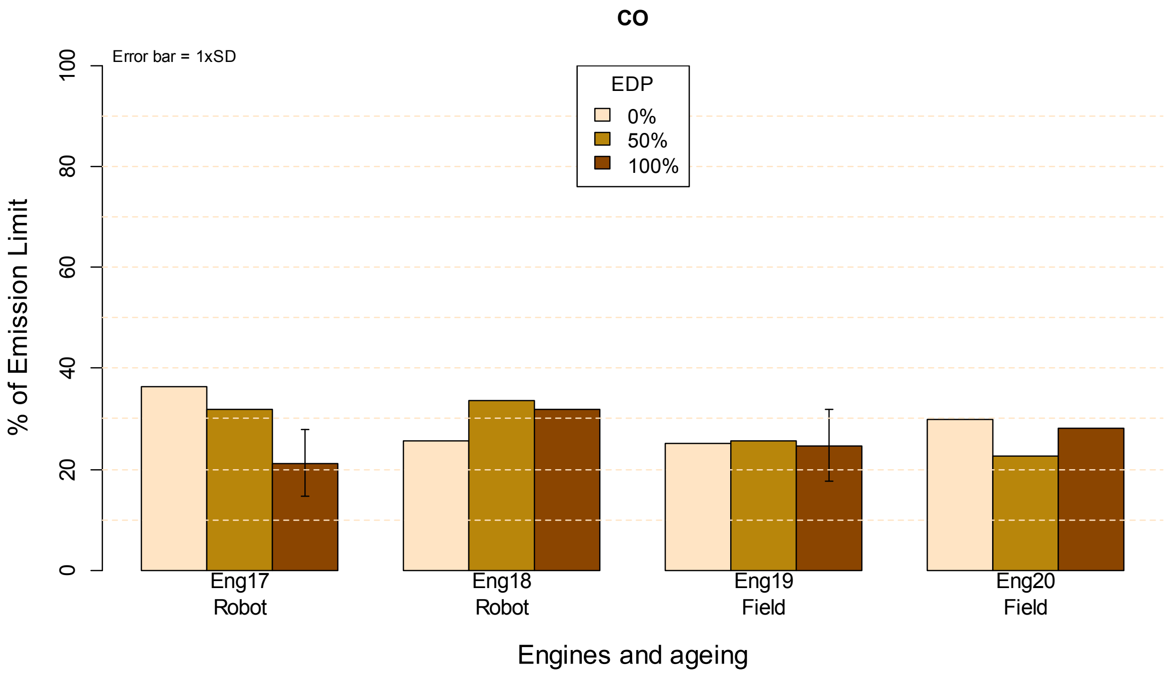
Figure 16. Emission data from OEM-3; per-test results. W= witnessed by JRC, C = performed by a certified body

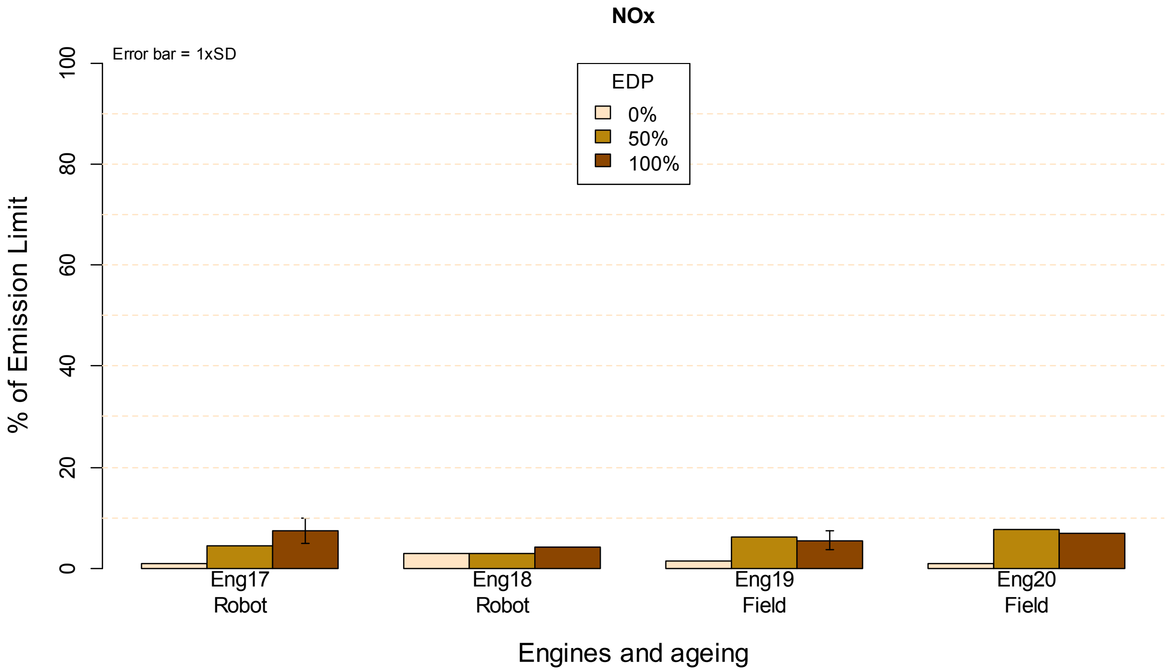


Source: OEM.

Figure 17. Emission data from OEM-3, aggregated results.






NOx
Error bar = 1xSD
EDP
0%
50%
100%
% of Emission Limit
0
20
40
60
80
100
Eng17
Robot
Eng18
Robot
Eng19
Field
Eng20
Field
Engines and ageing

Source: OEM.

3.5 Tests on OEM-4, SN:3 lawn mowers

OEM-4 provided 4 walk-behind (i.e., pedestrian-controlled) non-catalysed lawn mowers of category SN:3, see basic technical specifications in Table 3 and Table 14. Eng9 and Eng12 were not aged (EDP = 0%), while Eng10 and Eng11 had been aged by the OEM up to the full EDP = 100% (corresponding to 250 h) in the field and via the automated engine bench test procedures (robot ageing), respectively. Emissions of regulated pollutants are shown in Figure 18 to Figure 20 as inter-test comparison and aggregated averages with 1x standard deviation error bars.

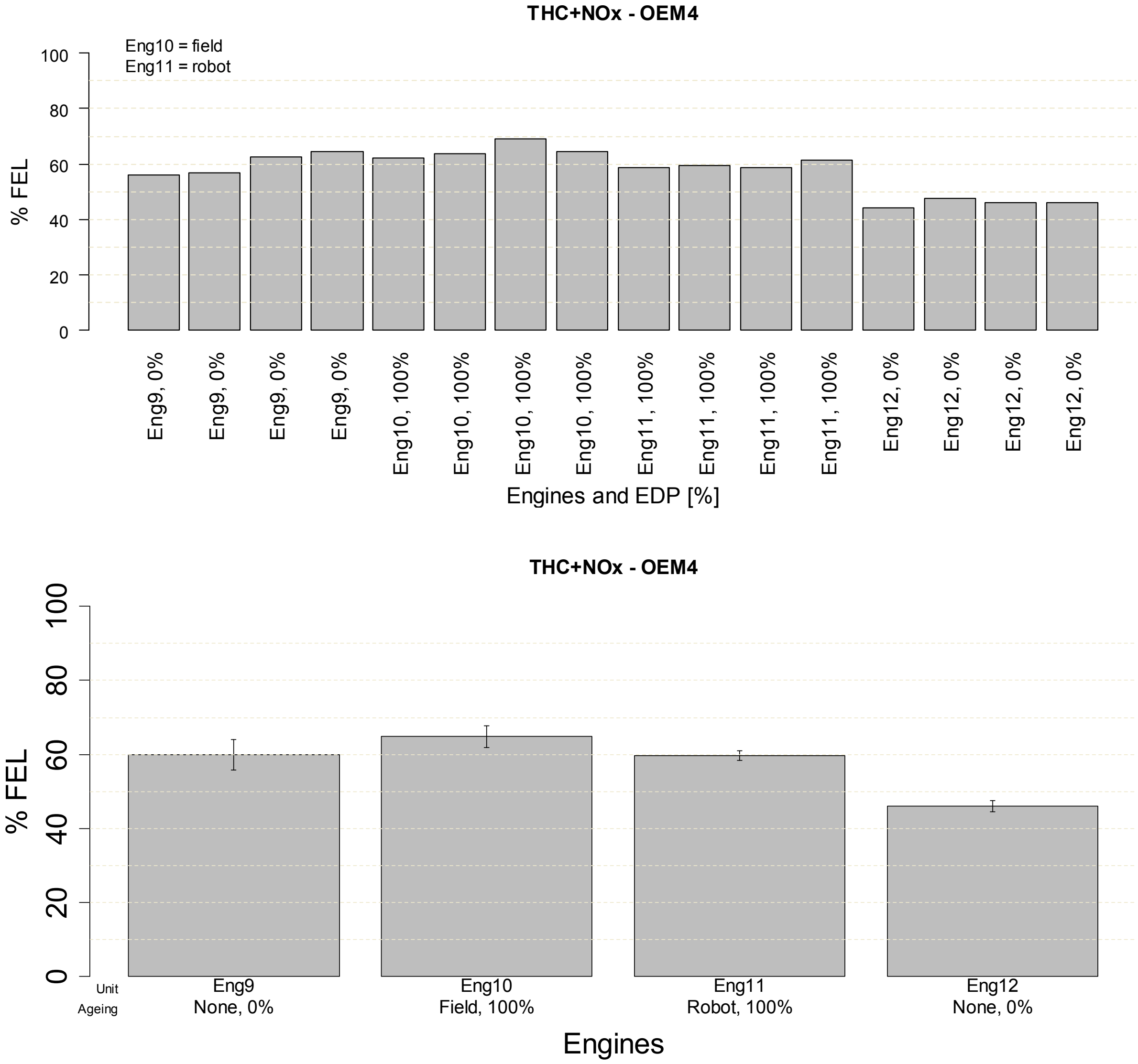
All engines emitted well below their assigned limits (between 60% and 70% of the limit values). As none of the engine was followed at JRC for the entire ageing procedure from EDP=0% to EDP=100%, it was not possible to discriminate between field and robot ageing based only on JRC data.

Table 14. OEM-4 engines tested at JRC.

Engine	Type	Ageing Type	EDP	Displacement	Class	Stage	Catalyst	Limit		
								HC+NOx	CO	NOx
			[%]	[cm^3]				[g/kWh]		
Eng9	Lawn Mower	None	0	190 cc	SN:3	II	No	16.1	610	10
Eng10	Lawn Mower	Field	100	190 cc	SN:3	II	No	16.1	610	10
Eng11	Lawn Mower	Robot	100	190 cc	SN:3	II	No	16.1	610	10
Eng12	Lawn Mower	None	0	190 cc	SN:3	II	No	16.1	610	10

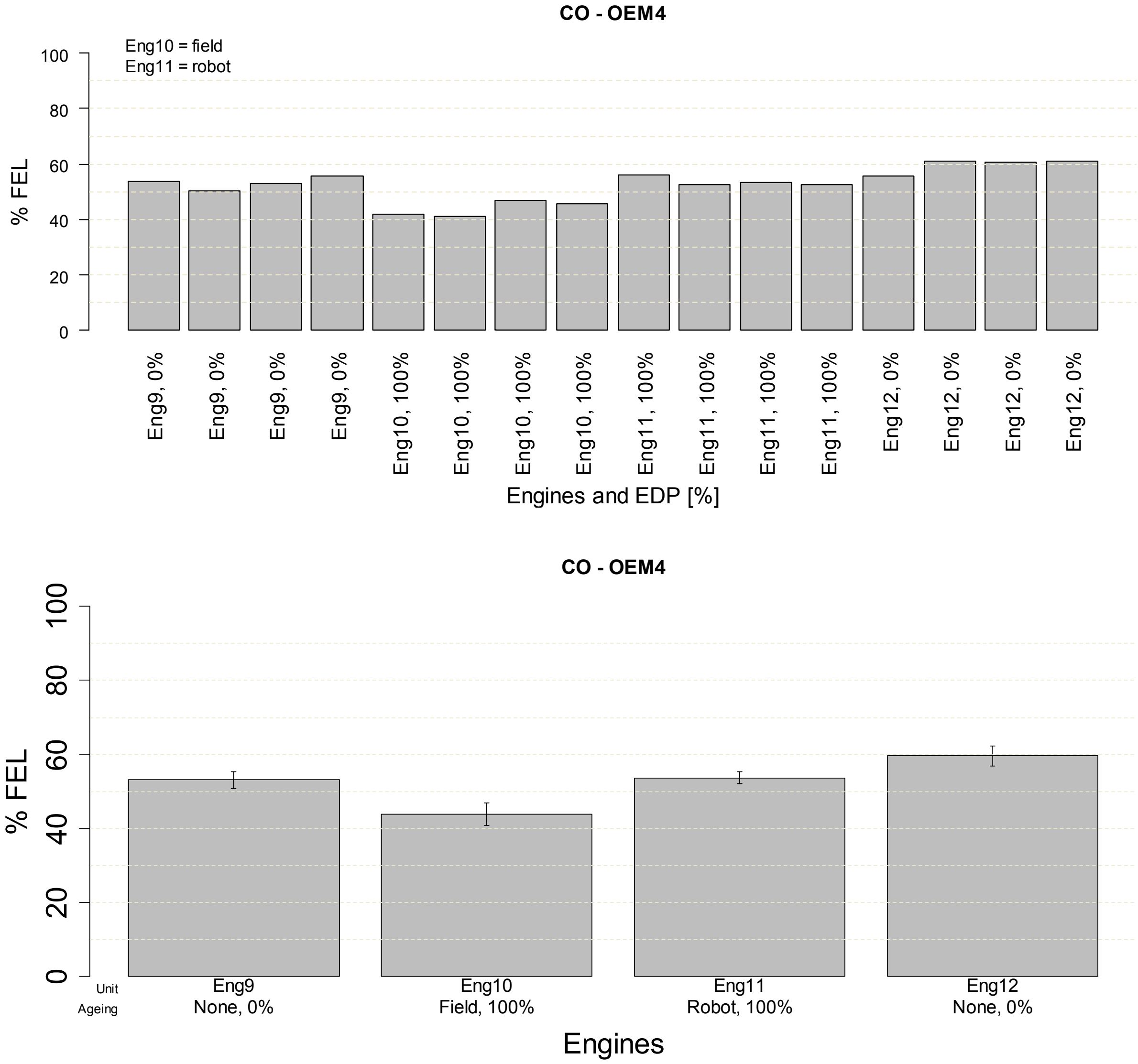
Source: OEM.

Figure 18. Emission data as percentage of the family emission limit for this class of engines. Upper panel: per-test results. Lower panel: engine-aggregated results.



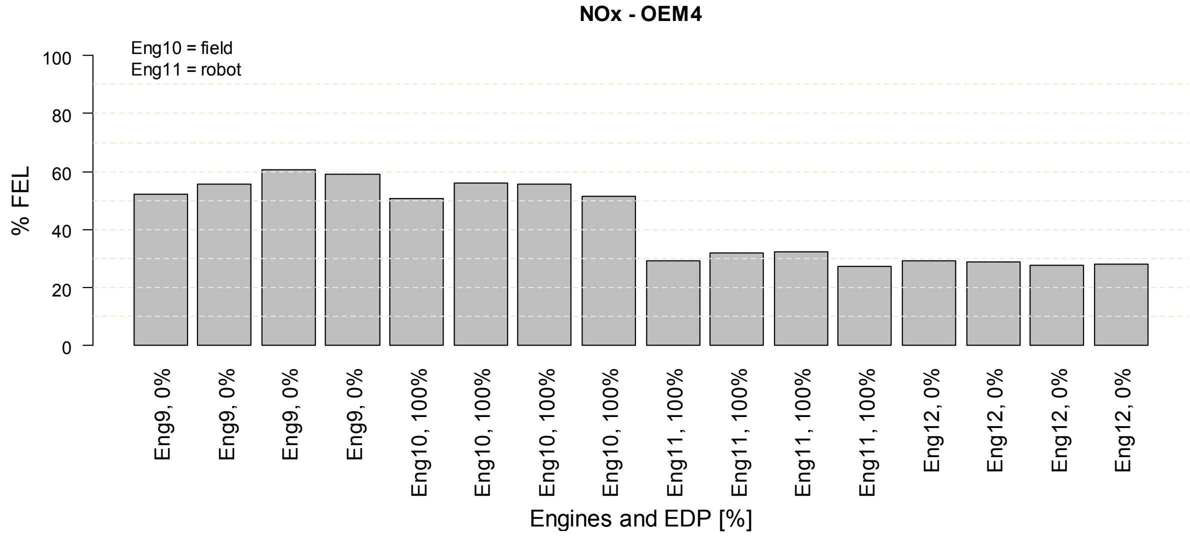
Source: JRC.

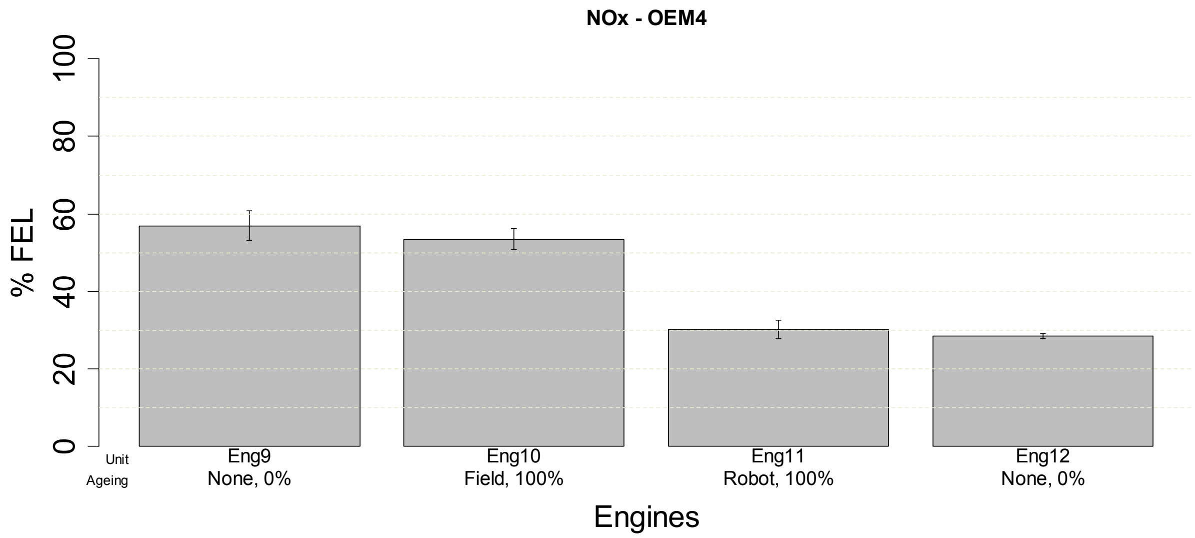
Figure 19. Emission data as percentage of the family emission limit for this class of engines. Upper panel: per-test results. Lower panel: engine-aggregated results.



Source: JRC.

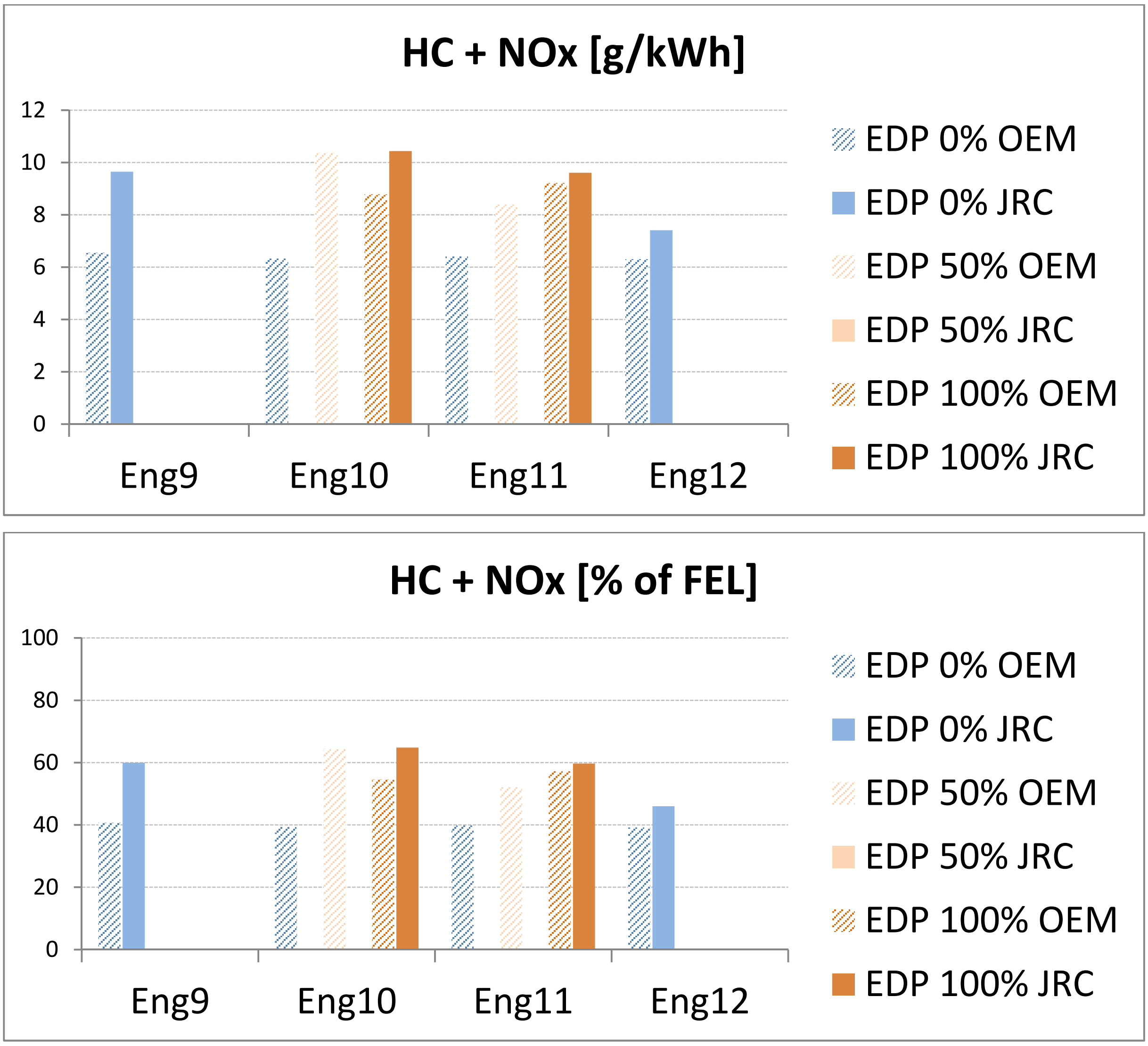
Figure 20. Emission data as percentage of the family emission limit for this class of engines. Upper panel: per-test results. Lower panel: engine-aggregated results.





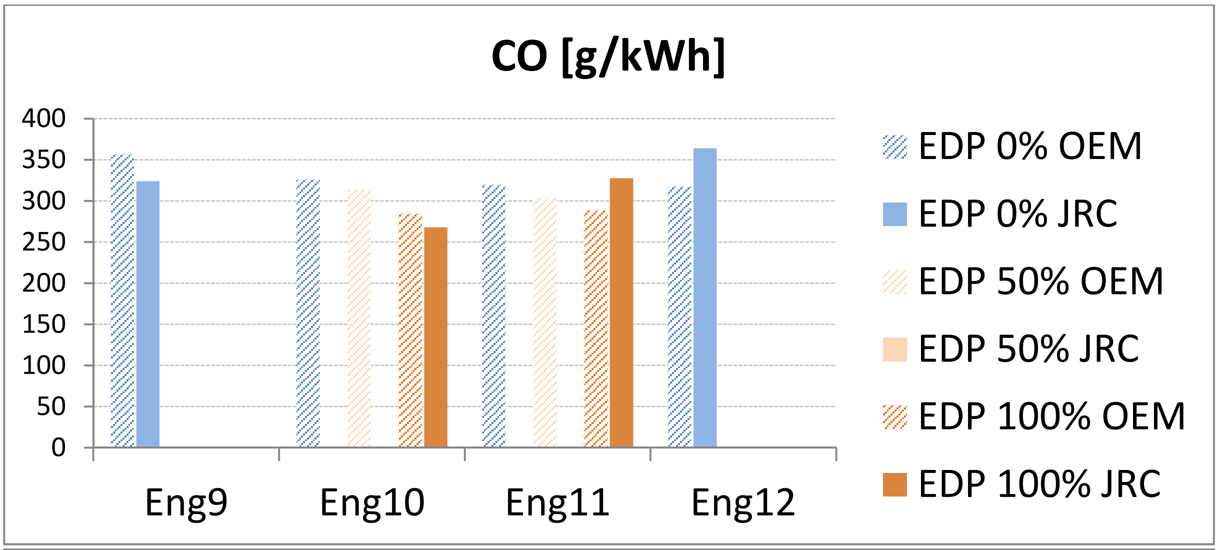
Source: JRC.

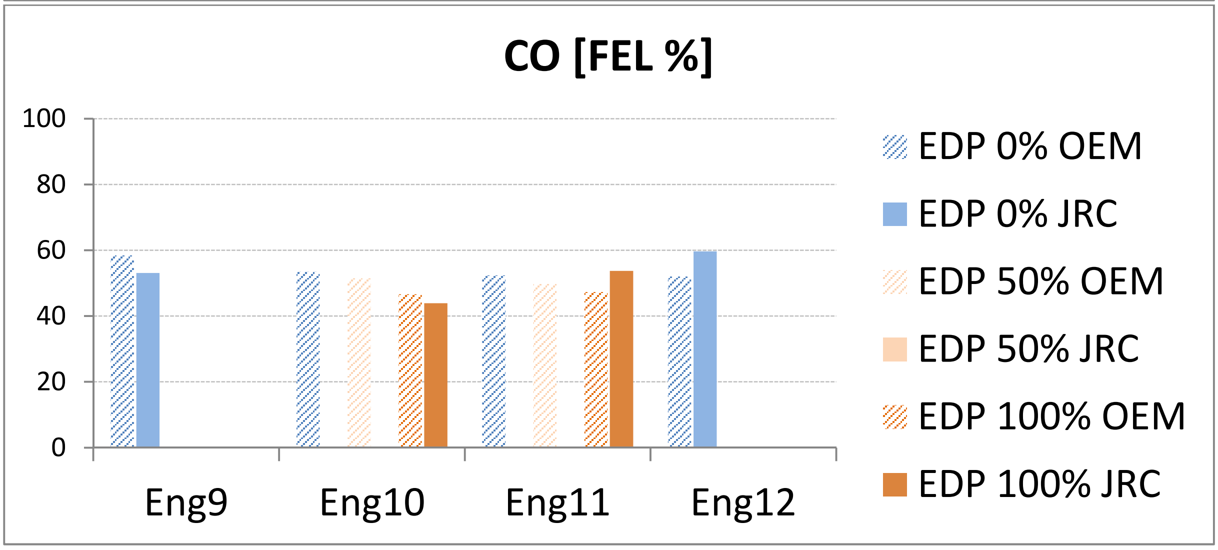
Figure 21. Comparison of JRC and OEM-4 emission data.



Source: JRC and OEM.

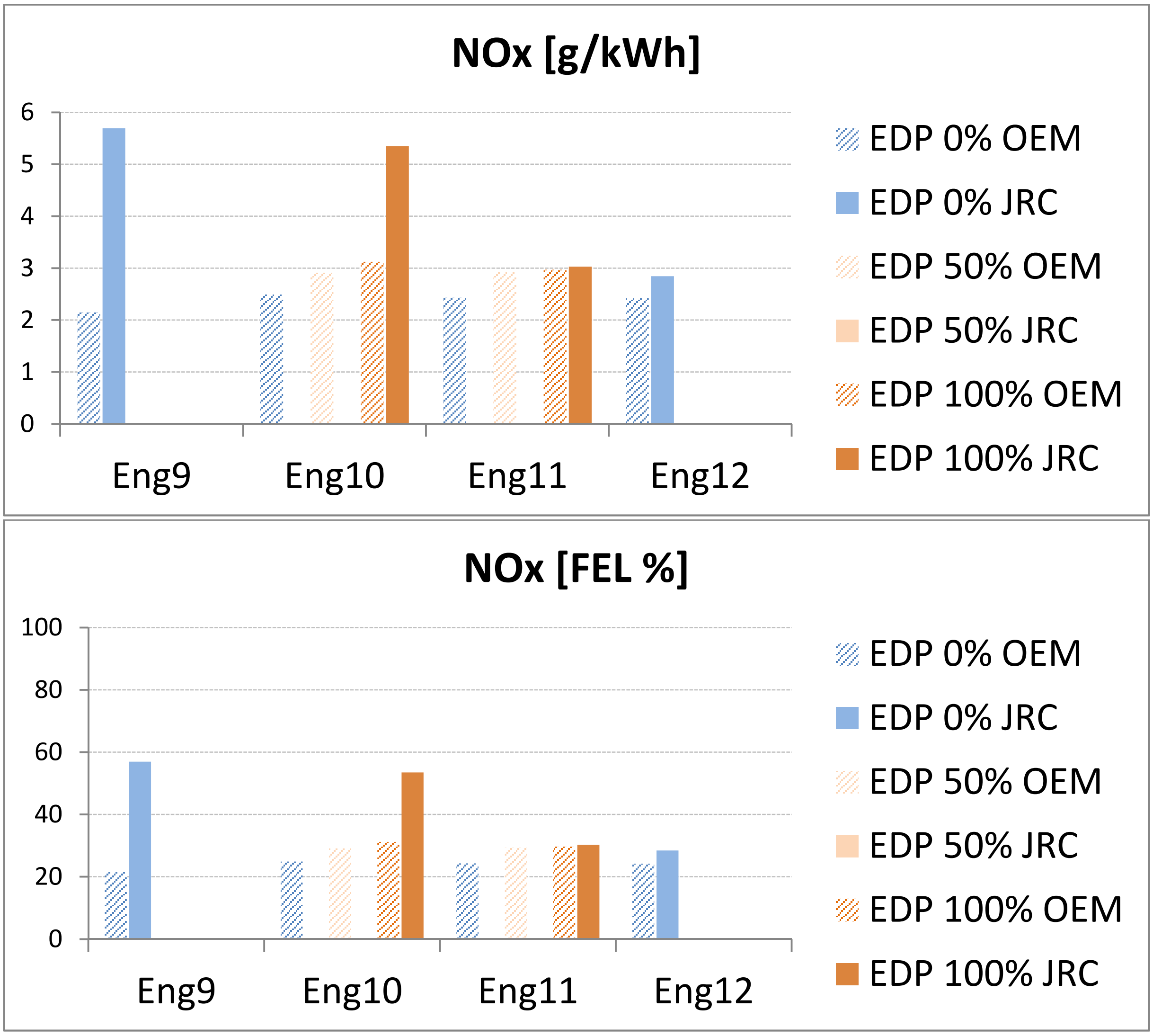
Figure 22. Comparison of JRC and OEM-4 emission data.





Source: JRC and OEM.

Figure 23. Comparison of JRC and OEM-4 emission data.



Source: JRC and OEM.

3.6 Emission data provided by EUROMOT

In the present section, exhaust emission data provided by the European Association of internal Combustion Engines Manufacturers (EUROMOT) are rearranged and discussed. Please refer to the original EUROMOT communication in Annex 3 which includes:

— Emission data (HC+NOx) from 45 hand-held units originally produced for US-EPA Phase III rulemaking;

— Emission data from 10 non-handheld units recently produced for EUROMOT by one of their associated manufacturers;

The data were provided to JRC in order to integrate with additional manufacturers' data the actual testing performed during the present ISM programme.

Disclaimer

Please note that JRC neither produced the data shown in this section and Annex 3, neither had the possibility to confirm the received data with additional testing on the same engines. For this reason, JRC is not responsible for the quality of such data.

Basic technical specifications and exhaust emissions of the hand-held and non-hand-held engines are summarized in Table 23 and Table 24, respectively. US-EPA engine classes, IV and V, correspond to EU SH:2 and SH:3 engines; see section 2.2. Results were analysed relative to the family emission limit (FEL).

Figure 24, upper panel, shows the HC+NOx exhaust emissions from a series of walk-behind and ride-on lawn mowers (units 9 to 16). Units 17 and 18 were not in the scope of the ISM programme and were therefore not included. As indicated by the annotations on the horizontal axis, some engines performed bench (robot) ageing, some field ageing, and 2 of them were tested as new.

Figure 24, lower panel, shows the HC+NOx exhaust emissions from a series of small hand-held engines of corresponding EU category SH:2 and SH:3.

We observed that:

— All engines complied with the indicated FEL in terms of HC+NOx.

— HC+NOx emissions of non-hand-held (NH) engines of category SN:3 and SN:4 ([8]) were at worst 30% below the respective FEL (Unit 15).

— HC+NOx emissions of SH:2 engines were in some cases very close to the FEL.

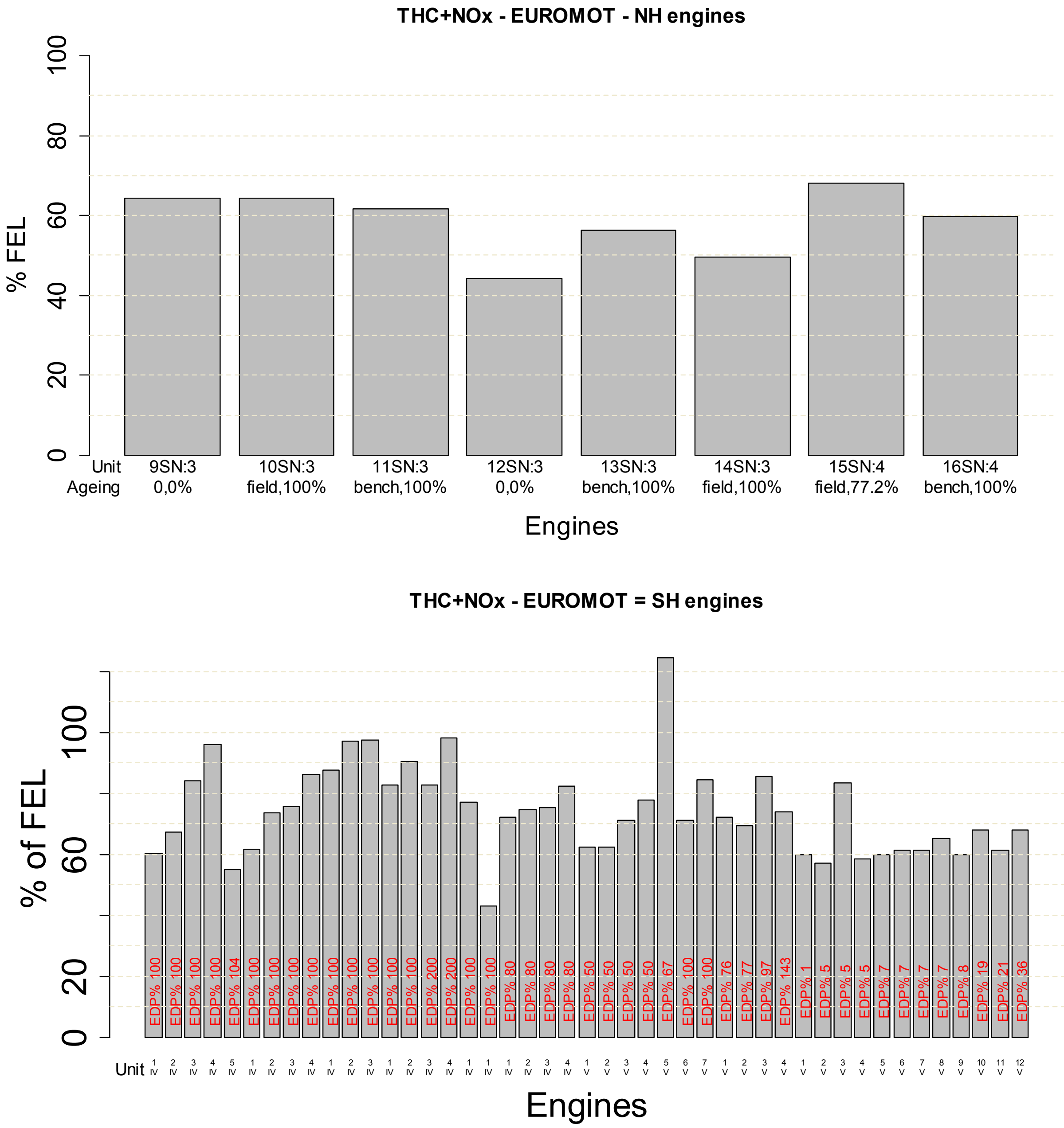
— HC+NOx emissions of SH:3 engines were at worst 15% below the FEL.

— Field ageing seems more severe than robot ageing considering units 10 and 11, while the opposite holds for units 13 and 14. However:

- Different units of the same engine model were tested at a unique fraction of the EDP, with no possibility to monitor the deterioration of emissions with ageing on the same unit.
- Different units of the same model may differ in emission already at the beginning of the EDP (e.g., Unit 9 and Unit 12), thus hindering further analysis on the severity of different ageing methodology**.**

([8]) Small non-road engine with displacement ≥ 225 cm^3 mounted in ride-on lawn mowers.

Figure 24. HC+NOx exhaust emissions (% of limit) from a series of small engines according to EUROMOT data. Upper panel: walk-back and ride-on lawn mowers (NH = non-hand-held). Lower panel: small hand-held engines (SH).



Source: EUROMOT.

3.7 Aggregated results

3.7.1 Overall emissions

Figure 25 and Figure 26 are the summary bar plots of all tests carried out at JRC and OEMs displaying averages and 1x standard deviation error bars. None of the engines overshot the corresponding family emission limit values (FEL = 100%) for both averaged and per-test values. JRC measurements were able to cover Eng1 to Eng4 over the full EDP, while Eng9 to Eng22 were tested at JRC only at one EDP point (0% or 100%), see Table 9. Mowers (Eng9 to Eng12), equipped with 4-stroke engines and blowers (Eng13 to Eng16), equipped with a stratified charged catalysed engine, exhibited the lowest HC+NOx emissions, while catalysed chainsaws Eng17 to Eng20 and blowers emitted less CO than the other engines. The largest NOx emissions were associated to 4-stroke mowers, as expected from basic combustion principles of 2-stroke and 4-stroke technologies. Their NOx emissions were anyway much lower than the limit values (40-60% lower). Note that in some cases the emissions were larger at 0% EDP than at 100% EDP and in few cases the emissions at 50% EDP were larger than at 100% EDP. The former situation may be explained by engine run-in in the very first hours of use after production and consequent large emissions. The latter situation may be ascribed to periodic regulations of the fuel/air mix at the carburettor during the EDP, with consequent increase or decrease of emissions due to leaner or richer running conditions.

Table 15 is the summary of maximum values of all JRC emission tests normalized to the respective limit values depending on engine class and chemical species; see Table 3. The values in Table 15 give indications on the environmental performance of the engines relative to their maximum allowed emissions in EU. The JRC values referred to blowers were extremely low, and lower than OEM corresponding tests, due to the different sampling methodology as pointed out in section 3.3. Average values were reported at the end of the Table as additional information, but any conclusion based on averages should consider the aggregation of different class of engines with very small statistical sub-samples. A more conservative approach, which considers only maximum values, reveals that emissions were about 10%, 30% and 40% below the limits for HC+NOx, CO, and NOx respectively. Maximum emission values of HC+NOx and CO from OEM were in very good agreement with JRC, as can be seen in Table 16, where all data provided by the OEMs in Table 22 were used. The only discrepancy is the maximum value of NOx, which was 60% (OEM) and 40% (JRC) below the limit. This was mainly due to i) low NOx concentrations in the exhaust (typical of small gasoline engines) and hence larger uncertainty of the analysers and ii) NOx concentration stability during testing. Hence, we can conclude that for all engines both CO and NOx levels were well below the limit values. This result may be considered a consistent starting point for future legislation developments, which typically include discussions on emission limit reduction. As supporting evidence, a similar range of emission values were reported in several items of the scientific literature; see for instance Magnusson et al. (2002), Aalander et al. (2005), Zardini et al. (2018) and references therein.

Table 15. Summary of maximum emissions from JRC tests. The overall average (Av.all) is reported for comparison with OEM results.

Engine	Type	JRC Max FEL %		
		HC+NOx	CO	NOx
Eng1	Chainsaw	84	36	51
Eng2	Chainsaw	92	46	11
Eng3	Chainsaw	76	58	27
Eng4	Chainsaw	88	69	7
Eng9	Mower	64	55	61
Eng10	Mower	69	47	56
Eng11	Mower	62	56	32
Eng12	Mower	48	61	29
Eng13	Blower	35	17	1
Eng15	Blower	42	15	3
Eng21	Chainsaw	74	62	10
Eng22	Chainsaw	86	62	11
Max all		**92**	**69**	**61**
Av. all		**68**	**49**	**25**

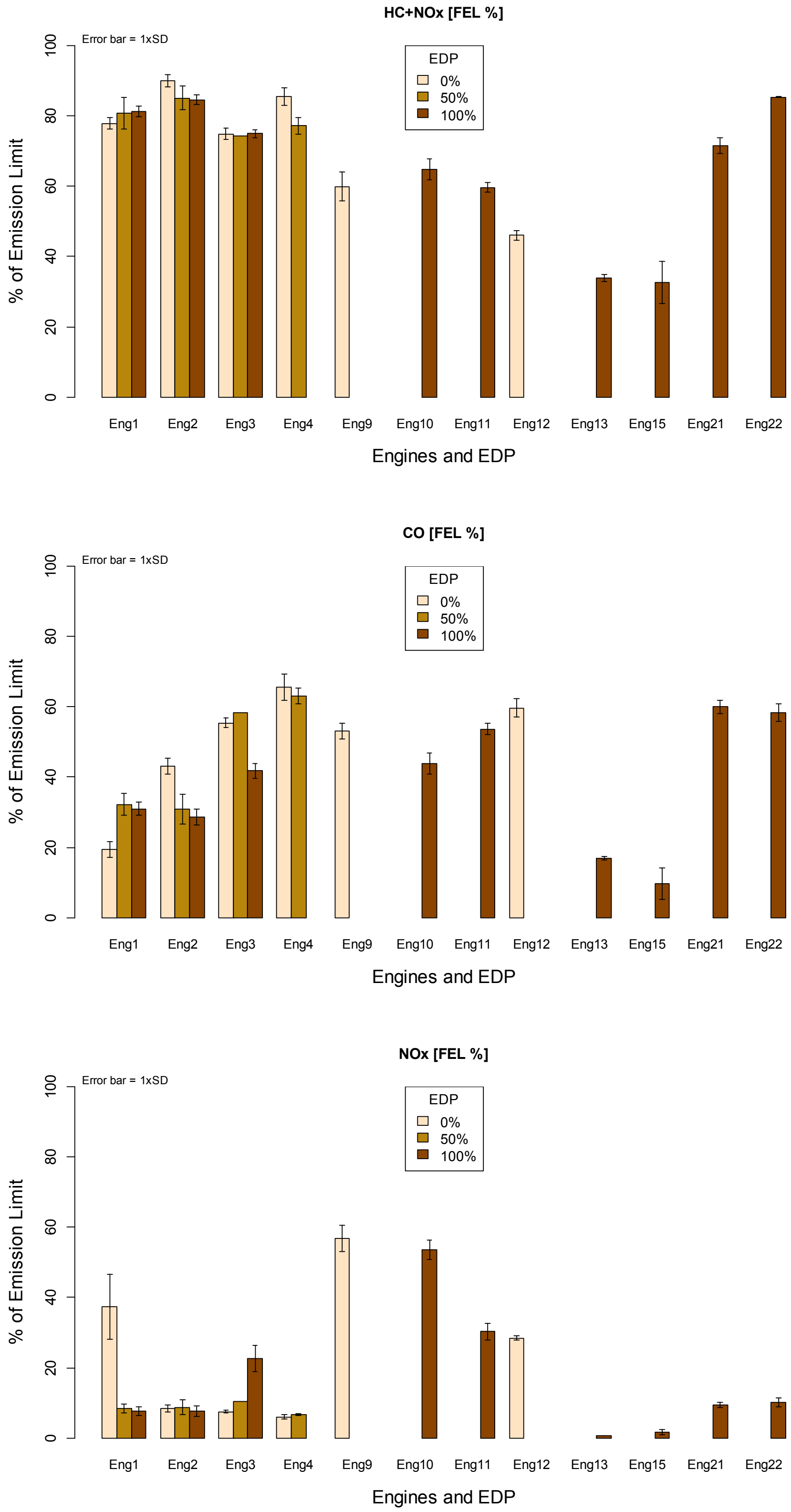
Source: JRC.

Table 16. Summary of maximum emissions from OEM emission tests. Average (Av.all) is reported for comparison with JRC results.

		OEM Max FEL %		
Engine	Type	HC+NOx	CO	NOx
Eng1	Chainsaw	80	35	13
Eng2	Chainsaw	85	38	12
Eng3	Chainsaw	89	70	40
Eng4	Chainsaw	76	71	20
Eng9	Mower	41	58	22
Eng10	Mower	64	53	31
Eng11	Mower	57	52	30
Eng12	Mower	39	52	24
Eng13	Blower	57	37	5
Eng14	Blower	60	38	4
Eng15	Blower	57	30	5
Eng16	Blower	73	47	5
Eng17	Chainsaw	78	36	9
Eng18	Chainsaw	68	34	4
Eng19	Chainsaw	84	30	8
Eng20	Chainsaw	85	30	8
Eng21	Chainsaw	91	73	14
Eng22	Chainsaw	92	67	23
Max all		**92**	**73**	**40**
Av all		**71**	**47**	**15**

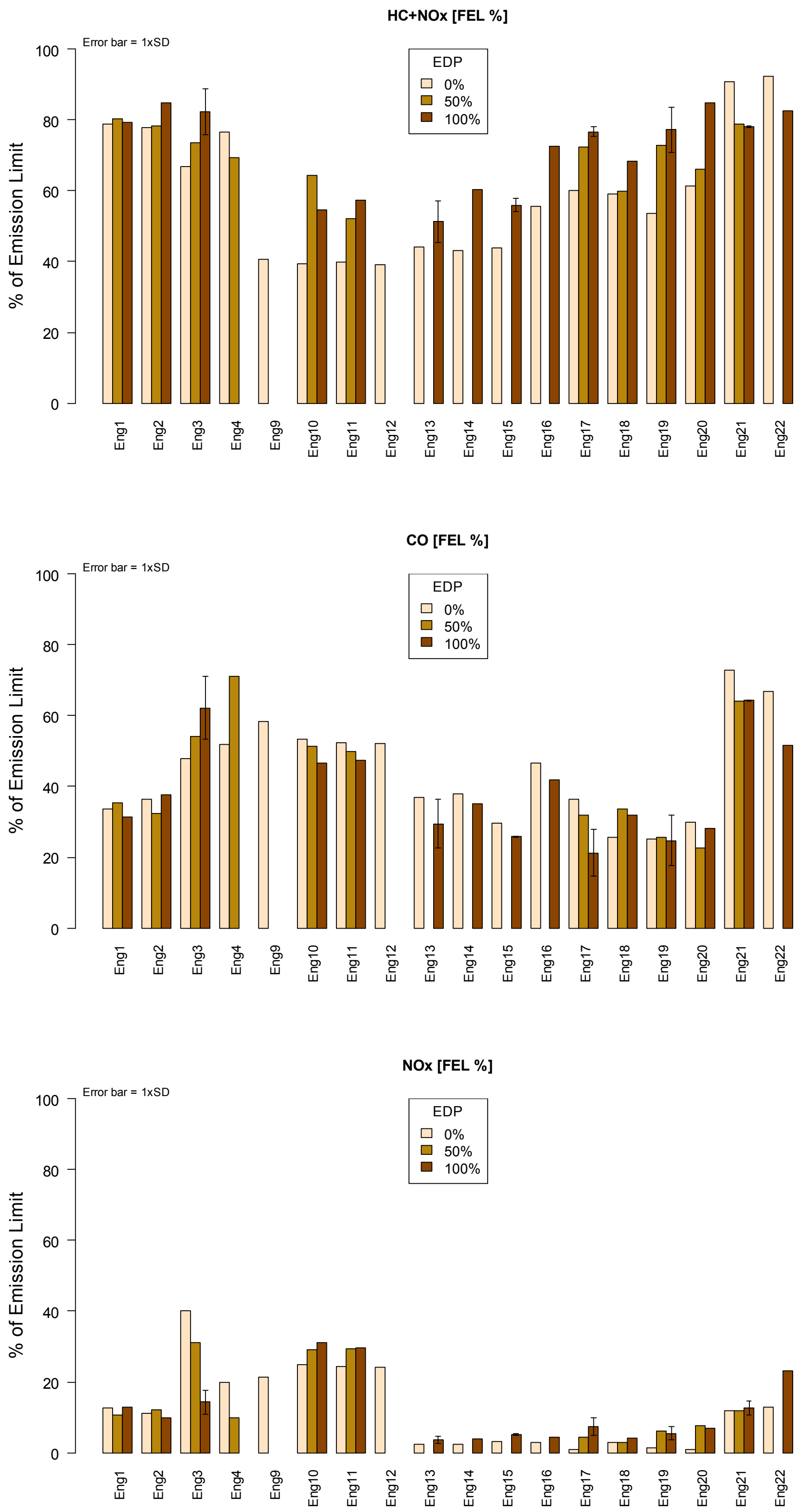
Source: OEM.

Figure 25. Summary of JRC emission tests.



Source: JRC.

Figure 26. Summary of OEM emission tests.



Source: OEM.

3.7.2 Field vs Robot ageing

The main scope of the In-service Monitoring Programme was the comparison between the two protocols for engine ageing, i.e. ageing in the test cell with an automated procedure (robot) or ageing directly in the field during normal service performed by professionals. OEMs were in charge to carry out the 2 ageing procedures on their own engines. All OEMs provided pairs of field- and robot-aged engines, see Table 3. In order to quantify the severity of the ageing procedure, the ratios of 100% EDP to 0% EDP emissions were compared for engines of the same model and different ageing methods and results are reported in Table 17. In case values at 100% EDP were missing, like for Eng4, the 50 % EDP to 0% EDP emission ratios were used. When emissions at 0% EDP were larger than both at 50% and 100%, and 50% EDP emissions were lower than at 100%, the ratios of 100% EDP to 50% EDP emissions were used (e.g. Eng20, CO from OEM tests). We considered the severity of ageing for HC+NOx and CO separately and also separately for JRC and OEM measurements.

Considering JRC testing (2 pairs of engines, Eng1 to Eng4), the largest 3 emission increases were a result of field ageing. The most severe ageing followed the field service of Eng1 considering both HC+NOx and CO emission levels (emission ratio = 1.04 and 1.6, respectively). The comparisons of the two pairs of engines, Eng1 versus Eng2 and Eng3 versus Eng4, indicated that field ageing was more severe than robot ageing, except for CO of Eng3 and Eng4 for which the ratio was not determinable due to emission decrease after ageing for both engines. The discrepancy between field and robot ageing was however not pronounced (about 10%) and considerable only for CO of Eng1 (above 50%). Therefore, based also on the limited dataset, we can conclude that field ageing was slightly more severe than robot ageing.

Considering OEM testing, the comparison could be performed on 8 pairs of engines. The largest emission increase with ageing was observed for HC+NOx of Eng11 (robot) and Eng19 (field) with ratio = 1.44 for both engines. The comparison of HC+NOx emissions of engine pairs yielded 2x robot cases versus 2x field cases of more severe ageing procedure. In terms of CO, the 100% EDP to 0% EDP largest emission ratios were equally distributed between field and robot ageing, with the largest emission increases related to Eng4 (robot) and Eng3 (field). A comparison of the engine pairs yielded 2x robot cases of ageing severity. Overall, the field and robot ageing severity were similar when HC+NOx was considered, while more severe ageing was associated to robot ageing when CO was considered. Therefore we can conclude that robot ageing was slightly more severe than field ageing only when CO was considered as discriminant.

Overall, the field and robot ageing technique were similar in terms of severity, but results based on JRC and OEM measurements were not in full agreement. JRC results pointed in the direction of field ageing, while OEM results pointed in the direction of robot ageing.

Table 17. Field vs Robot ageing. Engines are split into OEM groups. The ratio 100% EDP (50% when missing) to 0% EDP was calculated for HC+NOx and CO separately. 50% EDP was used when 0% EDP was larger than aged values. Eng13 to Eng16 and Eng17 to Eng20 were averaged based on ageing type.

			JRC				OEM			
Engine	**Type**	**Ageing**	**Ratio HC+NOx**	**Severity**	**Ratio CO**	**Severity**	**Ratio HC+NOx**	**Severity**	**Ratio CO**	**Severity**
Eng1	Chainsaw	Field	1.04	Field	1.60	Field	1.01		0.93	
Eng2	Chainsaw	Robot	0.94		0.66		1.09	Robot	1.04	Robot
Eng3	Chainsaw	Field	1.00	Field	0.75	NA	1.23	Field	1.30	
Eng4	Chainsaw	Robot	0.90		0.96	NA	0.91		1.37	Robot
Eng9	Mower	NA	NA	NA	NA	NA	NA		NA	NA
Eng10	Mower	Field	NA	NA	NA	NA	1.39		0.87	
Eng11	Mower	Robot	NA	NA	NA	NA	1.44	Robot	0.90	
Eng12	Mower	NA	NA	NA	NA	NA	NA		NA	
Eng13	Blower	Field	NA	NA	NA	NA	1.16	Equal	0.80	NA
Eng14	Blower	Field	NA	NA	NA	NA	1.40		0.93	
Eng15	Blower	Robot	NA	NA	NA	NA	1.28		0.87	
Eng16	Blower	Robot	NA	NA	NA	NA	1.31		0.90	
Eng17	Chainsaw	Robot	NA	NA	NA	NA	1.28	Field	0.58	Equal
Eng18	Chainsaw	Robot	NA	NA	NA	NA	1.15		1.24	
Eng19	Chainsaw	Field	NA	NA	NA	NA	1.44		0.99	
Eng20	Chainsaw	Field	NA	NA	NA	NA	1.38		1.24	
Eng21	Chainsaw	Robot	NA	NA	NA	NA	0.86	NA	0.88	NA
Eng22	Chainsaw	Field	NA	NA	NA	NA	0.89		0.77	

Source: JRC and OEM.

3.7.3 JRC versus OEM

All common emission tests independently performed at JRC and OEM facilities were grouped together for comparison and displayed in Figure 27. JRC deployed the raw exhaust sampling method for the analysis of pollutants, while OEMs testing was predominantly performed with the diluted gas method and few tests with the raw gas analysis. In detail, emission results as percentage of the family emission limit were plotted for 19 equal test conditions in terms of engine and ageing step (0%, 50%, 100% EDP, color-coded). Blowers were characterized by the largest discrepancy of HC+NOx, likely due to the different exhaust sampling methods (raw versus diluted gas sampling), as explained in section 3.3. However, CO and NOx results for blowers were in the range of variability of the other engine types. At a glance, JRC measured larger HC+NOx, smaller CO and smaller NOx values than OEMs.

In order to quantify the discrepancy between JRC and OEM results, Table 18 reports per-test deviations and a summary of all common tests with averages, minimum and maximum values and mean absolute deviation (MAD). As expected, NOx measurements exhibited the largest MAD (60%), mainly due to two outlier values and to the uncertainty of NOx analysers, which is larger for small NOx concentrations typical of small gasoline engines. HC+NOx and CO deviations were instead described by MAD=13% and MAD=19%, respectively, which we consider a remarkable good agreement, in the case of HC+NOx similar to the 10% variability associated to repeated tests at JRC with raw exhaust sampling method.

A subset of the dataset previously used to compare JRC and OEM emission tests can give indications on the agreement between raw (JRC) and diluted (OEM) gas sampling analyses. Test conditions are summarized in Table 18 excluding entries labelled with an asterisk "(*)". Results are very similar to the JRC vs OEM comparison with MAD = 58%, 15%, and 21% for NOx, HC+NOx and CO, respectively. MAD for NOx decreased to 37% after the 2 outliers were excluded, which we still consider a bad agreement. Apart from measurements of NOx at low concentrations like in this measurement campaign, the 2 techniques were found in reasonably good agreement.

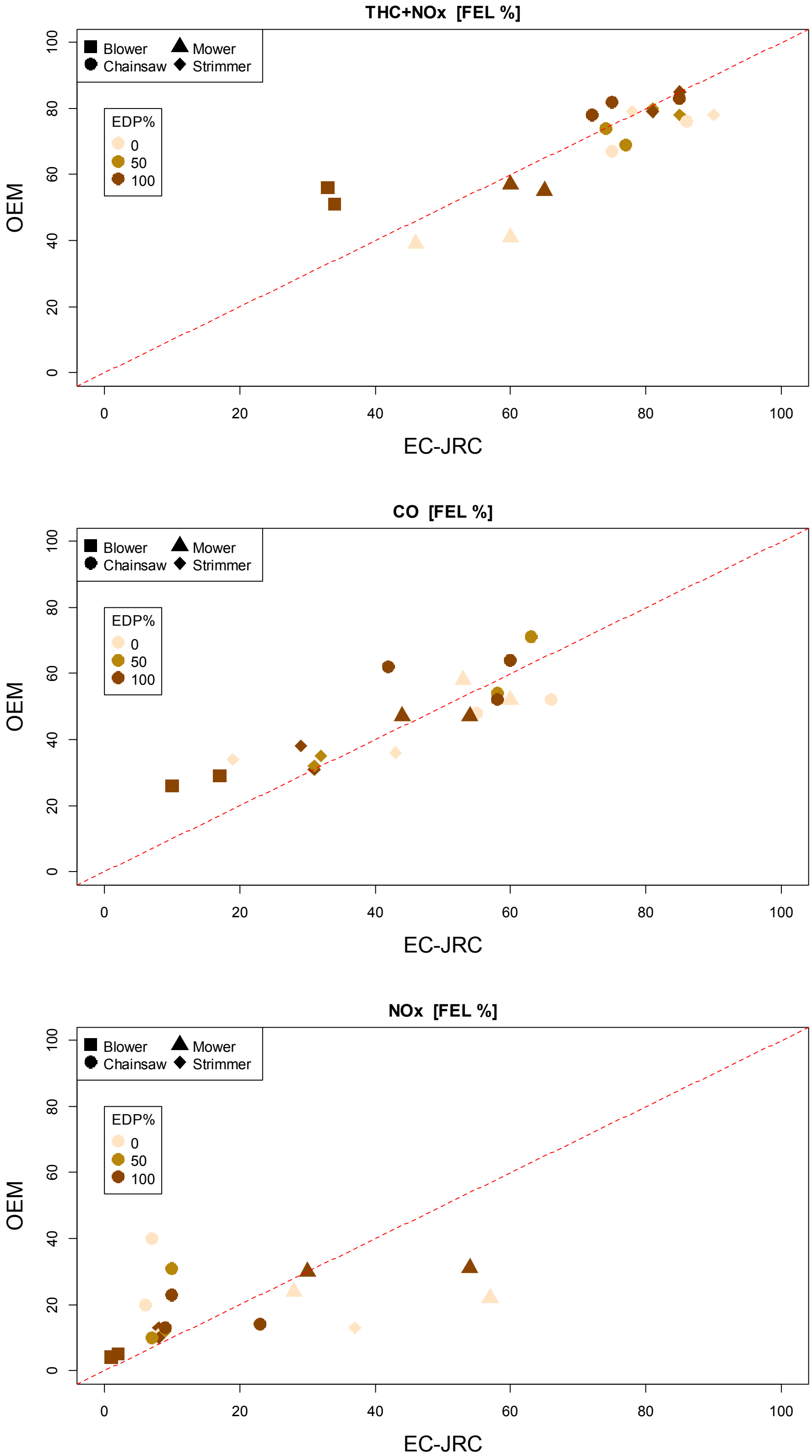
Table 18. Summary of percentage deviations between JRC and OEM emission test results for all common tests performed during the measurement campaign. Positive values in the columns named "Delta" are for JRC results larger than OEM. Absolute values are also reported together with overall averages, minimum and maximum values.

Engine	**EDP**	**Type**	**Delta (JRC/OEM)**			**Abs.Delta**		
			NOx	**HC+ NOx**	**CO**	**NOx**	**HC+ NOx**	**CO**
Eng1	0	Strimmer	196	-1	-42	196	1	42
Eng1	50	Strimmer	-22	1	-9	22	1	9
Eng1	100	Strimmer	-41	2	-1	41	2	1
Eng2	0	Strimmer	-25	16	18	25	16	18
Eng2	50	Strimmer	-28	9	-5	28	9	5
Eng2	100	Strimmer	-24	0	-24	24	0	24
Eng3(*)	0	Chainsaw	-81	12	16	81	12	16
Eng3(*)	50	Chainsaw	-67	1	8	67	1	8
Eng3	100	Chainsaw	58	-9	-33	58	9	33
Eng4(*)	0	Chainsaw	-70	12	27	70	12	27
Eng4(*)	50	Chainsaw	-34	11	-11	34	11	11
Eng9	0	Mower	165	47	-9	165	47	9
Eng10	100	Mower	71	19	-6	71	19	6
Eng11	100	Mower	2	4	14	2	4	14
Eng12	0	Mower	18	18	15	18	18	15
Eng13	100	Blower	-80	-34	-43	80	34	43
Eng15	100	Blower	-66	-42	-63	66	42	63
Eng21	100	Chainsaw	-25	-8	-7	25	8	7
Eng22(*)	100	Chainsaw	-56	3	13	56	3	13
Av.all			**-6**	**3**	**-8**	**59**	**13**	**19**
min			-81	-42	-63	2	0	1
max			196	47	27	196	47	63

(*) Tests to be excluded in the raw sampling vs diluted sampling comparison.

Source: JRC and OEM.

Figure 27. Comparison of emissions measured by JRC and OEMs for of all common tests. Red dashed line = 1:1 line.

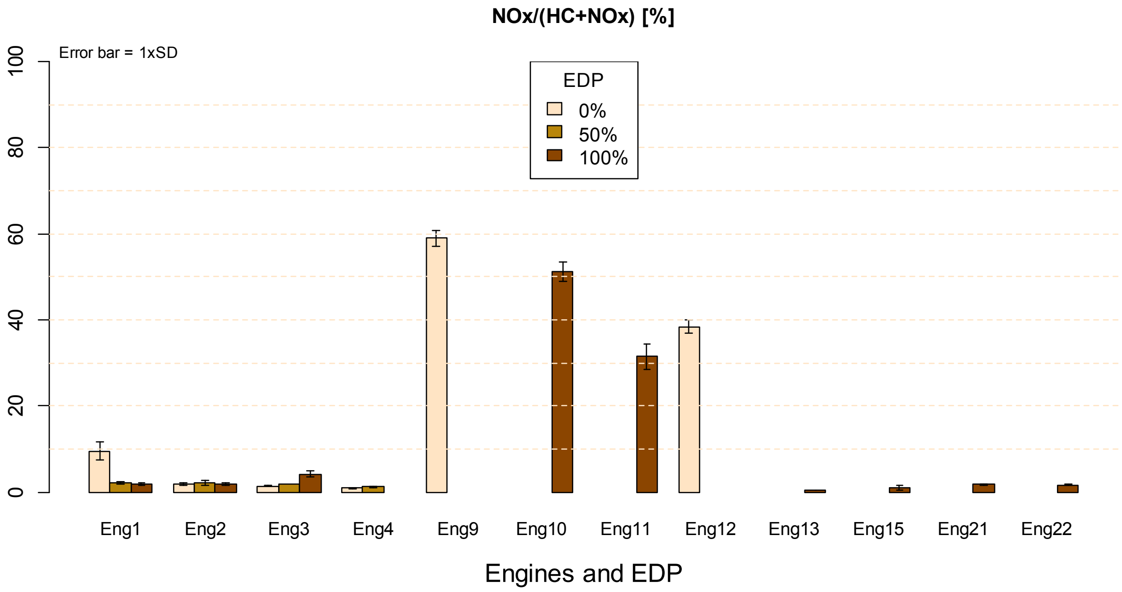


Source: JRC and OEM.

3.7.4 NOx contribution to HC+NOx emissions

Regulation (EU) 2016/1628 does not include a separate limit for NOx as it was the case with previous Stage II of Directive 97/68/EC and following amendments which did set a general limit value of 10 g/kWh for NOx (valid for all SH and SN classes) in addition to the specific HC+NOx limit. From basic principles, small spark ignition engines are large emitters of NOx compared to other engine classes (e.g., larger diesel engines). Nevertheless, given the importance of NOx in air quality management, it is informative to evaluate the NOx contribution to the HC+NOx emissions as in Figure 28. All tests at JRC show that the NOx contribution is below 10% for 2-stroke engines, while it can reach up to 60% in the case of 4-stroke engines.

Figure 28. Fraction (%) of NOx to HC+NOx emissions. Eng9 to Eng12 are 4-stroke engines.



Source: JRC.

4 Conclusions

In the framework of the new Regulation (EU) 2016/1628 we carried out an In-service Monitoring (ISM) Programme to monitor the emissions of 22 small engines (rated power < 19 kW) commonly used in gardening and forestry operations such as chainsaws, string trimmers, lawn mowers and blowers. Engines belonged to classes SH:2, SH:3 and SN:3 as per Stage II of Directive 97/68/EC, corresponding to classes NRSh-v-1a NRSh-v-1b and NRS-vr-1a as per Regulation (EU) 2016/1628. The engines were emission tested at 3 steps of their emission durability period (EDP), namely at 0%, 50% and 100% of the prescribed EDP. Manufacturers voluntarily provided the engines and carried out their ageing via 2 different methods: automated procedure in the test cell and directly in the field with normal engine operations. In the following, results are schematically summarized.

General

All engines complied with the emission limits prescribed for HC, CO and NOx at each and every step of the ageing procedure (EDP = 0%, 50%, 100%).

Field vs Robot ageing

Tests performed at JRC showed that the field ageing was more severe than robot ageing considering both HC+NOx and CO. However, the conclusion is based on a small dataset (2 pairs of engines). Tests performed by the OEMs showed that in terms of HC+NOx field and robot ageing were equivalent, while robot ageing is more severe than field ageing when considering CO.

All in all, the bench and field procedures seem to induce very similar ageing, with slightly larger increase in the measured emissions after field ageing.

Emission reduction

A potential for the reduction of the exhaust emissions was estimated based on the gap between the emission limit values and the emission results obtained during the ISM pilot programme for the chemical components considered by the legislation. Two scenarios are given, one based on maximum obtained emissions (conservative approach), and one based on the average emissions. The latter one is prone to statistical instability due to the small size of the sample.

Following the conservative approach, the reduction potentials were:

— 10% for HC+NOx (from both JRC and OEM results);

— 30% for CO (from both JRC and OEM results);

— 40% for NOx from JRC results and 60% for NOx from OEM results.

Following the approach based on average emissions, the reduction potentials were:

— 30% for HC+NOx (from both JRC and OEM results);

— 50% for CO (from both JRC and OEM results);

— 75% for NOx from JRC results and 85% for NOx from OEM results.

JRC vs OEM

A good overall agreement was established between JRC and OEM results in terms of HC+NOx (mean absolute deviation, MAD = 13%) and CO (MAD = 19%). Concerning NOx, the agreement was poorer (overall MAD = 60%, and MAD = 37% after excluding 2 outliers).

EUROMOT additional data

Emission data provided by EUROMOT (not measured during the ISM Programme, see section 3.6) showed that the HC+NOx reduction potential was 30% for SN:3 and SN:4 engines and 15% for SH:3 engines. No conclusion can be inferred for SH:2 engines as the emission values of several engines were less than 10% below the limit value.

5 Recommendations

Based on the experimental results included in this report and considering the existing legislation dealing with type-approval durability tests (Regulation (EU) 2016/1628), we strongly recommend that:

— An In-service Monitoring procedure should not be applied to engine classes NRSh-v-1a ([9]), NRSh-v-1b ([10]), and NRS-vr-1a ([11]) as it is already prescribed by the current legislation that the emissions should be measured over the whole emission durability period in order to pass the type-approval.

— In case of new engine models, or a new engine family, the manufacturer should demonstrate to the technical service during the type-approval that the automated ageing procedure (robot ageing) and the ageing during normal service are equivalent or that robot ageing is more severe.

— A standardized ageing cycle needs to be defined ([12]).

— A wider pilot programme comparing both protocols for engine ageing (i.e. ageing in the test cell with an automated procedure (robot) or ageing directly in the field during normal service performed by professionals) involving the most recent engine models should be repeated every 5 years in order to ensure that the durability procedure is suitable and effective to control pollutant emissions over the useful life of the engines.

Additional recommendations not directly linked to the In-service Monitoring procedure are as follows:

— The use of an alkylated fuel (an environmentally improved fuel with only trace content of aromatic compounds) instead of standard gasoline can be considered in order to improve the quality of emitted hydrocarbons (see Annex 4). Basic principles and scientific peer-reviewed literature indicate a dramatic reduction or no detection in the exhaust emissions of (i) aromatic compounds such as toluene and benzene (carcinogenic to humans), (ii) polycyclic aromatic hydrocarbons (PAH), and (iii) secondary organic aerosols (SOA, even though SOA emissions were measured on different engines from those studied hereby).

— A durability study aiming to assess the effect of the alkylate fuel on the durability requirements applicable to small engines would be highly desirable. As far as the authors are aware, at present no such study has been yet carried out.

Regulators may additionally consider:

— Reduction of the emission limit values of total hydrocarbons, carbon monoxide and nitrogen oxides for the engine classes NRSh-v-1a, NRSh-v-1b, and NRS-vr-1a in line with the findings of this report.

— The separation in total hydrocarbons and nitrogen oxides of the HC+NOx limit value, as the NOx limit is not present for small engines in Regulation (EU) 2016/1628 (NOx limit = 10 g/kWh in the previous legislation).

([9]) Small hand-held engines with rated power below 19 kW and swept volume below 50 cm^3.

([10]) Small hand-held engines with rated power below 19 kW and swept volume larger or equal to 50 cm^3.

([11]) Small non-hand-held engines with rated power below 19 kW and swept volume between 80 cm^3 and 225 cm^3.

([12]) The Air Resource Board of the State of California (CARB) prescribes that "Accumulation of durability hours for SI engines will be done using the existing certification test cycles (and approved alternative cycles) and weighting factors. The cycle used must be stated in the application for certification […]. Alternative service accumulation methods, e.g., accelerated ageing, component bench ageing, etc., are acceptable subject to advance approval by the ARB". See CARB (1999).

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List of abbreviations and definitions

CO = Carbon monoxide

CO_2 = Carbon dioxide

DG-GROWTH = Directorate General Internal Market, Industry, Entrepreneurship and SMEs

DF = Deterioration Factor

EC = European Commission

JRC = Joint Research Centre (of the European Commission)

EDP = Emission Durability Period

EU = European Union

EUROMOT = European Association of Engines Manufacturers

FEL = Family Emission Limit

HC = (Total) hydrocarbons, also referred to as THC

ISM = In-service Monitoring (programme)

JRC = Joint Research Centre (at EC)

OEM = Original Equipment Manufacturer

NOx = Oxides of Nitrogen

NH (engine) = Non-handheld (engine)

NRMM = Non-Road Mobile Machinery

NRS = Non-road small engine

NRSh = Non-road, small hand-held engine

PAH = Polycyclic aromatic compounds

PM = Particle Mass

SH (engine) = Small hand-held (engine)

SOA = Secondary Organic Aerosols

THC = total hydrocarbons, also referred to as HC

VELA = Vehicle Emissions Laboratories (of the JRC)

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Annexes

Annex 1. Emission data from EC-JRC testing

The data presented in this Annex were plotted and discussed in section 3.

Table 19. Emission test results for OEM-1 at EC-JRC.

Test No.	Engine	OEM	EDP [%]	HC g/kWh	NOx g/kWh	HC+ NOx g/kWh	CO g/kWh	CO2 g/kWh
4	Eng1	OEM-1	0	35.15	4.00	39.15	140.68	1038.41
5	Eng1	OEM-1	0	35.13	4.53	39.67	147.29	1043.65
6	Eng1	OEM-1	0	34.62	3.81	38.43	151.12	1015.31
7	Eng1	OEM-1	0	35.17	5.11	40.28	141.01	1055.75
8	Eng1	OEM-1	0	36.40	2.40	38.79	186.54	1019.62
9	Eng1	OEM-1	0	34.36	3.33	37.69	150.32	1000.52
10	Eng1	OEM-1	0	35.74	2.93	38.67	175.30	988.94
14	Eng2	OEM-1	0	44.27	0.94	45.21	338.76	918.01
15	Eng2	OEM-1	0	44.89	0.78	45.67	371.86	881.17
17	Eng2	OEM-1	0	43.15	0.94	44.09	348.79	909.98
18	Eng2	OEM-1	0	43.52	0.76	44.27	321.32	895.91
19	Eng2	OEM-1	0	45.29	0.76	46.06	352.59	877.69
93	Eng2	OEM-1	50	41.37	1.11	42.48	209.82	929.47
94	Eng2	OEM-1	50	43.56	0.71	44.28	275.36	885.81
95	Eng2	OEM-1	50	40.19	0.80	40.99	258.74	893.02
96	Eng1	OEM-1	50	41.09	0.71	41.80	286.78	848.74
97	Eng1	OEM-1	50	37.00	0.85	37.85	254.78	867.69
98	Eng1	OEM-1	50	40.65	0.95	41.60	237.13	867.69
176	Eng2	OEM-1	100	41.89	0.68	42.57	242.56	872.95
177	Eng2	OEM-1	100	42.31	0.64	42.95	245.44	866.63
178	Eng2	OEM-1	100	41.70	0.77	42.47	226.84	878.62
179	Eng2	OEM-1	100	40.40	0.96	41.36	206.09	892.86
180	Eng1	OEM-1	100	41.45	0.55	42.00	275.06	817.34
181	Eng1	OEM-1	100	39.96	0.74	40.70	246.58	836.57
182	Eng1	OEM-1	100	39.15	0.88	40.03	237.39	840.91
183	Eng1	OEM-1	100	39.57	0.87	40.44	245.08	832.36
184	Eng1	OEM-1	100	39.39	0.77	40.16	241.54	836.62

Source: JRC.

Table 20. Emission test results for OEM-2 at EC-JRC.

Test No.	Engine	OEM	EDP [%]	HC g/kWh	NOx g/kWh	HC+ NOx g/kWh	CO g/kWh	CO2 g/kWh
23	Eng3	OEM-2	0	54.02	0.70	54.72	343.43	795.17
24	Eng3	OEM-2	0	53.73	0.76	54.49	329.98	790.21
25	Eng3	OEM-2	0	51.76	0.77	52.53	329.10	789.13
26	Eng3	OEM-2	0	54.61	0.57	55.19	378.58	754.07
27	Eng3	OEM-2	0	57.23	0.43	57.66	429.57	708.50
28	Eng3	OEM-2	0	54.33	0.48	54.81	386.52	745.94
29	Eng3	OEM-2	0	53.12	0.49	53.61	374.15	745.59
30	Eng3	OEM-2	0	53.64	0.49	54.14	378.02	747.36
31	Eng3	OEM-2	0	51.49	0.54	52.03	367.07	761.17
32	Eng3	OEM-2	0	58.10	0.71	58.81	384.33	757.55
33	Eng3	OEM-2	0	55.62	0.70	56.32	373.67	753.33
34	Eng3	OEM-2	0	51.26	0.46	51.72	334.59	726.46
35	Eng3	OEM-2	0	45.14	0.56	45.70	270.80	745.85
36	Eng3	OEM-2	0	43.87	0.84	44.71	235.42	775.52
37	Eng4	OEM-2	0	65.07	0.40	65.47	467.06	722.82
38	Eng4	OEM-2	0	65.91	0.45	66.36	465.13	725.95
39	Eng4	OEM-2	0	64.35	0.43	64.78	457.01	724.61
40	Eng4	OEM-2	0	67.37	0.41	67.78	486.76	714.46
41	Eng4	OEM-2	0	68.47	0.39	68.86	483.22	721.12
42	Eng4	OEM-2	0	68.35	0.38	68.73	487.21	718.92
43	Eng4	OEM-2	0	65.82	0.22	66.04	428.03	676.58
44	Eng4	OEM-2	0	62.88	0.26	63.14	390.46	690.31
45	Eng4	OEM-2	0	62.22	0.26	62.47	387.68	696.03
46	Eng4	OEM-2	0	61.45	0.23	61.68	406.13	688.70
47	Eng4	OEM-2	0	60.13	0.25	60.39	379.91	696.33
48	Eng4	OEM-2	0	59.93	0.24	60.18	390.25	694.33
49	Eng4	OEM-2	0	55.27	0.30	55.57	359.98	716.79
50	Eng4	OEM-2	0	55.65	0.30	55.94	363.82	715.17
51	Eng4	OEM-2	0	55.29	0.29	55.57	368.67	716.58
52	Eng4	OEM-2	0	54.42	0.39	54.81	300.60	737.59
53	Eng4	OEM-2	0	51.71	0.69	52.40	239.87	772.56
54	Eng4	OEM-2	0	55.62	0.35	55.97	317.71	724.92
55	Eng4	OEM-2	0	57.15	0.33	57.48	348.66	709.94
56	Eng4	OEM-2	0	58.01	0.29	58.31	358.69	698.25
57	Eng4	OEM-2	0	51.89	0.41	52.30	292.60	735.28
58	Eng4	OEM-2	0	59.39	0.29	59.68	386.68	685.61
59	Eng4	OEM-2	0	56.76	0.35	57.11	350.23	701.46
60	Eng4	OEM-2	0	58.45	0.33	58.78	361.24	694.10
61	Eng4	OEM-2	0	61.70	0.57	62.27	402.30	728.03
62	Eng4	OEM-2	0	62.56	0.55	63.11	414.26	720.50
63	Eng4	OEM-2	0	58.93	0.67	59.60	370.88	745.05
123	Eng4	OEM-2	50	56.72	0.64	57.36	396.35	773.16
124	Eng4	OEM-2	50	54.78	0.67	55.45	372.62	763.76

125	Eng4	OEM-2	50	53.28	0.67	53.96	372.90	761.94
126	Eng3	OEM-2	50	52.53	1.03	53.56	351.08	800.55
185	Eng3	OEM-2	100	52.76	1.96	54.73	263.07	804.93
186	Eng3	OEM-2	100	51.33	2.68	54.01	238.12	817.82
187	Eng3	OEM-2	100	51.03	2.13	53.17	253.95	803.77
188	Eng21	OEM-2	100	52.44	1.00	53.45	353.91	724.11
189	Eng21	OEM-2	100	49.39	0.98	50.37	356.36	740.13
190	Eng21	OEM-2	100	50.04	0.86	50.91	374.85	738.43
191	Eng22	OEM-2	100	60.40	1.12	61.52	344.30	740.20
192	Eng22	OEM-2	100	60.30	1.08	61.38	340.82	739.55
193	Eng22	OEM-2	100	60.65	1.02	61.67	350.14	740.45
194	Eng22	OEM-2	100	60.65	0.83	61.48	373.93	729.05
195	Eng13	OEM-2	100	17.39	0.07	17.47	138.57	1001.00
196	Eng13	OEM-2	100	16.80	0.07	16.87	136.88	1026.31
197	Eng13	OEM-2	100	16.35	0.07	16.42	131.13	1027.37
198	Eng15	OEM-2	100	20.88	0.15	21.03	121.77	1050.03
199	Eng15	OEM-2	100	17.27	0.09	17.36	86.61	1067.19
200	Eng15	OEM-2	100	14.70	0.29	14.99	38.80	1026.97
201	Eng15	OEM-2	100	13.66	0.19	13.84	44.26	1079.81
202	Eng15	OEM-2	100	14.21	0.15	14.36	96.21	1035.09

Source: JRC.

Table 21. Emission test results for OEM-4 at EC-JRC.

Test No.	Engine code	OEM	EDP [%]	HC g/kWh	NOx g/kWh	HC+ NOx g/kWh	CO g/kWh	CO2 g/kWh
128	Eng9	OEM-4	0	3.79	5.22	9.02	328.64	909.68
129	Eng9	OEM-4	0	3.59	5.57	9.16	306.09	885.36
130	Eng9	OEM-4	0	3.98	6.07	10.05	322.52	927.85
131	Eng9	OEM-4	0	4.46	5.91	10.37	338.46	955.09
132	Eng10	OEM-4	100	4.95	5.07	10.02	254.59	953.52
133	Eng10	OEM-4	100	4.65	5.60	10.25	250.03	970.20
134	Eng10	OEM-4	100	5.53	5.57	11.10	286.75	1036.35
135	Eng10	OEM-4	100	5.22	5.16	10.38	279.70	965.64
136	Eng11	OEM-4	100	6.54	2.93	9.47	341.91	919.33
137	Eng11	OEM-4	100	6.38	3.20	9.58	321.82	928.71
138	Eng11	OEM-4	100	6.24	3.24	9.48	324.90	944.40
139	Eng11	OEM-4	100	7.17	2.74	9.91	321.82	946.38
152	Eng12	OEM-4	0	4.21	2.91	7.12	339.50	885.79
153	Eng12	OEM-4	0	4.81	2.89	7.69	373.04	899.33
154	Eng12	OEM-4	0	4.63	2.77	7.40	370.79	859.77
155	Eng12	OEM-4	0	4.62	2.81	7.43	372.08	871.10

Source: JRC.

Annex 2. Emission data provided by manufacturers

Table 22. Emission data provided by manufacturers.

OEM	Eng	Class	Facility	Samp-ling	EDP [%]	Ageing	JRC(1)	HC g/kwh	NOx g/kwh	HC+ NOx g/kwh	CO g/kwh	CO2 g/kwh
OEM-1	Eng1	SH2	OEM-1	CVS	0	Field	Y	38.17	1.26	39.42	269.80	918.00
OEM-1	Eng1	SH2	OEM-1	CVS	50	Field	Y	39.07	1.07	40.14	285.29	840.00
OEM-1	Eng1	SH2	OEM-1	CVS	100	Field	Y	38.40	1.29	39.70	251.61	851.00
OEM-1	Eng2	SH2	OEM-1	CVS	0	Robot	Y	37.81	1.11	38.92	293.10	906.00
OEM-1	Eng2	SH2	OEM-1	CVS	50	Robot	Y	37.93	1.21	39.13	260.51	914.00
OEM-1	Eng2	SH2	OEM-1	CVS	100	Robot	Y	41.42	1.00	42.42	303.68	869.00
OEM-2	Eng3	SH3	OEM-2	Raw	0	Field	Y	44.1	4	48.10	288.00	801
OEM-2	Eng3	SH3	OEM-2	Raw	50	Field	Y	49.9	3.1	53.00	326.00	770
OEM-2	Eng3	SH3	OEM-2	Raw	100	Field	Y	52.7	1.8	54.50	318.00	837
OEM-2	Eng3	SH3	OEM-2	CVS	100	Field	Y+W	62.72	1.14	63.86	423.30	759.38
OEM-2	Eng3	SH3	OEM-2	CVS	100	Field	Y+C	57.91	1.36	59.27	383.64	735.16
OEM-2	Eng4	SH2	OEM-2	Raw	0	Robot	Y	53.2	2	55.05	312.35	791
OEM-2	Eng4	SH2	OEM-2	Raw	50	Robot	Y	48.9	1	49.9	429	705
OEM-2	Eng13	SH2	OEM-2	CVS	0	Field	N	21.87	0.24	22.10	297.68	1315.35
OEM-2	Eng13	SH2	OEM-2	CVS	100	Field	Y	28.30	0.25	28.69	287.82	1184.80
OEM-2	Eng13	SH2	OEM-2	CVS	100	Field	Y+W	24.91	0.38	25.30	244.44	1221.69
OEM-2	Eng13	SH2	OEM-2	CVS	100	Field	Y+W+C	22.40	0.45	22.86	179.33	1301.57
OEM-2	Eng14	SH2	OEM-2	CVS	0	Field	N	21.30	0.24	21.54	305.19	1254.37
OEM-2	Eng14	SH2	OEM-2	CVS	100	Field	N	29.71	0.40	30.11	282.92	1147.00
OEM-2	Eng15	SH2	OEM-2	CVS	0	Robot	N	21.56	0.32	21.88	238.97	1380.35
OEM-2	Eng15	SH2	OEM-2	CVS	100	Robot	Y	28.13	0.54	28.67	208.64	1289.01
OEM-2	Eng15	SH2	OEM-2	CVS	100	Robot	Y+W	26.80	0.49	27.29	206.66	1257.93
OEM-2	Eng16	SH2	OEM-2	CVS	0	Robot	N	27.53	0.28	27.80	375.36	1228.56
OEM-2	Eng16	SH2	OEM-2	CVS	100	Robot	N	35.89	0.45	36.34	336.01	1227.17
OEM-2	Eng21	SH3	OEM-2	Raw	0	Robot	N	64.00	1.20	65.30	439.00	729.00
OEM-2	Eng21	SH3	OEM-2	Raw	50	Robot	N	55.60	1.20	56.70	386.00	742.00

OEM-2	Eng21	SH3	OEM-2	Raw	100	Robot	Y	54.90	1.40	56.30	388.00	754.00
OEM-2	Eng21	SH3	OEM-2	CVS	100	Robot	Y+W	54.99	1.13	56.12	386.52	712.74
OEM-2	Eng22	SH3	OEM-2	Raw	0	Field	N	65.20	1.30	66.50	403.10	740.00
OEM-2	Eng22	SH3	OEM-2	Raw	100	Field	Y	57.20	2.30	59.50	311.70	814.00
OEM-3	Eng17	SH2	OEM-3	Raw	0	Robot	N	29.94	0.08	30.02	293.00	1251.20
OEM-3	Eng17	SH2	OEM-3	Raw	50	Robot	N	35.70	0.43	36.13	257.30	1024.40
OEM-3	Eng17	SH2	OEM-3	Raw	100	Robot	N	37.27	0.56	37.83	208.60	1128.00
OEM-3	Eng17	SH2	OEM-2	CVS	100	Robot	N	37.92	0.91	38.83	133.41	1116.95
OEM-3	Eng18	SH2	OEM-3	Raw	0	Robot	N	29.25	0.30	29.55	207.20	1200.20
OEM-3	Eng18	SH2	OEM-3	Raw	50	Robot	N	29.68	0.28	29.96	271.50	1117.60
OEM-3	Eng18	SH2	OEM-3	Raw	100	Robot	N	33.70	0.41	34.11	255.90	1142.50
OEM-3	Eng19	SH2	OEM-3	Raw	0	Field	N	26.66	0.14	26.80	201.70	1247.00
OEM-3	Eng19	SH2	OEM-3	Raw	50	Field	N	35.86	0.61	36.47	207.20	1054.70
OEM-3	Eng19	SH2	OEM-3	Raw	100	Field	N	35.48	0.41	35.89	240.40	1115.70
OEM-3	Eng19	SH2	OEM-2	CVS	100	Field	N	37.17	0.77	37.94	132.84	1165.41
OEM-3	Eng19	SH2	OEM-2	CVS	100	Field	N	41.65	0.47	42.12	222.91	1067.01
OEM-3	Eng20	SH2	OEM-3	Raw	0	Field	N	30.52	0.09	30.61	239.60	1271.00
OEM-3	Eng20	SH2	OEM-3	Raw	50	Field	N	32.32	0.77	33.09	182.30	1165.60
OEM-3	Eng20	SH2	OEM-3	Raw	100	Field	N	41.66	0.70	42.36	225.40	1211.50
OEM-4	Eng9	SN3	OEM-4	CVS	0	None	Y	4.40	2.15	6.55	356.58	831.06
OEM-4	Eng10	SN3	OEM-4	CVS	0	Field	N	3.84	2.49	6.33	326.04	852.67
OEM-4	Eng10	SN3	OEM-4	CVS	50	Field	N	7.46	2.91	10.37	313.98	894.77
OEM-4	Eng10	SN3	OEM-4	CVS	100	Field	Y	5.28	3.12	8.78	284.44	927.64
OEM-4	Eng11	SN3	OEM-4	CVS	0	Robot	N	3.98	2.43	6.41	319.52	836.97
OEM-4	Eng11	SN3	OEM-4	CVS	50	Robot	N	5.46	2.93	8.39	303.33	841.08
OEM-4	Eng11	SN3	OEM-4	CVS	100	Robot	Y	6.25	2.97	9.22	288.65	862.60
OEM-4	Eng12	SN3	OEM-4	CVS	0	None	Y	3.89	2.42	6.31	317.33	836.18

(1) Y = test repeated at EC-JRC at the same ageing conditions (+1 hour). N = Test not repeated at RC-JRC. W = Test witnessed by a JRC member. C = Test performed by type-approval authority at OEM facility

Source: OEM.

Annex 3. Emission data provided by EUROMOT

The European Association of Internal Combustion Engine Manufacturers (EUROMOT) provided JRC with emission data from some of their members (anonymized). The original data were rearranged and discussed in section 3.6. Please note that Annexes of the original communication contain tabulated data and do not refer to Annexes of this report.

Annex 1

Handheld Data

Family	Unit#	Prod. Date	Engine Class	Engine Application	Engine Technology	Rated Power (hp)	EDP	Estimated Hours of Use	Use vs. EDP	HC+NOx FEL (g/kW-hr)	THC+NOx Emission Results As Is (g/kW-hr)	THC+NOx Emission Results After Maintenance (g/kW-hr)	THC+NOx Field Aged (g/kW-hr)[1]	Field Aged vs. FEL	Field Mods or repairs
A	1	Mrz 01	IV	BP Blower	2S-Cat	1,57	300	300	100%	72,4	No Test	43,69	43,69	60,3%	-
A	2	Jul 02	IV	BP Blower	2S-Cat	1,57	300	300	100%	72,4	48,603	No Test	48,603	67,1%	-
A	3	Mrz 01	IV	BP Blower	2S-Cat	1,57	300	300	100%	72,4	60,89	No Test	60,89	84,1%	-
A	4	Mrz 01	IV	BP Blower	2S-Cat	1,57	300	300	100%	72,4	100,174	69,46	69,46	95,9%	-
A	5	Jul 02	IV	BP Blower	2S-Cat	1,57	300	312	104%	72,4	39,748	No Test	39,748	54,9%	-
B	1	Apr 01	IV	BP Blower	2S-Cat	2,42	300	300	100%	72,4	40,83	44,53	44,53	61,5%	-
B	2	Mrz 01	IV	BP Blower	2S-Cat	2,42	300	300	100%	72,4	92,52	53,29	53,29	73,6%	-
B	3	Jun 03	IV	BP Blower	2S-Cat	1,45	300	300	100%	72,4	54,722	No Test	54,722	75,6%	-
B	4	Jun 03	IV	BP Blower	2S-Cat	1,45	300	300	100%	72,4	62,33	No Test	62,33	86,1%	-
C	1	Feb 05	IV	Chainsaw	2S-Cat	1,04	300	300	100%	74	64,742	No Test	64,742	87,5%	-
C	2	Feb 05	IV	Chainsaw	2S-Cat	1,04	300	300	100%	74	71,826	No Test	71,826	97,1%	-
C	3	Feb 05	IV	Chainsaw	2S-Cat	1,04	300	300	100%	74	71,984	No Test	71,984	97,3%	-
D	1	Sep 98	IV	Chainsaw	2S-Cat	1,25	50	50	100%	52	43	n/a	43	82,7%	-
D	2	Sep 98	IV	Chainsaw	2S-Cat	1,25	50	50	100%	52	47	n/a	47	90,4%	-
D	3	Sep 98	IV	Chainsaw	2S-Cat	1,25	50	100	200%	52	43	n/a	43	82,7%	-
D	4	Sep 98	IV	Chainsaw	2S-Cat	1,25	50	100	200%	52	51	n/a	51	98,1%	-
E1	1	Mrz 02	IV	T/B/H	2S-Cat	0,559	300	300	100%	67	57,051	51,554	51,554	76,9%	-
E2	1	Jan 02	IV	T/B/H	2S-Cat	0,523	300	300	100%	72,4	No Test	31,194	31,194	43,1%	-
F	1	Nov 04	IV	T/B/H	E-Tech II (w/cat)	0,83	125	100,4	80%	65	41,7	46,9	46,9	72,2%	-
F	2	Nov 04	IV	T/B/H	E-Tech II (w/cat)	0,83	125	100,5	80%	65	58,4	48,5	48,5	74,6%	-
F	3	Nov 04	IV	T/B/H	E-Tech II (w/cat)	0,83	125	100,1	80%	65	59,4	49,0	49	75,4%	-
F	4	Nov 04	IV	T/B/H	E-Tech II (w/cat)	0,83	125	100	80%	65	49,2	53,5	53,5	82,3%	-
G	1	Sep 00	V	Blower	2S-Cat	2,24	300	150	50%	45	27	28	28	62,2%	-
G	2	Nov 00	V	Blower	2S-Cat	2,24	300	150	50%	45	29	28	28	62,2%	-
G	3	Okt 00	V	Blower	2S-Cat	2,24	300	150	50%	45	34	32	32	71,1%	-
G	4	Dez 00	V	Blower	2S-Cat	2,24	300	150	50%	45	32	35	35	77,8%	-
G	5	Sep 00	V	Blower	2S-Cat	2,24	300	200	67%	45	58	56	56	124,4%	Engine rich
G	6	Feb 01	V	Blower	2S-Cat	2,24	300	300	100%	45	35	32	32	71,1%	-
G	7	Sep 00	V	Blower	2S-Cat	2,24	300	300	100%	45	37	38	38	84,4%	-
H	1	Jun 04	V	Chainsaw	Strat.charge	3,95	300	229	76%	68	50,1	49,1	49,1	72,2%	-
H	2	Jun 04	V	Chainsaw	Strat.charge	3,95	300	230	77%	68	45,7	47,1	47,1	69,3%	-
H	3	Jun 04	V	Chainsaw	Strat.charge	3,95	300	292	97%	68	61,1	58,1	58,1	85,4%	Not known
H	4	Jun 04	V	Chainsaw	Strat.charge	3,95	300	430	143%	68	No Test	50,2	50,2	73,8%	Not known
I	1	Mrz 04	V	Cut-off Saw	Stratified scavenging	4,5	300	4	1%	72	43	n/a	43	59,7%	-
I	2	Mrz 04	V	Cut-off Saw	Stratified scavenging	4,5	300	15	5%	72	41	n/a	41	56,9%	-
I	3	Mrz 04	V	Cut-off Saw	Stratified scavenging	4,5	300	15	5%	72	60	n/a	60	83,3%	-
I	4	Mrz 04	V	Cut-off Saw	Stratified scavenging	4,5	300	16	5%	72	42	n/a	42	58,3%	-
I	5	Mrz 04	V	Cut-off Saw	Stratified scavenging	4,5	300	20	7%	72	43	n/a	43	59,7%	-
I	6	Mrz 04	V	Cut-off Saw	Stratified scavenging	4,5	300	21	7%	72	44	n/a	44	61,1%	-
I	7	Mrz 04	V	Cut-off Saw	Stratified scavenging	4,5	300	21	7%	72	44	n/a	44	61,1%	-
I	8	Mrz 04	V	Cut-off Saw	Stratified scavenging	4,5	300	21	7%	72	47	n/a	47	65,3%	-
I	9	Mrz 04	V	Cut-off Saw	Stratified scavenging	4,5	300	23	8%	72	43	n/a	43	59,7%	-
I	10	Mrz 04	V	Cut-off Saw	Stratified scavenging	4,5	300	58	19%	72	49	n/a	49	68,1%	-
I	11	Mrz 04	V	Cut-off Saw	Stratified scavenging	4,5	300	63	21%	72	44	n/a	44	61,1%	-
I	12	Mrz 04	V	Cut-off Saw	Stratified scavenging	4,5	300	108	36%	72	49	n/a	49	68,1%	-

[1] Data shown is after maintenance, if available. If not, data shown is "as-is"

Source: EUROMOT.

Annex 2

Non-Handheld Data

Family	Unit#	Prod. Date	Engine Class	Engine Application	Engine Technology	Rated Power* (Kw)	EDP	Estimated Hours of Use	Use vs. EDP	HC+NOx FEL (g/kW-hr)	THC+NOx Emission Results As Is (g/kW-hr)	THC+NOx Emission Results After Maintenance (g/kW-hr)	THC+NOx Field Aged (g/kW-hr)[1]	Field Aged vs. FEL	Field Mods or repairs	
B	9	Jan 16	SN:3	WB Lawn mower	4S-EM	4,2	250	0	0%	16,1	-	10,37	10,37	64,4%	Airfilter, spark plug and oil change	0
B	10	Jan 16	SN:3	WB Lawn mower	4S-EM	4,2	250	250	100%	16,1	-	10,38	10,38	64,5%	Airfilter, spark plug and oil change	field
B	11	Jan 16	SN:3	WB Lawn mower	4S-EM	4,2	250	250	100%	16,1	-	9,91	9,91	61,6%	Airfilter, spark plug and oil change	bench
B	12	Jan 16	SN:3	WB Lawn mower	4S-EM	4,2	250	0	0%	16,1	-	7,12	7,12	44,2%	Airfilter, spark plug and oil change	0
B	13	Jan 16	SN:3	WB Lawn mower	4S-EM	4,2	250	250	100%	16,1	-	9,07	9,07	56,3%	Airfilter, spark plug and oil change	bench
B	14	Jan 16	SN:3	WB Lawn mower	4S-EM	4,2	250	250	100%	16,1	-	7,98	7,98	49,6%	Airfilter, spark plug and oil change	field
B	15	Sep 16	SN:4	Ride-on lawnmower	4S-EM	13,9	500	386	77%	12,1	-	8,241	8,241	68,1%	Airfilter, spark plug and oil change	field
B	16	Nov 16	SN:4	Ride-on lawnmower	4S-EM	12,3	500	500	100%	12,1	-	7,24	7,24	59,8%	Airfilter, spark plug and oil change	bench
B	17	Nov 12	N/A	Ride-on lawnmower	4S-EM	26	1000	1000	100%	12,1	-	5,49	5,49	45,4%	Airfilter, spark plug and oil change	bench
B	18	Nov 12	N/A	Ride-on lawnmower	4S-EM	26	1000	844	84%	12,1	-	6,15	6,15	50,8%	Airfilter, spark plug and oil change	field

*Kw rated according SAE J1940

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Source: EUROMOT.

Table 23. Emission results of SH engines from several OEMs, produced by EUROMOT for US-EPA and made available to JRC.

Family	Unit	Prod. Date	Engine Class	Engine Application	Engine Techno-logy	Rated Power (hp)	EDP	Use [h]	Use / EDP [%]	HC+NOx FEL [g/kWh]	HC+NOx Emission As Is [g/kWh]	HC+NOx Emission After Maintenance [g/kWh]	HC+NOx Emissions [g/kWh]	% FEL
A	1	Mar-01	IV	BP Blower	2S-Cat	1.57	300	300	100%	72.4	No Test	43.69	43.69	60.3%
A	2	Jul-02	IV	BP Blower	2S-Cat	1.57	300	300	100%	72.4	48.603	No Test	48.603	67.1%
A	3	Mar-01	IV	BP Blower	2S-Cat	1.57	300	300	100%	72.4	60.89	No Test	60.89	84.1%
A	4	Mar-01	IV	BP Blower	2S-Cat	1.57	300	300	100%	72.4	100.174	69.46	69.46	95.9%
A	5	Jul-02	IV	BP Blower	2S-Cat	1.57	300	312	104%	72.4	39.748	No Test	39.748	54.9%
B	1	Apr-01	IV	BP Blower	2S-Cat	2.42	300	300	100%	72.4	40.83	44.53	44.53	61.5%
B	2	Mar-01	IV	BP Blower	2S-Cat	2.42	300	300	100%	72.4	92.52	53.29	53.29	73.6%
B	3	Jun-03	IV	BP Blower	2S-Cat	1.45	300	300	100%	72.4	54.722	No Test	54.722	75.6%
B	4	Jun-03	IV	BP Blower	2S-Cat	1.45	300	300	100%	72.4	62.33	No Test	62.33	86.1%
C	1	Feb-05	IV	Chainsaw	2S-Cat	1.04	300	300	100%	74	64.742	No Test	64.742	87.5%
C	2	Feb-05	IV	Chainsaw	2S-Cat	1.04	300	300	100%	74	71.826	No Test	71.826	97.1%
C	3	Feb-05	IV	Chainsaw	2S-Cat	1.04	300	300	100%	74	71.984	No Test	71.984	97.3%
D	1	Sep-98	IV	Chainsaw	2S-Cat	1.25	50	50	100%	52	43	n/a	43	82.7%
D	2	Sep-98	IV	Chainsaw	2S-Cat	1.25	50	50	100%	52	47	n/a	47	90.4%
D	3	Sep-98	IV	Chainsaw	2S-Cat	1.25	50	100	200%	52	43	n/a	43	82.7%
D	4	Sep-98	IV	Chainsaw	2S-Cat	1.25	50	100	200%	52	51	n/a	51	98.1%
E1	1	Mar-02	IV	T/B/H	2S-Cat	0.559	300	300	100%	67	57.051	51.554	51.554	76.9%
E2	1	Jan-02	IV	T/B/H	2S-Cat	0.523	300	300	100%	72.4	No Test	31.194	31.194	43.1%
F	1	Nov-04	IV	T/B/H	E-Tech II (w/cat)	0.83	125	100.4	80%	65	41.7	46.9	46.9	72.2%
F	2	Nov-04	IV	T/B/H	E-Tech II (w/cat)	0.83	125	100.5	80%	65	58.4	48.5	48.5	74.6%
F	3	Nov-04	IV	T/B/H	E-Tech II (w/cat)	0.83	125	100.1	80%	65	59.4	49.0	49	75.4%
F	4	Nov-04	IV	T/B/H	E-Tech II (w/cat)	0.83	125	100	80%	65	49.2	53.5	53.5	82.3%
G	1	Sep-00	V	Blower	2S-Cat	2.24	300	150	50%	45	27	28	28	62.2%
G	2	Nov-00	V	Blower	2S-Cat	2.24	300	150	50%	45	29	28	28	62.2%

G	3	Oct-00	V	Blower	2S-Cat	2.24	300	150	50%	45	34	32	32	71.1%
G	4	Dec-00	V	Blower	2S-Cat	2.24	300	150	50%	45	32	35	35	77.8%
G	5	Sep-00	V	Blower	2S-Cat	2.24	300	200	67%	45	58	56	56	124.4%
G	6	Feb-01	V	Blower	2S-Cat	2.24	300	300	100%	45	35	32	32	71.1%
G	7	Sep-00	V	Blower	2S-Cat	2.24	300	300	100%	45	37	38	38	84.4%
H	1	Jun-04	V	Chainsaw	Strat.charge	3.95	300	229	76%	68	50.1	49.1	49.1	72.2%
H	2	Jun-04	V	Chainsaw	Strat.charge	3.95	300	230	77%	68	45.7	47.1	47.1	69.3%
H	3	Jun-04	V	Chainsaw	Strat.charge	3.95	300	292	97%	68	61.1	58.1	58.1	85.4%
H	4	Jun-04	V	Chainsaw	Strat.charge	3.95	300	430	143%	68	No Test	50.2	50.2	73.8%
I	1	Mar-04	V	Cut-off Saw	Stratified scavenging	4.5	300	4	1%	72	43	n/a	43	59.7%
I	2	Mar-04	V	Cut-off Saw	Stratified scavenging	4.5	300	15	5%	72	41	n/a	41	56.9%
I	3	Mar-04	V	Cut-off Saw	Stratified scavenging	4.5	300	15	5%	72	60	n/a	60	83.3%
I	4	Mar-04	V	Cut-off Saw	Stratified scavenging	4.5	300	16	5%	72	42	n/a	42	58.3%
I	5	Mar-04	V	Cut-off Saw	Stratified scavenging	4.5	300	20	7%	72	43	n/a	43	59.7%
I	6	Mar-04	V	Cut-off Saw	Stratified scavenging	4.5	300	21	7%	72	44	n/a	44	61.1%
I	7	Mar-04	V	Cut-off Saw	Stratified scavenging	4.5	300	21	7%	72	44	n/a	44	61.1%
I	8	Mar-04	V	Cut-off Saw	Stratified scavenging	4.5	300	21	7%	72	47	n/a	47	65.3%
I	9	Mar-04	V	Cut-off Saw	Stratified scavenging	4.5	300	23	8%	72	43	n/a	43	59.7%
I	10	Mar-04	V	Cut-off Saw	Stratified scavenging	4.5	300	58	19%	72	49	n/a	49	68.1%
I	11	Mar-04	V	Cut-off Saw	Stratified scavenging	4.5	300	63	21%	72	44	n/a	44	61.1%
I	12	Mar-04	V	Cut-off Saw	Stratified scavenging	4.5	300	108	36%	72	49	n/a	49	68.1%

Source: EUROMOT.

Table 24. Emission results from one OEM recently made available to EUROMOT.

Unit[(1)]	Prod. Date	Engine Class	Engine Application	Engine Techno-logy	Rated Power[(2)] [kW]	EDP [h]	Use [h]	Use / EDP [%]	HC+NOx FEL [g/kWh]	HC+NOx Emissions[(3)] [g/kWh]	% of FEL	Ageing
9	Jan-16	SN:3	WB Lawn mower	4S-EM	4.2	250	0	0%	16.1	10.37	64.4%	0
10	Jan-16	SN:3	WB Lawn mower	4S-EM	4.2	250	250	100%	16.1	10.38	64.5%	field
11	Jan-16	SN:3	WB Lawn mower	4S-EM	4.2	250	250	100%	16.1	9.91	61.6%	bench
12	Jan-16	SN:3	WB Lawn mower	4S-EM	4.2	250	0	0%	16.1	7.12	44.2%	0
13	Jan-16	SN:3	WB Lawn mower	4S-EM	4.2	250	250	100%	16.1	9.07	56.3%	bench
14	Jan-16	SN:3	WB Lawn mower	4S-EM	4.2	250	250	100%	16.1	7.98	49.6%	field
15	Sep-16	SN:4	Ride-on lawnmower	4S-EM	13.9	500	386	77%	12.1	8.241	68.1%	field
16	Nov-16	SN:4	Ride-on lawnmower	4S-EM	12.3	500	500	100%	12.1	7.24	59.8%	bench

(1) All Units from a single OEM
(2) kW rated according SAE J1940
(3) After maintenance for all Units: Air filter, spark plug and oil change

Source: EUROMOT.

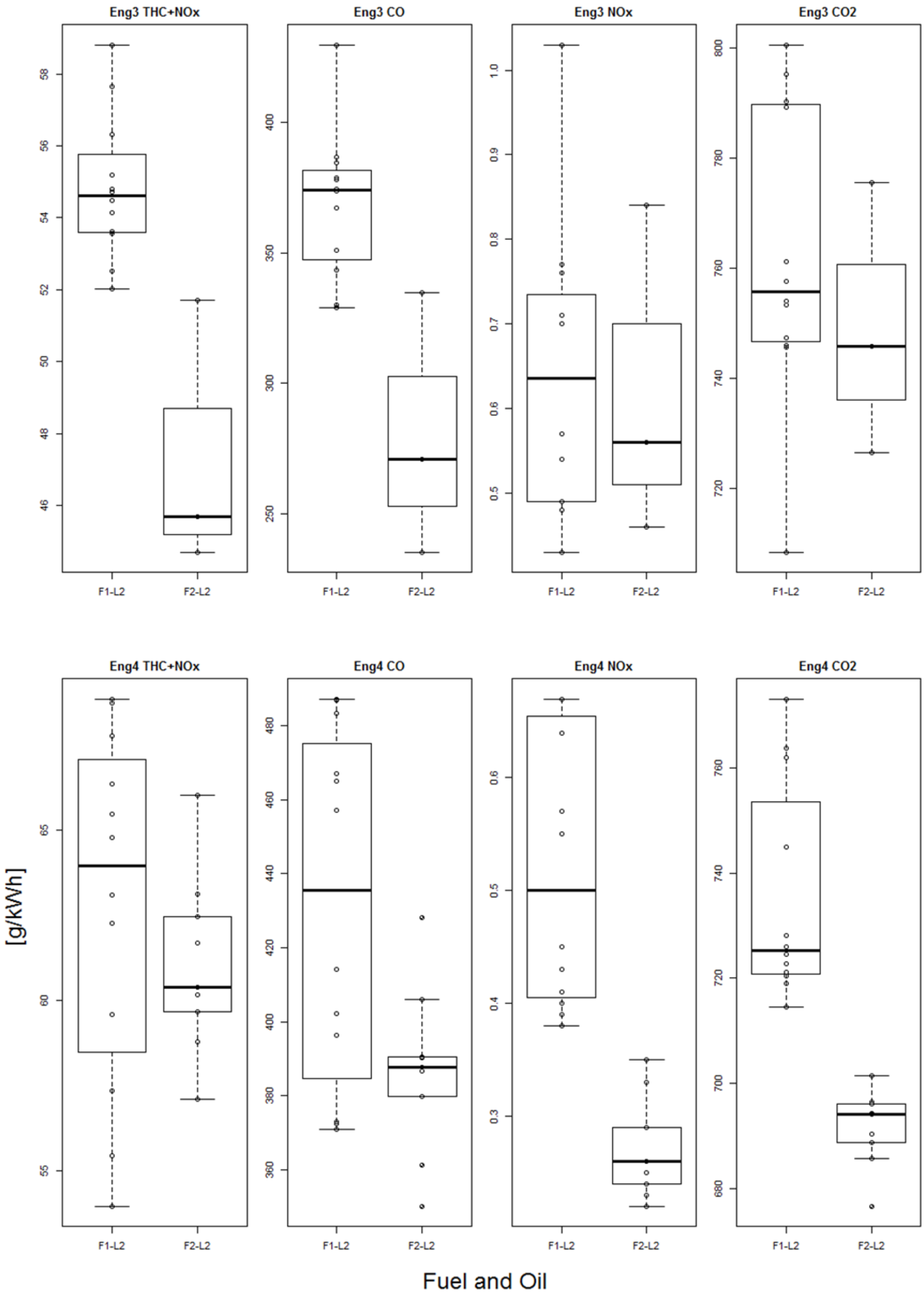
Annex 4. Alkylated fuel

From basic principles, the very low concentration of aromatics in the alkylate fuel (0.4% vol/vol versus 34% of the reference fuel, see Table 5) should result in lower emissions of compounds such as toluene and benzene (carcinogenic to humans) and polycyclic aromatic hydrocarbons (PAH). In addition, primary emissions should have a lower potential for the photo-chemical formation in the atmosphere of secondary pollutants such as secondary organic aerosols (SOA).

During the ISM programme, the alkylate fuel was tested on Eng3 and Eng4 in order to assess the impact on gaseous emissions as can be seen in Figure 29. HC and CO were either reduced (about 30% for Eng3) or unaffected (Eng4), NOx and CO_2 were either unaffected (Eng3) or reduced (Eng4). This demonstration exercise is supported by several other studies in the peer-reviewed scientific literature. For instance, Magnusson and Nilsson (2011) observed emission reductions of regulated compounds in the range 0% to 50% with the use of the alkylate fuel, but also reported a slight CO increase in lean conditions. A 5% to 20% HC increase and a 5% to 20% CO reduction depending on the presence/absence of an added oxidation catalyst were reported by Christensen et al. (2001) together with a strong reduction (50% to 70%) of PAH. Aalander et al. (2005) found reductions of 7% for HC, 5% – 12% for CO, and 30% for NOx. Czerwinski et al. (2001) reported a 20% – 25% reduction for both HC and CO and a slight increase in NOx emissions with the use of the alkylate fuel. Concerning SOA, the only study which addressed the effect of alkylate fuel was based on small engines mounted on 2-wheelers (hence different from the engines presented in this report) is Zardini et al. (2014) who measured dramatic SOA reductions (90% – 100%). As pointed out by Zardini et al. (2018), gaseous and particulate pollutants emissions were compound specific and reacted differently to the alkylated fuel depending on the engine cycle (2-stroke and 4-stroke). Available literature data reported a range of effects from emission reduction, or no effect, to slight increase. However, while the absolute amount of emitted pollutants might not differ (or slightly increase) from the case of standard fuel, the quality of the emissions is certainly improved with reduction of harmful aromatics, PAH and SOA).

Note that the environmental requirements of the engines in this report do not include particle mass or number and do not separate methane from non-methane hydrocarbons. In addition, like in the case of other utility engines and transport vehicles, the total hydrocarbons are not speciated. It is therefore not possible to fully evaluate the effect of the use of an alkylate fuel based solely on the procedures described in the existing EU legislation.

Figure 29. Emission results for Eng3 and Eng4 depending on standard (F1) or alkylate (F2) fuels.



Source: JRC.

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