Final Report supporting the Article 12 review under the MCP Directive

Final Report

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Acronyms

Acronym	Definition
AS:	Air staging
BAT	Best available technique
BAT-AEL:	BAT associated emission level
BF:	Bag filter
BFB:	Bubbling fluidised bed
BOOS:	Burner out of service
CC:	Combined cycle
CCGT:	Combined-cycle gas turbine
CFB:	Circulating fluidised bed
CHP:	Combined heat and power
CO:	Carbon monoxide
COD:	Chemical oxygen demand
COG:	Coke oven gas
DF:	Dual fuel (engine type)
DLN:	Dry low NOx burner
DS	Dry scrubber
DSI:	Duct sorbent injection
EER:	Energy efficiency range
EGR:	Flue-gas or exhaust-gas recirculation
ESP:	Electrostatic precipitator
ETS:	(European) Emissions Trading System
FBC:	Fluidised bed combustion
FC:	Fuel choice
FGD:	Flue gas desulphurisation (wet scrubber)
FS:	Fuel staging
GC:	Flue gas condenser
GD:	Gas diesel (engine type)
GF:	Grate firing
GT:	Gas turbine
HFO:	Heavy fuel oil
I&S:	Iron and Steel
IED:	Industrial Emissions Directive (2010/75/EU)
IPPC:	Integrated Pollution Prevention and Control
ISO:	International Organisation for Standardisation
KoM:	Kick-off meeting
LCP:	Large combustion plant
LHV:	Lower heating value
LNB:	Low-NOx burner
LNG:	Liquefied natural gas
MCP:	Medium combustion plant
MCPD:	Medium combustion plant directive
MIS:	Micro isolated system

Acronym	**Definition**
MS:	(European) Member State
NG:	Natural gas
NOx:	Nitrogen oxides (NO + NO_2, normally expressed as NO_2)
OCGT:	Open-cycle gas turbine
OPER:	Optimal performance emission range
OTNOC:	Other than normal operating conditions
PAH:	Polycyclic aromatic hydrocarbon
PC:	Pulverised combustion
PFBC:	Pressurised FBC
PM:	Particulate matter
PM10:	Particulate matter of less than 10 µm
PM2.5:	Particulate matter of less than 2.5 µm
SC:	Supercritical (steam)
SCR:	Selective catalytic reduction
SDA:	Spray dry absorber
SG:	Spark-ignited (engine type)
SIS:	Small isolated system
SNCR:	Selective non-catalytic reduction
SO_2:	Sulphur oxide
SOx:	Sulphur oxides (SO_2 and SO_3)
TOC	Total organic carbon
TRL	Technology readiness level
US DOE:	United States Department of Energy
US EPA:	United States Environmental Protection Agency
USC:	Ultra-supercritical (steam)
VOC:	Volatile organic compound
SWS	Seawater scrubber
WS	Wet scrubber
WG:	Working group

1 Introduction

1.1 The MCP information exchange

The Medium Combustion Plant (MCP) Directive sets emission limits for NO_x, SO_2 and dust for new and existing MCPs by technology type, capacity and fuel type. The Directive entered into force on 18 December 2015 and Member States are required to transpose it into national legislation by 19 December 2017.

Article 6(10) of the MCP Directive states the following: "*The Commission shall organise an exchange of information with Member States, the industries concerned and non-governmental organisations on the emission levels achievable with best available and emerging technologies and the related costs. The Commission shall publish the results of the exchange of information*." Article 12 of the MCP Directive requires the Commission to review and assess the need for action in relation to energy efficiency, CO emissions, the provisions concerning plants which are part of small isolated systems (SIS) or micro isolated systems (MIS), and Part 2 of Annex II in line with state-of the art technologies.

Ricardo was contracted by the European Commission to provide support for meeting its obligations under Articles 6(10) and 12 of the MCP Directive by organising and managing an information exchange process **to gather information from Member States, MCP operators and suppliers, abatement equipment suppliers and other relevant stakeholders on the environmental performance and costs of best available and emerging technologies to reduce emissions from MCPs**. The terms of reference for this support can also be found in Circabc[1]. The MCP Working Group (WG) was established to provide inputs to the information exchange and review the resulting **Technology Report**[2].

1.2 Objectives of the MCP information exchange

The overall objective of this information exchange was to provide support to the Commission to enable it to meet its obligations related to Articles 6(10) and 12 of the MCPD. The core element of the initiative was to analyse updated information on the environmental performance and costs of technologies to reduce emissions from MCPs. This included best available and emerging technologies.

The aim of the Technology Report was to provide technical information on the capabilities of MCPs and the environmental performance of primary and secondary technologies used in these units to reduce their environmental impact. The Technology Report developed as part of this information exchange is not legally binding.

The aim of **this document** is to provide the Commission with the information needed to deliver elements of the MCPD Article 12 review. The specific objectives were to analyse and document :

- whether there is a significant further emission reduction potential for MCPs in SIS and MIS;
- the potential for further reducing emissions from new MCP (potential for adopting lower emission limit values (ELVs) for new plant);
- the advantages and limitations of regulating carbon monoxide emissions (potential environmental impacts including trade off with NOx emissions and a comparison of costs and benefits);
- the benefits of setting minimum energy efficiency standards in line with best available techniques.

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[1] https://circabc.europa.eu/w/browse/f4bbf066-1905-4290-8ec2-3ef6507e10db

[2] https://circabc.europa.eu/ui/group/06f33a94-9829-4eee-b187-21bb783a0fbf/library/f4bbf066-1905-4290-8ec2-3ef6507e10db?p=1&n=10&sort=modified_DESC or Appendix 2 of this document

1.3 Methodology of the information exchange

This information exchange did not follow the same process as the so-called “Seville process” and requirements established under Article 13 of the Industrial Emissions Directive (IED) to review and develop BAT reference documents (BREFs). A much more streamlined approach was adopted to reflect the scope of the exchange. In this case, the overall timeline for this information exchange was 18 months.

The Kick-off Meeting (KoM) held in March 2018 focused on the scope/priorities of the exchange of information, timeline, the strategy for data collection, specific tasks to be carried out by the members of the group and the stakeholders to be contacted. The design of the questionnaire was done in spring 2018 incorporating comments from WG members and findings from an initial test with a small number of operators.

The final meeting was used to discuss the draft findings and resolve outstanding issues of the information exchange and to conclude the technical discussions within the group. In between these meetings there was a co-ordinated exchange of information to ensure that sufficient evidence is available to determine best available and emerging technologies for MCPs. The timetable for the steps for the MCP information exchange and the main milestones are summarised in Table 1-1.

Table 1-1 Timeline for MCP information exchange

Step	MCP information exchange milestone	Actual dates
1	Activation of WG: expressions of interest from interested parties and decisions on WG composition	January 2018
2	Dissemination of background paper for KoM	February 2018
3	KoM of the WG	6 March 2018
4	Design of the questionnaires	March 2018
5	Collection of information and data	Deadline August 2018
6	First draft Technology report	March 2019
7	Final meeting	23 May 2019
8	Draft Final Technology report	31 July 2019
9	Final Technology report	26 September 2019

For the emissions data (excluding energy efficiency), there were 68 plant technology-fuel-pollutant combinations analysed, though only 32 of these had 6 or more sample points, which was agreed to be considered the threshold of plants needed for a full analysis. For energy efficiency, 8 out of 17 met this threshold. Table 1-2 shows two characteristics about the dataset:

- Firstly, the sample size column is the initial sample size as measured by number of received questionnaires per plant-fuel category.
- Secondly, the pollutant-specific figures are the sample sizes after initial data cleaning and identification of usable data.

Samples that are not in bold in Table 1-2 have not been fully analysed due to smaller sample size. Finally, it should be noted that any multi-fuel plant that uses only one type of fuel for > 90% of its total thermal fuel input, is placed into that fuel category. Of 35 engines and boilers that indicated to use multiple fuels, all but 2 plants have been re-categorised either through the threshold of 90%, or because they only used variations of another fuel category (different types of solid biomass, other gaseous or other liquid fuel).

Table 1-2 Summary of sample sizes across the 17 categories

Category	Fuel	Type	MCP sample size	MCPs with data on each environmental parameter				
				dust	SO_2	NO_X	CO	Energy Efficiency
1	Solid biomass	Boiler	53	**47**	**25**	**51**	**45**	**32**
2	Other solid fuel	Boiler	13	**12**	**13**	**13**	**7**	**11**
3	Gas oil	Boiler	4	3	3	3	3	3
4	Gas oil	Reciprocating Engine	10	**6**	**6**	**7**	**7**	**8**
5	Gas oil	Gas Turbine	2	2	2	2	2	2
6	Other liquid fuel	Boiler	2	1	1	1	2	2
7	Other liquid fuel	Reciprocating Engine	6	**6**	**6**	**6**	**6**	**6**
8	Other liquid fuel	Gas Turbine	0	0	0	0	0	0
9	Multifuel	Boiler	2	2	1	2	1	1
10	Multifuel	Reciprocating Engine	0	0				
11	Multifuel	Gas Turbine	0	0				
12	Natural Gas	Boiler	97	**13**	**16**	**74**	**46**	**48**
13	Natural Gas	Reciprocating Engine	35	5	**13**	**33**	**22**	**27**
14	Natural Gas	Gas Turbine	27	1	4	**21**	**16**	**12**
15	Other gaseous fuel	Boiler	19	6	8	**14**	**13**	5
16	Other gaseous fuel	Gas Turbine	0	0				
17	Other gaseous fuel	Reciprocating Engine	11	1	**6**	**10**	**10**	**11**
Total			**281**	**105**	**104**	**237**	**180**	**168**

1.4. Article 12 review

The emission limit values set in the MCPD must be applied from 20 December 2018 for new plants and by 2025 (or 2030) for existing plants, depending on their capacity. It also includes requirements related to the monitoring of emissions of carbon monoxide (CO). The Directive entered into force on 18 December 2015 and Member States must transpose it by 19 December 2017. Article 6(10) states that there should be an information exchange on MCP capabilities.

In addition to the requirement for an information exchange on best available technologies for MCPs, a review clause was included in Article 12 requiring the Commission to investigate a number of additional issues that arose during the negotiations. Article 12 states the following:

"*1.By 1 January 2020, the Commission shall review progress in relation to the energy efficiency of medium combustion plants and assess the benefits of setting minimum energy efficiency standards in line with best available techniques.*

2.By 1 January 2023, the Commission shall assess the need to review the provisions concerning plants which are part of SIS or MIS, as well as Part 2 of Annex II, on the basis of state-of-the-art technologies.

As part of this review, the Commission shall also assess whether for certain or all types of medium combustion plants there is a need to regulate CO emissions.

Thereafter, a review shall take place every ten years and shall include an assessment of whether it is appropriate to set stricter emission limit values in particular for new medium combustion plants.

3.The Commission shall submit a report on the results of the reviews referred to in paragraphs 1 and 2 to the European Parliament and to the Council accompanied by a legislative proposal where appropriate..”

1.5 This report

This report is based on data included in the Technology Report that was shared with WG members at the end of July 2019. It analyses the information from plants that are currently in operation provided by WG members and related technical literature. The most relevant information sources are the completed questionnaires provided by MCP operators (and reviewed by MSs). The structure for this document is as follows:

- Section 1 presents the analysis and findings with regards to SIS/MIS plant capabilities. This section focuses on whether MCPs operating in isolated systems will be capable of meeting the MCP Directive requirements.
- Section 3 presents the analysis undertaken and findings with regard to the potential to set revised ELVs for new MCPs.
- Section 4 presents the analysis undertaken and findings with regards to the potential to establish carbon monoxide (CO) emission limit values for MCPs.
- Section 5 presents the analysis undertaken and findings with regards to the potential to set energy efficiency ranges.

2 Potential to reduce emissions from SIS or MIS

2.1 Introduction

This section presents the analysis of the environmental performance of MCPs in small isolated systems (SIS) and micro isolated systems (MIS). Articles 3(13) and 3(14) in Article 2 of Directive 2009/72/EC define small isolated systems and micro isolated systems. It is the same definition as referred to for LCPs above:

- **‘small isolated system’** means any system with consumption of less than 3 000 GWh in the year 1996, where less than 5 % of annual consumption is obtained through interconnection with other systems;
- **‘micro isolated system’** means any system with consumption less than 500 GWh in the year 1996, where there is no connection with other systems;

This evidence-based assessment reviewed the potential for SIS/MIS plants to meet their specific requirements set in the MCPD. This section is structured as follows:

- Section 2.2 describes the emissions baseline (i.e. current emissions data for SIS/MIS plants) using data from the survey and literature review.
- Section 2.3 describes the emission reduction potential from using the complete range of technologies in the market.
- Section 2.4 describes the specific constraints for SIS/MIS plants, their impact on technology selection and impact on emission reduction potential.
- Section 2.5 provides a high-level estimate of costs and benefits and a set of observations.

2.2 SIS/MIS emission baseline

2.2.1 Overview

As part of the MCP information exchange, the questionnaire included fields to capture whether the MCP plant was operating in a SIS or MIS. Out of 283 validated questionnaires, 17 included information for plants in a SIS or MIS. These 17 questionnaires (summarised in Table 2-1) contained environmental performance data from 2017 on the most common combustion configurations used in isolated systems (engines and gas turbines).

The data gathered is most probably driven by the fact that, according to Article 6(4) of the MCPD, existing MCPs in SIS/MIS are not required to meet ELVs until 2030. Most of these plants are old and there were no “new” plants in the data set (in this study “new” plants are those that have been commissioned since 2016 which differs to the definition of new plants from the MCPD). The majority of them apply no specific abatement technologies. The gas oil diesel engines are small in order to provide flexible power supply. A few other MCPs, not shown in the table, were erroneously reported as SIS or MIS and were excluded from this analysis e.g. a Romanian biomass plant (#602) and a Polish plant using solid fuel (#562).

Table 2-1 Data collected from SIS/MIS plants in this project

Type	Fuel	NO_x data	SO_x data	Dust data	Data from SIS	Data from MIS	Plant age	Size (MW_{th})
Boilers	Gas oil	Reported as SIS/MIS but are located in mainland (Romania, Poland, Italy)						
Boilers	Other solid fuel							

Type	Fuel	NO_x data	SO_x data	Dust data	Data from SIS	Data from MIS	Plant age	Size (MW_{th})
Engine	Gas oil	7	6	7	**2**	**5**	5 plants older than 2007 and no new plants (>2016)	3.2-8.6
Engine	Other liquid fuel(1)	8	8	8	**4**	**4**	No new plants (>2016)	12.6-45.8
G. T.	Gas oil	2	2	2	**2**	**0**		46-49

(1) Mainly heavy fuel oil

2.2.2 Current emission levels in SIS/MIS based on data from questionnaires

No valid questionnaire data was received from non-SIS/MIS plants for the plant and fuel type categories described above. A comparison between SIS/MIS and non-SIS/MIS plants has therefore not been possible using data from questionnaires (one exception). Section 2.2.3 summarises the capabilities of these type of plants based on data from the literature review.

The emissions data and contextual information provided in questionnaires indicated that the majority of these SIS/MIS MCPs do not have abatement technologies installed (only two plants have dust filters). However, these existing plants do not have to meet the requirements of the MCPD until 2030. The full questionnaire data analysis for these plant categories is provided in the Technology Report (see appendix 2 of this document, primarily sections 3.1.6 and 3.1.7).

Generally speaking, with limited exceptions, the data analysis shows that, for these plant categories, there are no clear correlations on environmental performance with plant loads, plant size or plant age. There is one larger installation from Spain with higher SO_x and NO_x emission levels than others that bias the plant size correlation coefficient, which is thus not significant.

Regarding **NO_x emissions**, the SIS/MIS MCP performance is summarised in Table 2-2.

- In the case of engines (both gas oil and other liquid fuels) the average emissions reported for gas oil engines are high since these plants have not reported the use of NOx abatement technologies (they apply filters and one uses lower sulphur fuel). There is no evidence of any correlation of emissions performance with plant age or plant size.
- Data for turbines using gas oil is scarce (only two data points) but the average emission levels are close to the MCPD ELV.

Table 2-2 NO_x emissions performance from SIS/MIS plants

Technology	Fuel	NO_x median (mg/Nm^3)	Plant size and/*or age	MCPD ELV (mg/Nm^3)	Technologies reported
Engine	Gas oil	1,093	Before 18/05/2006	**1,850** (2)	None
		1,513	1-5 MWth (after 18/05/2006)	**250** (1)	
		No plants in the survey were >5 MWth and after than 18/05/2006		**190**	
Engine	Other liquid (3)	2,034	Before 18/05/2006	**1,850** (2)	
		1,311	1-5 MWth (after 18/05/2006)	**250** (1)	

Technology	Fuel	NO_x median (mg/Nm^3)	Plant size and/*or age	MCPD ELV (mg/Nm^3)	Technologies reported
		No plants in the survey were 5-20 MWth and after than 18/05/2006			
		1,762	>20 MWth and after 18/05/2006	**190**	
Gas Turbine	Gas oil	194	Not applicable	**200**	

(1) 250 mg/Nm^3 in the case of engines with a rated thermal input equal to or greater than 1 MW and less than or equal to 5 MW.
(2) 1,850 mg/Nm^3 for diesel engines constructed before 2006 and for dual fuel engines in liquid mode.
(3) Mainly fuel oil.

Regarding **SO_x emissions**, SIS/MIS MCP performance is summarised in Table 2-3.

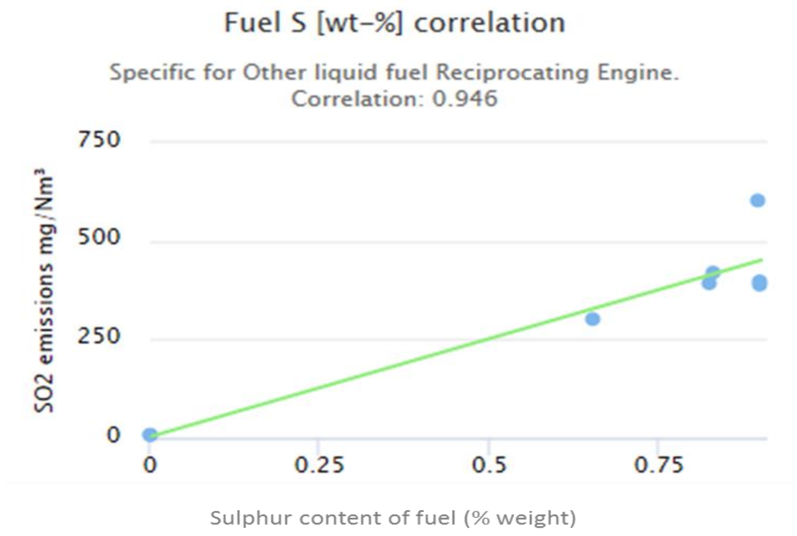
- The MCPD does not set requirements for units using gas oil as fuel. Nevertheless, two plants (#521 and #522) that use fuel with low sulphur content deliver much lower SOx values (average 0.75 mg/Nm^3) than the rest (see Figure 2-1).
- The main driver/root cause for this performance is the sulphur content in the fuel being used i.e. plants using high fuel sulphur content (0.5-1%) are generating higher emissions than the ELV. The plants #530 and #531 are using biodiesel with low sulphur content and delivering much lower SOx emission (7-8 mg/Nm^3).

Table 2-3 SO_x emissions performance from SIS/MIS plants

Technology	Fuel	SO_x median (mg/Nm^3)	Average. Sulphur in fuel (%)	MCPD ELV (mg/Nm^3)	Technologies reported
Engine	Gas oil	22	0.05	**-**	Fuel choice
Engine	Other liquid	8	0.05	**120(1)**	Fuel choice
Engine	Other liquid	416	0.8	**120(1)**	None
G. T.	Gas oil	3-8.4	0.1	**-**	None

(1) 120 mg/Nm^3 from 1/1/2030 for existing MCP in SIS/MIS .

Figure 2-1 Analysis of fuel sulphur content relative to SOx emissions for engines using other liquid fuels



Regarding **dust emissions**, SIS/MIS MCP performance is summarised in Table 2-4.

- As for SOx, the MCPD does not set requirements for units using gas oil. Nevertheless, the (#521 and #522) gas oil engines using a particulate filter generate lower emissions (5.5-6.9 mg/Nm^3) than the average in this cluster.
- The reported emission values of engines using other liquid fuels are generally above the ELV set in the directive for larger plants (>20 MWth) although some of the best performers are already operating below the limit. The data does support a correlation of emission performance with plant size (as indicated in the directive ELV table 3).

Table 2-4 Dust emissions performance from SIS/MIS plants

Technology	Fuel	Dust median (mg/Nm^3)	size (MW$_{th}$)	MCPD ELV (mg/Nm^3)	Technologies reported
Engine	Gas oil	17.8	3.3-8.6	**-**	None
	Gas oil with filter	5.7	5.3	**-**	Filter
Engine <20 MWth	Other liquid	71	12.6	**20(1)**	None
Engine >20 MWth		24	27-46	**10**	
G. T.	Gas oil	3.7-4.6	46-49	**-**	

(1) 20 mg/Nm^3 if plants <20 MW$_{th}$

The evidence gathered via the questionnaires implies that there are no specific technologies being applied in these SIS/MIS engines for dust other than filters in two gas oil engines.

2.2.3 Emissions performance based on literature review

This section summarises the emissions performance data gathered in the literature review for these types of plants. This includes data for common configurations used in SIS/MIS gathered from Member States national policies setting ELVs, equipment manufacturer design warrants and other relevant documents. The ELVs presented here are not specific for SIS/MIS.

The most stringent ELVs included in national legislation have been selected in this analysis. These most stringent ELVs show indirectly the capabilities of MCPs. These ELVs may be achieved by combustion plant design, selection of fuels and/or by application of abatement devices.

Emission performance for engines has a large variability since there are many engine designs. Most of the emission data available in literature (e.g. manufacturer data sheets) is presented in different units, with grams per kilowatt hour (g/KWh) being the most common to compare with shipping regulations and/or non-road mobile machinery (NRMM) regulations. Contextual information is required to convert this information, otherwise numerous assumptions need to be made which limits the overall robustness.

Table 2-5 describes **ELVs for NO_x** for each one of the common plant categories in SIS/MIS. In the MCPD, there are a number of ELVs recognising the fact that there are various type of engines and performance is influenced by size, age and engine type. Regarding Member State ELVs, the most stringent for other liquid fuels engines was 150 mg/Nm^3.

Emissions from gas oil engines have been reported in scientific literature in the range of 200-400 mg/Nm^3 and 150-500 mg/Nm^3 for other liquid fuels, all using SCR. Data on 90-300 for natural gas lean burn engines has been reported by the US National Renewable Energy Laboratory (NREL). NOx data was provided to the information exchange from various equipment manufacturers of gas turbines using liquid fuels. These data sets contain performance values (80-120 mg/Nm^3) warranted (by manufacturers) from 2011 for liquid fuel turbines from Canada information exchange regulatory initiative 2011. Some of these turbines are using either water injection or low NOx burners. There is also data from United States Department of Energy (US DoE) on turbines achieving NOx emission values of 18 mg/Nm^3.

Table 2-5 NOx ELVs vs reported SIS/MIS emission data

Type	Fuel	Size (MW_{th})	Age of plant	NO_x ELV in MS (mg/Nm^3)	NO_x literature (mg/Nm^3)	MCPD ELV new (mg/Nm^3)	MCPD ELV existing (mg/Nm^3)	SIS/MIS reported NO_x median (mg/Nm^3)
Engine	Gas oil	All	Before18/5/2016	None	200-400(1)	190	1,850	1,093
		1-5 MW_{th}	After 18/5/2016				250	1,513
		>5 MW_{th}					190	No data
Engine	Other liquid	all	After 18/5/2016	150	150-500(1)	N.A.	1,850	2,034
		1-5 MW_{th}	Before 18/5/2016			225	250	1,311
		5-20 MW_{th}				225	225	No data
		>20 MW_{th}				190	190	1,762
G. T.	Gas oil	all	all	None	18-120(2)	75	200	194

(1)Using SCR.

(2)Using either water injection or low NOx burners.

Regarding SOx, the Netherlands has an ELV of 65 mg/Nm^3 for other liquid fuel engines which is almost half of the value of the ELV in the directive for these units (see Table 2-6).

Table 2-6 SOx ELVs vs reported SIS/MIS emission data

Type	Fuel	Size (MW$_{th}$)	Age of plant	SO$_x$ ELV in MS (mg/Nm^3)	SO$_x$ literature (mg/Nm^3)	MCPD ELV new (mg/Nm^3)	MCPD ELV existing (mg/Nm^3)	SIS/MIS reported SO$_x$ median (mg/Nm^3)
Engine	Gas oil	all	all	None	None			22
Engine	Other liquid	all	New before 1/1/2025	65	30-900(1)	590	120(2)	390
Engine	Other liquid	all	New after 1/1/2025			120		
G. T.	Gas oil	all	all	None	None			5.7

(1) Source: “Emission Calculation check guide”, CIMAC 2008, Fuel sulphur content composition related variability leading to wider emissions (2) Applies to existing plants after 2030

In case these SIS/MIS plants were to switch to natural gas, Belgium sets a SOx ELV for gas turbines using natural gas of 35 mg/Nm^3 which is higher than the values gathered in the survey for turbines using gas oil.

Regarding dust, (Austria) has set more stringing ELV for other liquid fuels engines at 3 mg/Nm^3 ELV well below the ELV in the directive for these units. Higher values were reported in questionnaires by plants with no abatement measures (see Table 2-7).

Table 2-7 Dust ELVs vs reported SIS/MIS emission data

Type	Fuel	Size (MW$_{th}$)	Age of plant	Dust ELV in MS (mg/Nm^3)	Dust literature (mg/Nm^3)	MCPD ELV new (mg/Nm^3)	MCPD ELV existing (mg/Nm^3)	SIS/MIS reported Dust median (mg/Nm^3)
Engine	Gas oil	all	all	None	None			22.1
Engine	Other liquid	1-5	all	3	20-100(2)	20(1) -	-20	23.9
Engine	Other liquid	5-20 20-50	all			10(1) 10	20- 10	
G. T.	Gas oil	all	all	None	None			4.1

(1) Until 1 January 2025, 75 mg/Nm^3 for diesel engines which are part of SIS or MIS;
(2) Source: “Emission Calculation check guide”, CIMAC 2008, Fuel nature and composition related variability leading to wider emissions

In case these SIS/MIS plants were to use cleaner fuels: Belgium sets dust ELVs for gas turbines using natural gas. This ELV (5 mg/Nm^3) is higher than the values gathered in the survey for this gas turbines using gas oil.

2.3 Emissions reduction that can be achieved in SIS/MIS using all technologies for engines and gas turbines

2.3.1 Generic technologies on the market

This section describes the emission reductions that can be achieved in SIS/MIS MCPs by implementing available technologies on the market without taking into account the potential limitations in SIS/MIS which are subsequently described in Section 2.4 below (Specific constraints for SIS and MIS). Specific measures that can be applied to these types of plants are described in sections 2.3.2 and 2.4.2.

It should be noted that these plants often operate in the context of high variability in demand (see section 2.4) and many of them will be used as a backup or emergency mode due to renewable energy sources being the primary option. Both new and existing plants operating a small number of hours per year (e.g. less than 500 h/y) may be exempted from the MCPD ELVs.

The following tables describe, for each pollutant, the potential applicable emission reduction for the most common SIS/MIS configurations and application of relevant abatement technologies. The pollutant baseline figures are median values from questionnaires from SIS/MIS gas oil engines. These illustrative examples provide an estimation on achieved emission using common abatement technologies and are not generated for every single plant type (not covering all exemptions in directive tables). Tables do not include technologies that are not applicable to these plant types (based on the findings documented in the Final Technology Report).

Table 2-8 shows how the SIS/MIS plants could theoretically achieve the MCPD limits using some of the existing technologies. It is important to note that this does not take into consideration any specific restrictions that SIS/MIS MCPs may face. Green cells show cases where the MCPD requirements are achieved (for the base case, not taking footnote exemptions into account) for existing plants.

Table 2-8 NO_X Emission reduction that can be achieved for SIS/MIS gas oil engines per technology

Type	Fuel	NOx baseline median(mg/Nm^3)	Technology	Abatement efficiency (%)	Achievable NOx emission level (mg/Nm^3)
Engine	Gas oil	1,271	(FC)	80	254
			(EGR)	70	381
			(ET)	40	762
			(LB)	40	762
			(WSA)	60	508
			(SNCR)	50	635
			(SCR)	90	127
Gas turbine	Gas oil	194	(DLN)	90	19
			(FC)	80	38
			(EGR)	70	58
			(WSA)	60	77
			(RAT)	25	145
			(SNCR)	50	97
			(SCR)	90	19
Engine	Other liquid fuels	1,859	(FC)	80	371

Type	Fuel	NOx baseline median(mg/Nm^3)	Technology	Abatement efficiency (%)	Achievable NOx emission level (mg/Nm^3)
			(EGR)	70	557
			(ET)	40	1,115
			(LB)	40	1,115
			(WSA)	60	743
			(SCR)	90	186
			(SNCR)	50	929

Legend: green cell if meeting MCPD ELVs.

A similar analysis has been done for SOx. For this pollutant, there is only an ELV for engines using other liquid fuels. There are also some technologies only applicable to boilers not included in this assessment. Table 2-9 shows that the majority of technologies would achieve emission levels below the MCPD ELVs.

Table 2-9 SO_X emissions reduction that can be achieved for SIS/MIS per technology

Type	Fuel	SOx baseline (mg/Nm^3)	Technology	Abatement efficiency (%)	Achievable SOx emission level (mg/Nm^3)
Engine	Other liquid fuel	390	(FC)	80	78
			(TF)	80	78
			(WS)	94	23

Legend: green cell if meeting MCPD ELVs.

There is only a dust ELV for SIS/MIS engines using other liquid fuels. There are also some technologies only applicable to boilers not included in this assessment. Table 2-10 shows that bag filters, ESPs, cleaner fuels and wet flue gas scrubbers would lead to emission levels well below the MCPD ELV.

Table 2-10 Dust emissions reduction that can be achieved for SIS/MIS per technology

Type	Fuel	PM baseline (mg/Nm^3)	Technology	Abatement efficiency (%)	Achievable PM emission level (mg/Nm^3)
Engine	Other liquid fuel	24	(BF)	99	0.2
		24	(SF)	99	0.2
		24	(ESP)	98	0.5

Legend: green cell if meeting MCPD ELVs.

2.3.2 Additional options to minimise SIS & MIS impact

This section describes additional measures that can reduce the environmental impact of SIS/MIS combustion plants. These include a wider set of measures to facilitate switching to cleaner fuels that are not always so easily accessible to SIS/MIS. This section considers how cleaner fuels such as lower sulphur liquid fuels, LNG or natural gas should be more accessible for these plants in the future. It is reported (EUROMOT 2017) that emissions from diesel generators used on islands could be significantly reduced by the use of lower sulphur fuels and modern combustion technologies[3]. NO_X emissions from larger engines have decreased by up to 40% since the 1990s mainly due to improvements in the engines themselves. The following subsections describe measures applicable to engines for ships because they also can be applicable to engine MCPs.

2.3.2.1 Marine fuels offer enlargement to meet stricter ship regulations

Demands for cleaner marine liquid fuels are increasing due to tighter ship regulation limits entering into force. This larger demand for alternative fuels is projected to be met by 2020, with a suite of different fuels being offered by mineral oil refinery operators:

- petroleum fuels with a sulphur content of 0.10% or less (to comply with emission control area (ECA) requirements and in engines that use marine gas oil (MGO));
- petroleum fuels with a sulphur content between 0.10% and 0.50% m/m;
- liquified natural gas (LNG);

Some oil refineries are not investing in processes to manufacture these cleaner fuels and others are taking longer to finalise their plant retrofits. As such, it is not certain that refineries will meet global demand by 2020 (EnSys and Navigant, 2015). It has been calculated that it is unlikely that the capacity of desulphurisation units such as hydrogen and sulphur plants could be expanded in time (EnSys and Navigant, 2015). The capacity of sulphur plants would need to increase by 60-75% while the capacity of hydrogen plants would need to expand by 30-50% between 2016 and 2019 in order to meet demand (Ramsey, 2017). The issue of insufficient sulphur and hydrogen capacity was also noted by the CE Delft study, but the results were arrived at on the assumption that these can expand in time.

In a study conducted by Concawe (2017), the modelling results showed a lack of feasible options to produce sufficient marine fuels to meet demand at the new sulphur specification, with the main limitations being imposed by sulphur recovery units and hydrogen production units.

The demand for high sulphur fuel oil (HSFO) in combination with scrubbers was forecasted to be around six million tonnes/year in 2020. The blending of 0.50% sulphur marine fuel was calculated to amount to 25 million tonnes/year in 2020 in Europe alone, and will result in multiple products, which can be divided into two categories:

- Heavy fuels at 0.50% sulphur: 30–50% of the demand.
- Distillate fuels: 50–70% of the demand

2.3.2.2 LNG used for mid-size combustion units

There is a growing level of interest in liquified natural gas (LNG) as a fuel due to its low environmental impact and attractive price. LNG is associated with practically no SOx or PM emissions, considerably reduced NOx emissions and has lower CO_2 emissions than liquid or solid fuels (The Oxford Institute for Energy Studies, 2018) (see Table 2-11). The overall GHG impact compared to conventional liquid fuels is, however, uncertain when full lifecycle emissions and the impact of methane slip (the seepage of un-combusted natural gas during the utilisation stage e.g. through ductwork) are considered (The Oxford Institute for Energy Studies, 2018).

Table 2-11 Emissions factors for marine fuels Source: (The Oxford Institute for Energy Studies, 2018)

Emission	Heavy Fuel Oil HFO(g/g of fuel)	Middle Distillates Oil MDO(g/g of fuel)	LNG(g/g of fuel)
SO_X	0.049	0.003	Trace
CO_2	3.114	3.206	2.750
CH_4	trace	trace	0.051

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[3] https://www.euromot.eu/wp-content/uploads/2018/02/EUROMOT-LCP-BREF-position-for-remote-areas-such-as-MIS-and-SIS-plants-Liquid-fired-reciprocating-engine-plant-2017-04-04.pdf

Emission	Heavy Fuel Oil HFO(g/g of fuel)	Middle Distillates Oil MDO(g/g of fuel)	LNG(g/g of fuel)
NO_X	0.093	0.087	0.008
PM	0.007	0.001	trace

2.3.3 New cleaner fuels distribution approaches reaching larger territory share

2.3.3.1 Natural gas grid reaching some SIS/MIS

In recent years a number of private companies are investing in gas fuel grids connected to isolated systems. In Balearic Islands (Spain) new grid developments are supplying MCPs since 2014 and more recently the island of Ibiza[4]. There are ENDESA (ENEL) MCPs being fed with this supply.

Enagas S.A. installed two offshore submarine pipelines - one 20 inch diameter pipe of approximately 123 km, defined as the West of Ibiza pipeline between Denia (mainland Spain) and Ibiza, and the other a 20 inch diameter pipe of approximately 146 km defined as the East of Ibiza pipeline between Ibiza and Mallorca.

2.3.3.2 LNG distribution developments

In Europe, LNG is particularly attractive economically as, by contrast to in the US, the price excludes the costs of regasification of the LNG and network entry.

There are a number of initiatives to further develop the distribution of LNG to seaports, isolated systems and ship fleets: The 'CORE LNGas Hive'[5] project funded by the EU is developing logistics for the supply of LNG (small scale and bunkering) as a fuel especially for the maritime sector, in the Iberian Peninsula.

2.4 Specific constraints for SIS and MIS

This section describes the specific constraints of MCPs operating in isolated systems. These constraints are described estimating the implication on plant design, selection of applicable technologies or plant retrofits as well as implications for additional costs.

2.4.1 Introduction to constraints for plants in SIS or MIS

Electrically Isolated systems are subject to several specific technical challenges which may result in a number of direct or indirect impacts[6]. These limitations are described below:

Fuel choice constraints. Isolated systems typically rely on combustion of gas oil or heavy fuel oil.

- There is seldom (e.g. some exceptions are Ibiza since 2014, Majorca since 2010) access to natural gas pipelines to enable replacement of liquid fuels with cleaner fuels.
- The reliance on oil imports for power generation renders islands vulnerable to oil price volatility (although in some cases fuel cost is subsidised for SIS/MIS and/or paid by government). Many islands suffer economically from this dependency on fuel imports. The lack of economies of scale makes the import of these fuels more expensive for islands.
- Directive 2016/802 is the codified version of the EU's transposition of MARPOL Annex VI and sets requirements for both marine fuels and those used on land. It establishes limits on the maximum sulphur content of fuels. Cleaner liquid fuel will also be available (at higher prices than high sulphur fuel oil) to enable ships to meet this directive. If these combustion plants are located in the seaport area, they have been required to meet requirements on low sulphur fuel

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[4] https://www.deme-group.com/references/balearic-pipeline-project
[5] http://corelngashive.eu/en/
[6] https://www3.eurelectric.org/media/38999/eu_islands_-_towards_a_sustainable_energy_future_-_eurelectric_report_final-2012-190-0001-01-e.pdf

use since 2010. The Directive establishes limits on the maximum sulphur content of fuels as follows:

  - HFO used in installations on land: maximum 1% sulphur content.
  - Gas oil used in installations on land: maximum 0.1% sulphur content.

Operating mode and plant load suffer from a need for flexible generation in isolated grids.

- Many islands are tourist hotspots. This can lead to combustion units and average loads in some seasons being significantly lower than peak demand. Tourism based economies also have high daily variations in demand. Due to their isolation, island energy operators have to take extra measures to ensure system stability and security of supply. Many of these combustion plants would have low operating hours (<1500 h/y) and low operating rates below stable loads. To avoid this issue, operators rely on multiple diesel engines to be able to cope with fluctuating demand, some of which are inherently redundant, and to cover the possibility of failures. Without connection to mainland supply, power generation on islands must cope with daily and seasonal variations and the possibility of plant failures. Combinations of small combustion units (such as engines) provide flexibility in coping with the variable demand characteristic of island systems, as units can be stopped and started depending on demand. Diesel engines are suitable for isolated systems and the use of diesel engines in remote locations is expected to continue over the next 10 years (ICF, 2013)[7]. For NO_X reduction, SCR can be less suited to be retrofitted to existing island generators because at lower operating loads and during starting and stopping cycles exhaust gas temperature is too low for the catalyst in the SCR unit to function
- Another driver for flexible generation is the increasing share of renewable energy, demoting combustion plants to a backup role with more flexible and variable plant loads.

Generation and emission technologies selection: Some secondary abatement equipment for diesel engines e.g. SCR and WS can be less suited to the variable demand and frequent stop-starting characteristic of island systems.

- Lack of economic scale. Due to their small size, islands lack economies of scale in financing and power production. Investment decisions in retrofits such as abatement devices have justification challenges due to economic viability.
- Disconnected from continental infrastructure. This can make supply of equipment and reagents more difficult and leads to limited options for industrial waste disposal. A small isolated system obtains less than 5% of annual consumption from interconnection, and a micro isolated system has no connection with other systems. Reagent supply for SCR as well as disposal of used catalyst elements presents higher logistical costs for plants on islands than on the mainland. Alternatives for NO_X reduction have been compared by Wik & Niemi (2016) and include humidification, emulsion, water injection, and EGR. It was noted however that these systems also suffer from reduced abatement at lower loads.
- Restricted availability of fresh water resources. This may generate an impact in some emission abatement technologies that require reagents (might be solved with use of seawater scrubbers).
- Lack of land area is an additional hurdle for many of the operators producing electricity in SIS. These plants are sometimes located in small industrial sites with constraints/difficulties to enlarge their space availability. Some of the required retrofits to meet new regulations require additional space for implementing assets (e.g. ESPs) in the existing plant lay-out. SCR reactors require a large space in the plant (EUROMOT, 2017) [8] that may not be possible in the original plant design. WS also occupy a large footprint.

Table 2-12 provides a summary of the constraints described above.

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[7] https://jshippingandtrade.springeropen.com/articles/10.1186/s41072-016-0009-z https://byt.cevre.gov.tr/Pictures/Files/Editor/document/Other%20Useful%20Documents/Collection%20and%20Analysis%20of%20Data%20for%20Review%20per%20Art.%2030(9)%20IED%20Directive.pdf

[8] https://www.euromot.eu/wp-content/uploads/2018/02/EUROMOT-LCP-BREF-position-for-remote-areas-such-as-MIS-and-SIS-plants-Liquid-fired-reciprocating-engine-plant-2017-04-04.pdf

Table 2-12 Constraints on MCPs operating at SIS or MIS

Specific SIS/MIS feature	Description/ root cause	Impact on combustion plant technology selection	Alternative measures
Fuel choice	No access to gas grid/asset	Some cleaner fuels not accessible (e.g. NG)	Use other cleaner fuels (e.g. LSFO)
	Economy of scale to install natural gas gasification	Use low sulphur fuel	Not applicable
Larger share of renewables for energy generation	Combustion units remain to cover peaks	Operating <1500 h/yr. or below stable load rates	ELVs not applicable on low loads. Implement technologies suitable for small units.
Limited back up options in the small grid	One or few combustion plants to ensure redundancy (backup/ emergency)	Frequent start and shut downs Combustion plant design as series of various small units (e.g. engines)	
Large demand variation	Touristic area leads to larger population (demand) change		
	Some abatement technologies require stable waste gas flow rate	SCR: at lower operating loads and during starting and stopping cycles exhaust gas temperature is too low for the catalyst in the SCR unit to function WS: reagents supply challenging ESP: space limitations and capex (viable for large new plants)	NO$_X$: humidification, emulsion, water injection, and EGR SO$_X$: cleaner fuels (such as LSFO) Dust: bag filters
Disconnected from continental infrastructure	Supply of equipment and reagent more difficult and leads to limited options for industrial waste disposal		
Space constraints	Space constraints	Space restriction to retrofit SCR, WS or ESP in existing plants	

2.4.2 Constraints on SIS/MIS plant technology selection

This section describes how specific SIS/MIS constraints can impact the selection of emission reduction technologies. The analysis is consistent with the applicability restriction sets included in the Final Technology Report. The exercise is done only for common SIS/MIS MCP categories that are expected to require additional effort to meet the MCPD requirements.

NOx emission reductions: Regarding the techniques commonly used to reduce NOx, Table 2-13 shows how only a few measures will present limitations due to the constraints described above (cells highlighted in orange). The majority of measures should remain available and not impacted by SIS/MIS limitations.

Table 2-13 Impact of SIS/MIS constraints on NOx emission reductions

Technology	Acronym	Impact	Costs relative to non-SIS/MIS MCPs
Dry low-NOX burners	(DLN)	No specific SIS/MIS constraints	No specific additional cost
Use of clean fuels	(CF)	Potential limitations on availability of cleaner fuels	Cleaner fuels will have higher costs (economy of scales)

Technology	Acronym	Impact	Costs relative to non-SIS/MIS MCPs
Flue-gas or exhaust-gas recirculation	(EGR)	No specific SIS/MIS constraints	No specific additional cost
Lean-burn concept and advanced lean-burn concept	(RAT)		
Low-NOX combustion concept in diesel engines (engine tuning)	(ET)		
Water/steam addition	(WSA)	Requires water uptake treatment with reagents	
Oxidation catalysts	(OC)	No specific SIS/MIS constraints	
Selective catalytic reduction	(SCR)	Constraints due to stable loads (constraints on space availability are not specific to SIS/MIS)	Additional cost related with reagents disposal.
Selective non-catalytic reduction	(SNCR)		

Legend: Orange cells when a technology has restrictions for SIS/MIS

SOx emission reductions: Regarding the techniques commonly used to reduce SOx, Table 2-14 shows how measures will present limitations due to the constraints described above (cells highlighted in orange).

Table 2-14 Impact of SIS/MIS constraints on SOx emission reductions

Technology	acronym	Impact	Costs relative to non-SIS/MIS MCPs
Use of clean fuels	(CF)	Potential limitations on availability of cleaner fuels	Cleaner fuels will have higher costs (economy of scale).
Seawater scrubber	(SWS)	Constraints due to stable loads	
Wet scrubber	(WS)		Reagent and waste disposal cost.

Legend: Orange cells when a technology has restrictions for SIS/MIS

Dust emission reductions: Regarding the techniques commonly used to reduce dust, Table 2-15 shows how measures will present limitations due to the constraints described above (cells highlighted in orange).

Table 2-15 Impact of SIS/MIS constraints on dust emission reductions

Technology	acronym	Impact	Costs relative to non-SIS/MIS MCPs
Bag filter	(BF)	No specific SIS/MIS constraints	No specific additional cost
Soot filter	(SF)		
Electrostatic precipitator	(ESP)	Constraints due to stable loads	No specific additional cost (other than less viable for small plants)
Wet scrubber	(WS)		

Legend: Orange cells when a technology has restrictions for SIS/MIS

2.5 Summary on cost and benefits

2.5.1 Estimation of cost and benefits .

This section provides an estimation for environmental benefits and associated costs of reducing emission from plants operating in SIS/MIS. This review is done at plant level using illustrative examples for common configurations used in these isolated systems. A number of assumptions are required to estimate these benefits at plant level. Table 2-16 displays assumptions on plant loads and flue gas volumes. This table shows different flue gas volumes for different plant sizes. The estimation assumes an average plant load of 50% throughout the year.

Table 2-16 Assumptions to estimate SIS/MIS mass emissions at plant level

Type of plants	Average plant size (MW_{th})	Specific flue gas volume (1) (k Nm^3/h)	Load factor (%)	Operating hours at 50% (h/y)	Specific flue gas volume (k Nm^3/y)
Gas oil Turbines	3 (1-5)	23.3	50%	4,400	102,649
	12,5 (5-20)	91.5			402,626
	35 (20-50)	179.3			789,307
Gas oil engines	3 (1-5)	10.2	50%	4,400	45,205
	12,5 (5-20)	42.8			188,357
	35 (20-50)	119.8			527,400
Other liquid fuel engines	3 (1-5)	10.2	50%	4,400	45,205
	12,5 (5-20)	42.8			188,357
	35 (20-50)	119.8			527,400

(1) data from "Analysis of the impact of various options to control emissions from the combustion of fuels in installations with Total Rated Thermal Input <50MW" (DG Environment, 2014)t.

An illustrative example is developed for a medium plant size (12.5 MWth). Table 2-17 shows the calculation from emission concentrations to emission loads per plant. The MCPD does not have requirements on dust or SOx for gas oil engines and turbines, therefore investment on retrofitting these types of MCPs will not be necessary. The emission reduction percentages are based on the selection of a given technology shown below in Table 2-18.

Table 2-17 Example of emission reduction loads for example SIS/MIS plants (12.5 MWth)

Type of plants	Pollutant	Baseline emission level (mg/Nm^3)	Baseline emission load per plant (t/y)	Emission reduction per plant (%)	Achieved emission load per plant (t/y)
Gas Oil engines	NOx	1,271	239	50	120
	SOx	22.1	No MCPD requirements		
	Dust	8.5			
Other Liquid engines	NOx	1,859	349	50	174
	SOx	390	73	90	66
	Dust	24	4	99	4
Gas oil Turbines	NOx	194	78	50	39
	SOx	5	No MCPD requirements		
	Dust	4			

These emission reductions are based on the selection of technologies that are suited for SIS/MIS plants (see Table 2-18). This estimation assumes that the technology used for NOx emissions reduction will be EGR, bag filters for dust and sea water scrubbers for SOx.

Table 2-18 Cost per plant on technology adopted

Pollutant	Technology	Cost (capex +opex) (EUR/MW) (1)	Plant size (MW_{th})	Cost/plant (annualised capex +opex) (EUR/y)
NOx	EGR	191	12.5	2,387
SOx	Sea water scrubber	2,683	12.5	33,537
Dust	Bag filter	1,117	12.5	13,962

(1) Data from Table 4-1 of the Technology Report

Error! Reference source not found. shows emission reduction benefits based on EEA damage cost functions[9]. This has been done for both the EU average damage cost and an average for island Member States (namely Cyprus and Malta) reflecting where SIS and MIS typically operate. Benefits are significantly larger than the costs of abating these pollutants for the common plant configuration (at average plant size). Estimations shows that, even when selecting the most sophisticated (expensive) technologies, the benefits are significantly higher than abatement costs.

Table 2-19 Monetised benefits for example SIS/MIS plants (12.5 MWth)

Type of plants	Pollutant	Emission reduction per plant (t/y)	Damage cost factor EU average (EUR/t)	Damage cost factor island average (1) (EUR/t)	Benefits/Cost EU average (ratio)	Benefits/Cost island average (1) (ratio)
Gas Oil engines	NOx	120	10,650	1,296	535	65
Other Liquid engines	NOx	174	10,650	1,296	776	94
	SOx	66	27,250	3,844	54	8
	Dust	4	66,046	13,169	19	4
Gas oil Turbines	NOx	39	10,650	1,296	174	21

(1) Average for Malta and Cyprus

3.5.4 Observations in relation to achievable set of ELV for SIS/MIS

The analysis described in the previous sections provides evidence on the potential for MCPs in isolated systems to achieve the ELV requirements of the MCPD. Most of the data gathered in the questionnaire shows that MCPs in SIS/MIS have not yet implemented abatement techniques (most probably because ELV for existing plants are not mandatory until 2030). These MCPs face specific constraints when operating in isolated systems which can impact on the selection of technologies to reduce in particular emissions on NOx.

Nevertheless, the analysis has shown the following observations in relation to achievable set of ELV for SIS/MIS ELVs:

(1) New SIS/MIS plants will have less restrictions (on technology applicability) because equipment providers are designing better performing devices and also there are no space availability restrictions to install abatement devices (such as SCRs).

(2) Reported current performance of existing plants meets a number of the MCPD ELVs (not just those in footnotes) and would not require large efforts to meet ELVs for dust and SOx. This was achieved mainly by primary measures since very limited abatement was reported as part of the survey.

(3) There are several technologies for different pollutants not affected by SIS/MIS limitations. Most of the available technologies would be sufficient to ensure that MCPD requirement are met.

(4) Regarding fuel selection: a wider set of cleaner fuels will be available and available volumes will be larger linked to increasing maritime demand. Some isolated systems are also now being connected to mainland natural gas grids.

3 Potential to reduce emissions from new MCPs

3.1 Introduction

This section assesses the potential for setting more stringent ELVs for new MCPs. This task only considers the pollutants and ELVs in the MCPD Annex II Part 2.

As reported in the impact assessment accompanying the Clean Air Policy Package, domestic legislation in a number of Member States includes more stringent ELVs (e.g. in the Netherlands). NOx ELVs for large engines under the NRMM Regulation 2016/1628 are also lower than the MCPD. An improved understanding of current achievable emission levels for new (and existing) MCPs may provide evidence to support the tightening of ELVs for new plants in the MCPD.

The section is structured as follows:

- Section 3.2 describes the data gathered and assessed from questionnaires as part of the information exchange.
- Section 3.3 describes evidence of MCP performance from literature.
- Section 3.4 describes observations in relation to achievable set of ELV for new MCPs.
- Section 3.5 provides an initial high level cost estimation for each plant category and Member State to meet this hypothetical set of revised ELV for new MCPs.

3.2 Analysis of questionnaire data

3.2.1 Data from new MCPs in questionnaires

This section assesses whether newer plants are performing better than existing plants and whether they meet the new plants ELVs from the MCPD.

The MCP information exchange questionnaires included fields to capture the plant age (year of first commissioning). It was agreed with the WG to use performance data from MCPs that have been commissioned recently as an indicator of new plants. Since data was only reported for three plants commissioned in 2018, the definition for “new plants” was extended to include **plants commissioned in 2016 and beyond**.

Out of a total of 281 validated questionnaires, 15 new plants were identified. Table 3-1 summarises the data from new plants that was collected for four different plant categories.

Table 3-1 Data collected from new plants

Technology	Fuel	NO_x #data	SO_x #data	Dust #data	EE #data	Total # questionnaires	Quest. From new plants
Boiler	Biomass	42	19	41	28	46	**6**
Engine	Gas Oil	7	6	7	7	10	**1**
Engines	NG	33	12	5	23	34	**2**
Boilers	NG	71	17	16	48	96	**6**

Complete data analysis for these categories can be found in the Appendix 2 of this Report. This includes analysis of plant age as a potential factor impacting on environmental performance.

In general, the data from these new plants (commissioned 2016 or later) shows that most of them have **similar performance to existing plants**. There are a number of documents (such as the report generated by the energy efficiency task force in LCP BREF[9] or Euromot reports [10]) showing how equipment manufacturers claim to be achieving gradual improvements with time in the long term[11] (see section 5.2.3 of this report).This is not proven by the limited reported data from the questionnaires.

Regarding **NO_x emissions** to air, Table 3-2 presents data on NO_x emission from new plants compared with their corresponding MCPD ELVs as well as with the existing MCPs that returned questionnaires as part of the information exchange.

- In the case of biomass boilers, the new plants do not perform statistically better than existing.
- Regarding gas oil engines: data is from a new engine in a SIS/MIS and the NOx emission value is higher than the median for the existing reporting MCPs.
- New natural gas boilers perform better on NOx emissions than the existing reporting MCPs: their median emission value is 59 mg/Nm^3 which is below the best performers (25th percentile) in this category.
- There is only one data point for new natural gas engines, so it is not possible to draw conclusions although the emission value is close to the median for the existing plants sample.

Table 3-2 NO_x emission performance from new plants

Technology	Fuel	New plants NO_x median (mg/Nm^3)	All existing plants NO_x median (mg/Nm^3)	All existing plants NO_x p25 (mg/Nm^3)	MCPD ELV existing	MCPD ELV new	Technologies reported by new plants
Boiler	Biomass	**103-304**(1)	257	179	650	300 *(2)*	(AS)(LNB)
Engine	Gas Oil	**1,756**	1,271	845	1,850	190*(3)(4)*	-
Engines	NG	**103**	100	49	190	95	-
Boilers	NG	**59**	90	73	250	100	(AS)

(1) Min and max values shown here when the sample size was small to derive median

(2) 500 mg/Nm^3 in the case of plants with a total rated thermal input equal to or greater than 1 MW and less than or equal to 5 MW.

(3) Engines running between 500 and 1 500 hours per year may be exempted from compliance with those emission limit values if they are applying primary measures to limit NOx emissions and meet the emission limit values set out in footnote

(4). Until 1 January 2025 in SIS and MIS, 1 850 mg/Nm^3 for dual fuel engines in liquid mode and 380 mg/Nm^3 in gas mode; 1 300 mg/Nm^3 for diesel engines with ≤ 1 200 rpm with a total rated thermal input less than or equal to 20 MW and 1 850 mg/Nm^3 for diesel engines with a total rated thermal input greater than 20 MW; 750 mg/Nm^3 for diesel engines with > 1 200 rpm.

Regarding **SO_x emissions** to air, Table 3-3 presents data on SO_x emission from new plants compared with their corresponding MCPD ELVs as well as with the new MCPs that returned questionnaires as part of the information exchange.

- In the case of biomass boilers, the SOx values for new MCPs is below the median for the existing plants in this group.
- Gas oil engines data is from a new engine in a SIS/MIS location with lower regulatory pressures (no ELV till 2030). The SOx emission value is higher than the median for the existing MCP population.

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[9] Available in BATIS for LCP BREF review TWG members only

[10] https://www.euromot.eu/wp-content/uploads/2017/03/EU_IED_Review_plants_smaller_than_50_MW_2013-01-04.pdf

[11] https://www.nrel.gov/docs/fy04osti/34783.pdf

- There is no data from natural gas engines or boilers to compare with the existing population.

Table 3-3 SO_x emission performance from new plants

Technology	Fuel	New plants SO_x median (mg/Nm^3)	All existing plants SO_x median (mg/Nm^3)	All existing plants SO_x p25 (mg/Nm^3)	MCPD ELV existing	MCPD ELV new	Technologies reported by new plants
Boiler	Biomass	**4.3**	11	3	200	200	(WS)
Engine	Gas Oil	**26**	22	5	-	-	-

Regarding **dust emissions** to air, Table 3-4 presents data on dust emission from new plants compared with their corresponding MCPD ELVs as well as with the rest of the MCPs that returned questionnaires as part of the information exchange. This table shows that new biomass boilers are not performing better than the rest of the population. There is no data from other types of new plants.

Table 3-4 Dust emission performance from new plants

Technology	Fuel	New plants dust (mg/Nm^3)	All existing plants Dust median (mg/Nm^3)	All existing plants Dust p25 (mg/Nm^3)	MCPD ELV existing	MCPD ELV new	Technologies reported by new plants
Boiler	Biomass	10	11	3.9	30/50	20/30/50	-

3.2.2 Correlation of emissions values with plant age in each category-pollutant

For each data set (MCP cluster) there is a comparison of environmental performance with plant age. In the majority of cases (32 combination plant categories with pollutants), the plant age was not a key factor influencing the emission performance i.e. data from more modern plants (commissioned later) do not seem to be significantly better than those that were commissioned earlier.

There are some exceptions where plant age was proven as a significant factor i.e. new plants performing better than older plants. This was identified for:

- Boilers using other solid fuels (both dust and SOx).
- Engines using other liquid fuels (SOx)
- Multifuel boilers (dust): weak correlation but no high emission values for new MCPs

3.2.3 Data from best performing plants in questionnaires

For many plant categories, the best-achieved emission levels **(defined as 25th percentile for purpose of this study**) are below the ELVs for new plants in the MCPD. Section 3.4 compares the best achieved emission levels in questionnaires with Member States ELVs and MCPD ELVs. This section is only a summary of questionnaire data achieved by best performing plants.

Regarding MCPs using **solid fuels,** both biomass and other solid fuels best achieved levels are below the MCPDs ELVs for dust and SO_x. All best achieved NO_x values are also below the ELVs except for larger plants (5-50 MW_{th}) in other solid fuels.

Regarding MCP using **liquid fuels**: the data from boilers is scarce and the data from engines comes from old SIS/MIS engines most of which are using fuels with high sulphur content (0.8%). The best-achieved levels are above MCPDs ELVs in both NO_x and SO_x and well below for dust ELVs.

Regarding **gaseous fuels**: most data in questionnaires comes from plants using natural gas. In all categories the best achieved levels are well below the MCPD ELV for NO_x. There are no ELVs for dust or SO_x.

3.3 Evidence from literature sources

The Technology Report provides a complete analysis per each MCP plant type of the evidence found in the literature review (from both national regulations and other sources such as MCP warranty data). This section summarises this evidence. Section 3.4 compares the best achieved emission levels in questionnaires with Member States ELVs and MCPD ELVs.

The emission limit values from different Member States is a useful reference because it provides an indication as to what emission values should be achievable by MCP operators. The tables presented in this section provide data from the most stringent ELVs currently in place in one or more Member State in each MCP category. In most cases, there are ELVs from Austria, Netherlands or Belgium that are lower than the MCPD limit values. Green cells show where the evidence (from literature or Member State ELVs) is lower than MCPD requirements. The performance values (other than national ELVs) are compiled under the “literature” column in these tables.

Regarding MCPs using **solid fuels**: the most stringent Member State ELVs for NOx and dust are significantly below the ones in MCPD . Member State ELVs for SOx are below the MCPD limits for other solid fuels. There are also performance values from literature below the MPCD ELVs for all three categories including also performance values from literature using SCR. (see Table 3-5).

Table 3-5 Member States and literature ELVs for solid fuels MCPs

			Dust (mg/Nm^3)		SO_2 (mg/Nm^3)		NO_X (mg/Nm^3)	
Fuel	**Type**	**MWth**	MS ELV	literature	MS ELV	literature	MS ELV	literature
Solid biomass	Boiler	1-5	20	0.5-10	200	1-24	275	70
		5-20	5		200		145	
		20-50	5		200		145	
Other solid	Boiler	1-5	5	5-45	200	250	100	45-90
		5-20	5		200		100	
		20-50	5		200		100	

Legend: Green cells denote where evidence is lower than MCPD’s ELVs for new plants.

Member States have set NOx ELVs for **MCPs using liquid fuels** at levels that are well below the ELVs in the directive. This is the case for all fuels/plant types (except gas oil engines). There are also national level ELVs on dust and SOx for gas oil boilers and turbines to limit emission from these sources (although these are not regulated in the directive) (see Table 3-6). No robust data from literature for dust and SOx emission from these MCPs has been identified.

Table 3-6 Member States and literature ELVs for liquid fuels MCPs

			Dust (mg/Nm^3)		SO_2 (mg/Nm^3)		NO_X (mg/Nm^3)	
Fuel	**Type**	**MWth**	MS ELV	literature	MS ELV	literature	MS ELV	literature
Gas oil	Boiler	All	5	-	200	-	120	35-50

			Dust (mg/Nm^3)		SO$_2$ (mg/Nm^3)		NO$_X$ (mg/Nm^3)	
Fuel	**Type**	**MWth**	MS ELV	literature	MS ELV	literature	MS ELV	literature
Gas oil	Engine	All		-		-	190	118
		All (^{1})					225	
Gas oil	Turbine		5	-	50	-	65	-
Other liquid	Boiler	1-5	5	-	200	-	120	-
		5-50	5	-	200	-	120	-
Other liquid	Engine	1-5	3	-	65	-	150	150
		5-50	3	-	65	-	150	
		1-5 (1)	3	-	65	-	150	
		5-50 (1)	3	-	65	-	150	
Other liquid	Turbine	1-5	3	-	65	-	50	-
		5-50	3	-	65	-	50	-

Legend: Green cells denote where evidence is lower than MCPD's ELVs for new plants. Grey cells denote that pollutant not covered by ELVs in the MCPD.
(^{1}) Dual fuel engine in liquid mode

Regarding MCPs using **gaseous fuels**: there are some ELVs that are identical in (the most stringent) Member State regulations and the directive. This is the case for the NOx ELV for small natural gas engines as well as natural gas turbines. This is also the case for SOx in other gaseous fuels. In the majority of plant categories, the most stringent ELV in Member States for NOx is below the one in the directive (see Table 3-7). No robust data from literature for dust and SOx emission from these MCPs has been identified.

Table 3-7 Member States and literature ELVs for gaseous fuels MCPs

			Dust (mg/Nm^3)		SO$_2$ (mg/Nm^3)		NO$_X$ (mg/Nm^3)	
Fuel	Type	MWth	MS ELV	literature	MS ELV	literature	MS ELV	literature
Natural Gas	Boiler	All	5		35		70	15
Natural Gas	Engine	1-2,5			10		95	5-11
		1-2,5 (1)			10		95	
		2,5-50			10		35	
		2,5-50 (1)			10		35	
	Turbine	All			10		50	6-11
Other gaseous	Boiler	All	5		5		120	49
	Turbine	All			10		50	
Other gaseous	Engine	1-2,5			15		35	
		2,5-50			15		35	

Legend: Green cells denote where evidence is lower than MCPD's ELVs for new plants. Grey cells denote that pollutant not covered by ELVs in the MCP.
(^{1}) Dual fuel engine in gas mode

3.4 Achievable ELVs for new plants

3.4.1 Criteria

This section presents an overview of achievable set of ELVs for new MCPs using the following criteria:

(i) The ELVs are presented as a **single value** (not as a range) to provide consistency with the current approach used in the MCPD.

(ii) It is assumed that those environmental issues that were not relevant in the past assessment (e.g. dust for gas engines) will remain the same. This means that plant categories that **did not have an ELV** for a given pollutant in the MCPD will remain the same, because expected contributions to overall emissions are low from those sources.

(iii) For each plant category-pollutant combination the most stringent achievable emission value is selected based on the evidence presented in this section. This has been selected as the **lower value among** the available evidence from the following options:

- Data from best performing plants from the survey: p25 (**defined for the purpose of this study**) only when sample size is larger than 7 data points, or
- Literature review: the most stringent Member State ELV or data from literature review.

3.4.2 Solid fuels

For MCPs using solid fuels, an achieved set of ELVs for NOx would be based for small biomass plants on the survey (189 mg/Nm^3) and underpinned by Member States ELVs for the remaining categories. The achieved ELVs for dust can be based on survey data for every plant category. SOx ELVs should be based on the survey for biomass plants and Member State ELVs for other solid fuels (see Table 3-8).

Table 3-8 Achievable ELVs for solid fuel MCPs

		Dust (mg/Nm^3)			SO$_2$ (mg/Nm^3)			NO$_x$ (mg/Nm^3)		
Type	MW	Survey	MS ELV	MCPD	Survey	MS ELV	MCPD	Survey	MS ELV	MCPD
Solid biomass boiler	1-5	3	20	50	5	200	200	189	275	500
	5-20	4	5	30	5	200	200	173	145	300
	20-50	4	5	20	5	200	200	165	145	300
Other solid boiler	1-5	9.5	5	50	365	200	400	322	100	500
	5-20	9.5	5	30	365	200	400	322	100	300
	20-50	9.5	5	20	365	200	400	322	100	300

Legend: green cells denotes the source used to select the achievable ELV for each cluster (lowest value among sources)

3.4.3 Liquid fuels

For NOx and SOx, data from the survey has not been useful since most MCPs were SIS/MIS engines with ELVs applicable only in 2030. Achievable ELVs are based on Member State ELVs. For dust, some engines from the survey were reported to be using dust filters. (see Table 3-9).

Table 3-9 Achievable ELVs for liquid fuel MCPs

			Dust (mg/Nm^3)			SO$_2$ (mg/Nm^3)			NO$_x$ (mg/Nm^3)		
Fuel	**Type**	**MW**	**Survey**	**MS ELV**	**MCPD**	**Survey**	**MS ELV**	**MCPD**	**Survey**	**MS ELV**	**MCPD**
Gas oil	Boiler	1-50	No ELV (dust, SO$_2$) for these plants in MCPD						-	120	200
	Engine	1-50							844	-	190
		1-50(1)							844	-	225
	Turbine	1-50							-	65	75
Other liquid	Boiler	1-5	-	5	50	-	200	350	-	120	300
		5-50	-	5	20	-	200	350	-	120	300
	Engine	1-5	2.6	3	20	228	65	120	1,613	150	190

Fuel	Type	MW	Dust (mg/Nm^3)			SO_2 (mg/Nm^3)			NO_X (mg/Nm^3)		
			Survey	MS ELV	MCPD	Survey	MS ELV	MCPD	Survey	MS ELV	MCPD
		5-50	2.6	3	10	228	65	120	1,613	150	190
		1-5 (1)	2.6	3	20	228	65	120	1,613	150	225
		5-50 (1) (2)	2.6	3	10	228	65	120	1,613	150	225
	Turbine	1-5	-	5	20	-	65	120	-	50	75
		5-50	-	5	10	-	65	120	-	50	75

Legend: green cells denotes the source for the used to select the achievable ELV for each cluster (lowest value among sources). Grey cells denote that pollutant not covered by ELVs in the MCP.
(1) Duel fuel in liquid mode; (2) Diesel engine below 20MW with low rpms

3.4.4 Gaseous fuels

For NOx, the data from questionnaires on natural gas engines and turbines can underpin achievable ELVs for natural gas engines above 2.5 MW. This is also the case for other gaseous fuel boilers. For SOx, the evidence is different for every category (survey, MS ELVs and MCPD. There are no ELVs for dust in these categories under the MCPD (see Table 3-10).

Table 3-10 Achievable ELVs for gaseous fuel MCPs

Fuel	Type	Mw	Dust (mg/Nm^3)			SO_2 (mg/Nm^3)			NO_X (mg/Nm^3)		
			Survey	MS ELV	MCPD	Survey	MS ELV	MCPD	Survey	MS ELV	MCPD
Natural Gas	Boiler	1-50	No ELV (dust, SO_2) for these plants in MCPD						73	70	100
	Engine	1-2,5							49	95	95
		1-2,5 (1)							49	95	190
		2,5-50							49	35	95
		2,5-50(1)							49	35	190
	Turbine	1-50							26.2	50	50
Other gaseous	Boiler		No ELV (dust) for these plants in MCPD			2.6	5	35	26.7	70	200
	Turbine					-	10	15	-	50	75
	Engine	1-50				-	15	15	-	35	190

Legend: green cells denotes the source for the achievable ELV selected for each cluster (lowest value among sources). Grey cells denote that pollutant not covered by ELVs in the MCP.
(1)Duel fuel engine in gas mode.

3.5 Cost of measures

This section describes the costs required for MCPs to achieve set of ELVs based on an initial high-level estimation from the above section. This is done using the following basic steps that are described in the following sections:

- Section 3.5.1 explains how more efficient technologies have been selected.
- Section 3.5.2 describes how the cost for every plant type can be estimated.
- Section 3.5.3 describes the steps to project cost for each MS population of MCPs.
- Section 0 describes observations in relation to achievable set of ELV for new MCPs

Assumptions and limitations for every estimation step are described accordingly recognising that this is simply a high-level estimate at this stage and more in-depth assessment would need to be undertaken to deliver a more robust estimate. The tool used for this estimation is provided in Appendix 1 of this document.

3.5.1 Step 1. Technologies required

This section identifies and selects technologies required per plant type for the achievable set of ELVs for new plants.

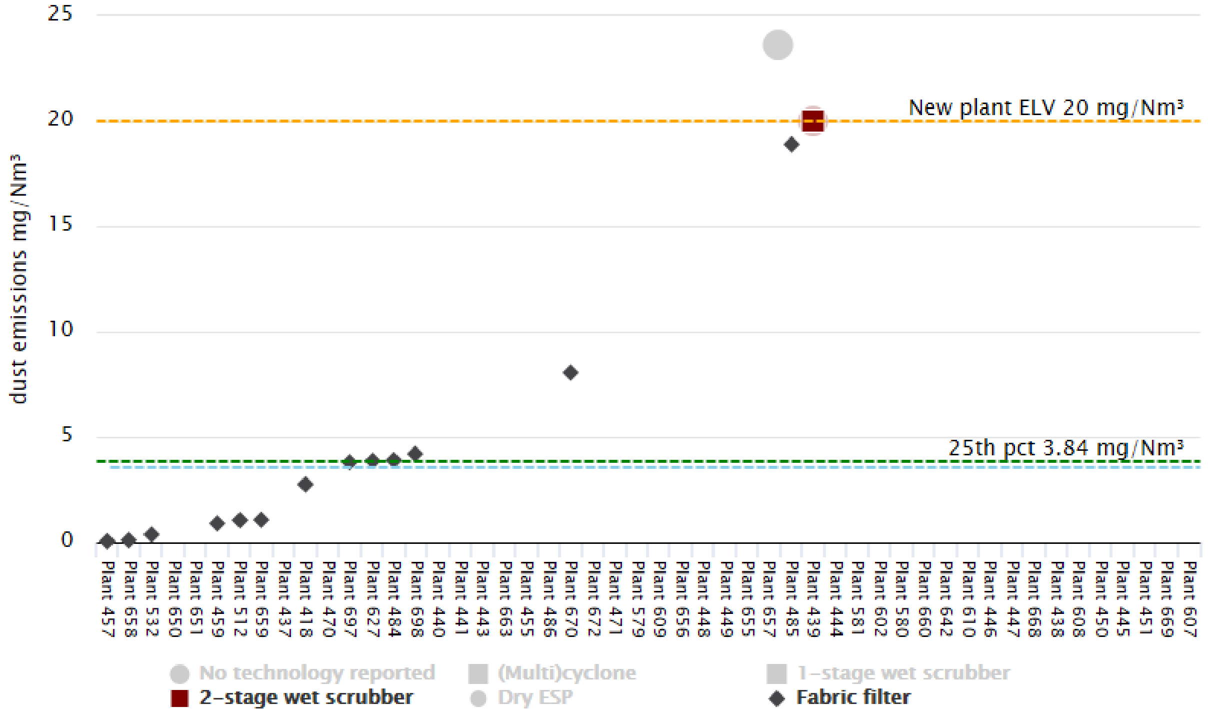
3.5.1.1 Approach

The following steps have been taken:

1.1 Confirm baseline (current emission levels): This was done assigning technologies that are required to meet the current MCPD ELVs for new plants. These technologies should be delivering emission levels below the ELVs based on data gathered from the questionnaires.

Example: for solid biomass boilers 4 mg/Nm^3 is the achievable ELV for new plants. The data from survey proves that most plants using bag (fabric) filter achieve this value. See figure x.

Figure 3-1 Example of technology selection to ensure new ELV are met (solid biomass boilers)



Limitations: technology selection (for each ELV set) is based on average values achieved with every option. Maximum and minimum values delivered by most technologies may vary significantly from these average values.

1.2 Define which technologies are required: Technologies identified to meet an achievable set of ELVs (if any) should have higher abatement efficiencies than those assumed in the baseline. Data from questionnaires was reviewed to ensure that these technologies deliver lower emission values than the baseline.

Limitations: This approach may overestimate the technologies required to meet any new ELVs as some might be achievable with a combination of various primary technologies (e.g. EGR with LNB) with a lower cost (or achievable under the baseline with now further changes).

1.3 Compare both technologies: the abatement efficiencies and the unit cost (EUR/MW) were compared for each plant type.

Assumption: For those cases where the ELV difference is smaller (revised ELV is 33% or less than existing ELV), the estimation assumes improvements with time and/or plant optimisation will be able to achieve those emission levels with the same technology (expert judgement). This is based on the assumption that there is an overdesign margin e.g. if the existing ELV is 150 mg/Nm^3 and the revised one is 100 mg/Nm^3, our approach assumes that plant optimisation will be sufficient to reach revised ELV by increasing the dose of NH_3 (in a SNCR) or increasing the scrubber recirculation flowrate (dependent on pollutant).

Limitation: The method assumes that the baseline emission levels are the current MCPD ELVs for new plants as this is what they have to achieve. This does not take into account any plants operating in Member States where more stringent limits (than MCPD) are already in place i.e. it may lead to an overestimation of benefits and costs. Nor does it take into account that some new plants might be able to meet any revised ELVs without any further changes.

Table 3-11 shows the technologies that have been assigned to deliver the achievable set of ELVs for new plants. All these technologies have higher abatement efficiencies than those assumed to deliver the baseline values (existing ELVs for new plants). In some cases (such as natural gas boilers) the new ELV is close to the existing ELV so we have assumed that there is no need to change the technology selection.

Table 3-11 Technologies to achieve ELV scenario in section 3.4

Pollutant	Fuel	plant	Difference: Achievable ELV vs current ELV (baseline) (%)	Baseline technology	% abatement baseline	Technology required for achievable set of ELV	% abatement new technology
NO_x	Solid biomass	Boiler	45-52	EGR	40	SCR	90
	Other solid fuels	Boiler	67-80	EGR	40	SCR	90
	Liquid fuel	Boiler	40-60	EGR	40	SCR	90
	Liquid fuel	Engines and G.T.	0-33			Similar ELV	
	Natural gas	Boiler	30			Similar ELV	
	Natural gas	Engines and G.T.	48-74	FS, LB	40	SCR	90
	Other gaseous	G.T.	33			Similar ELV	
	Other gaseous	Engines and boilers	82-87	LNB	50	SCR	90
SO_2	Solid biomass	Boilers	98	FC		DS	90
	Other solid fuels	Boilers	50	FC		DS	90
	Liquid fuels	Boilers, engines and G.T.	43-46	FC		WS	94
	Other gaseous fuels	Boilers	93	FC		WS	94
	Other gaseous fuels	Engines and G.T.	0-33			Similar ELV	
Dust	Solid biomass	Boilers	80-94	MC	65	BF	99
	Other solid fuels	Boilers	75-90	MC	65	ESP	98
	Liquid fuels	Boilers, engines and G.T.	50-90	None		BF	99

Legend: orange cells denotes that achievable ELV can be reached with technology in use (optimising plant performance)

3.5.2 Step 2. Cost and benefits per plant type

The cost estimations are based on the new technologies to be adopted per plant type (that were selected in the previous step/section). Table 3-12 shows the technology cost (EUR/MW) under both the baseline and achievable set of ELVs. These costs are total annualised cost (Capex plus Opex). For each plant type an extra cost has been calculated as the difference between these two scenarios.

Limitation: the method does not take into account the cross-media effect of one technology in reducing other pollutants e.g. a wet scrubber may have been selected to reduce SOx but the impact on dust emissions reduction has not been taken into account.

Limitation: the approach does not take into account cost to retrofit existing plants as the focus is on new plants only nor specific flexibilities in the directive for plants in SIS/MIS (such as ELVs applying only after 2025).

Table 3-12 Cost data for selected technologies

Pollutant	Fuel	Plant type	Technology required for achievable set of ELV	Cost of new technology (1) (EUR/MW)	Cost of existing technology (EUR/MW)	Extra cost (EUR/MW)
NO_x	Biomass	Boilers	SCR	3,730	191	**3,539**
	Other solid fuel	Boilers	SCR	3,730	191	**3,539**
	Liquid fuel	Boilers	SCR	3,730	191	**3,539**
	Liquid fuel	Engines and G.T.	Similar ELV			**-**
	Natural gas	Boiler	Similar ELV			**-**
	Natural gas	Engine and G.T.	SCR	3,730		**3,730**
	Other gaseous	Turbine	Similar ELV			**-**
	Other gaseous	Engine and Boilers	SCR	3,730	51	**3,679**
SO_2	Biomass	Boiler	Dry S	756		**756**
	Other solid fuel	Boiler	Dry S	756		**756**
	Liquid fuels	Engine, boiler and G.T.	WS	2,683		**2,683**
	Other gaseous	Boilers	WS	2,683		**2,683**
	Other gaseous	Engine and G.T.	Similar ELV			**-**
Dust	Biomass	Boiler	BF	1,107	302	**805**
	Other solid fuels	Boiler	ESP	2,535	302	**2,233**
	Liquid fuels	Engine, boiler and G.T.	BF	1,107	0	**1,107**

(1) Data from Table 4-1 of the Technology Report (average value)

Legend: orange cells denotes that achievable ELV can be reached with technology in use (optimising plant performance)

In order to estimate a cost per year, the following sources of information were required for the calculation:

- Cost per plant for each technology – these are based on the Technology Report. These costs are consistent with MCPD impact assessment report and were reviewed by WG members. Those costs were expressed as EUR/MW.

- Flue gas flow rates and yearly average plant loads for each different plant type have been taken from "*Analysis of the Impacts of Various Options to Control Emissions from the Combustion of Fuels in Installations with a Total Rated Thermal Input below 50 MW*" (Amec, 2016), to ensure consistency with previous MCP regulatory analysis. Some of these loads are very low and leading to lower emission reduction loads.
- Cost data to estimate environmental benefits per pollutant have been taken from EEA reference central case for EU average.

The estimation of costs (and benefits) for reducing emission for these MCPs plant categories requires several steps. First, an emission load estimation was calculated based on both emission concentration reduction values and flue gas volumes for each type of plant. After doing this exercise for every pollutant, these are grouped for every plant type generating an overall annual cost per plant type (that includes NOx, SOx and dust extra abatement costs). The results are shown in Table 3-13. Some plant types such as natural gas boilers or other gaseous fuels turbines will require no additional cost to meet the revised sets of ELVs because these have been assumed to be achievable with baseline technology (i.e. technology that is expected to be applied to meet the current ELVs in the MCPD for new plants). There are a number of plant types with significant additional cost due to the need to incorporate sophisticated (expensive) devices such as SCRs or ESPs.

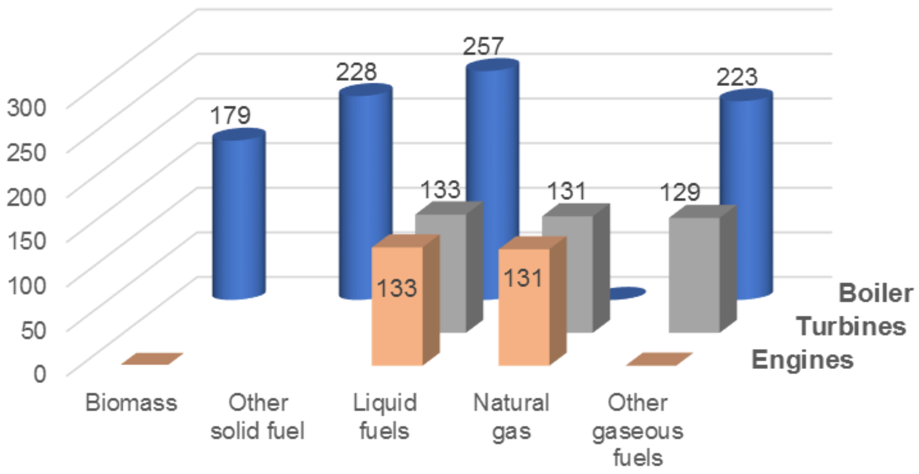
Table 3-13 Additional annual cost per plant category to achievable ELV scenario in section 3.4 (cost per plant in each category)

Fuel	technology	MW range	**Total cost (K EUR/y)**	**SOx cost** (EUR/y)	**NOx cost** (EUR/y)	**Dust cost** (EUR/y)
Biomass	Boiler	1-5	15	2,268	10,617	2,415
		5-20	64	9,450	44,238	10,063
		20-50	179	26,460	123,865	28,175
Other solid fuel	Boiler	1-5	20	2,268	10,617	6,699
		5-20	82	9,450	44,238	27,913
		20-50	228	26,460	123,865	78,155
Liquid fuels	Boiler	1-5	22	8,049	10,617	3,321
		5-20	92	33,538	44,238	13,838
		20-50	257	93,905	123,865	38,745
	Engines	1-5	11	8,049	0	3,321
		5-20	47	33,538	0	13,838
		20-50	133	93,905	0	38,745
	Turbines	1-5	11	8,049	0	3,321
		5-20	47	33,538	0	13,838
		20-50	133	93,905	0	38,745
Natural gas	Boiler	1-5	0	0	0	0
		5-20	0	0	0	0
		20-50	0	0	0	0
	Engine	1-5	11	0	11,190	0
		5-20	47	0	46,625	0
		20-50	131	0	130,550	0
	Turbine	1-5	11	0	11,190	0
		5-20	47	0	46,625	0
		20-50	131	0	130,550	0
	Boiler	1-5	19	8,049	11,037	0

Fuel	technology	MW range	**Total cost (K EUR/y)**	**SOx cost** (EUR/y)	**NOx cost** (EUR/y)	**Dust cost** (EUR/y)
Other gaseous fuels		5-20	80	33,538	45,988	0
		20-50	223	93,905	128,765	0
	Turbine	1-5	0	0	0	0
		5-20	0	0	0	0
		20-50	0	0	0	0
	Engine	1-5	11	0	11,037	0
		5-20	46	0	45,988	0
		20-50	129	0	128,765	0

When taking a closer look at the results for the largest plants (20-50 MWth) it is apparent that boilers are the one expected to incur the greatest costs to meet revised ELVs (with the exception of natural gas boilers). Turbines and engines seem to have a lower cost than boilers (with other gaseous fuels requiring no extra cost). See Figure 3-2 below.

Figure 3-2 Comparative cost per plant/fuel type at a given size (20-50 MWth)



The emission reduction loads have been used to **estimate benefits.** There are a few reasons why the monetary benefits that have been estimated are, in few cases, below the additional cost required. The main drivers for this are the low yearly average load factors used (based on previous MCP studies done in the past). Yearly costs are fixed and calculated for the (maximum) plant design size while annual benefits will be proportional to the effective load used during the year (which is proven to be low for many MCPs).

The following sensitivity analysis was carried out to illustrate this finding for all fuels and plants configuration. Table 3-14 presents the cost benefit ratios (benefits divided by cost) for baseline load assumptions (e.g. 1847 h/y for 1-5 MW boilers) and higher ones (working all year at 100% except circa one-month maintenance shutdown). For higher all many emission reduction benefits exceed the abatement costs associated with potential stricter ELVs. For example, for mid-size boiler (5-20 MWth) using natural gas operating 8,000 hours per year the environmental benefits will be 49% higher than the abatement cost (1.49 ratio) while when operating 2,945 hours per year the environmental benefits achieved by reducing emissions will be only 55% of the abatement costs for these plants. The root cause for benefits being lower in turbines (e.g. than engines) is that the emission reduction in NOx is smaller: 25 mg/Nm^3 emission reduction (while in engines is 40 mg/Nm^3).

Table 3-14 Impact of load assumptions on CBA calculations

Fuel	Technology	Size (MWth)	Baseline Load (h/y)	Benefits/ cost (baseline)	High Load (h/y)	Benefits/ cost (high load)
Biomass	Boiler	1-5	1,847	4.60	8,000	19.91
		5-20	2,945	5.58	8,000	15.17
		20-50	1,894	3.14	8,000	13.25
Other solid fuel	Boiler	1-5	1,847	6.44	8,000	27.90
		5-20	2,945	7.75	8,000	21.06
		20-50	1,894	4.38	8,000	18.49
Liquid fuels	Boiler	1-5	1,847	2.28	8,000	9.87
		5-20	2,945	2.83	8,000	7.69
		20-50	1,894	1.15	8,000	4.84
	Engines	1-5	1,847	1.51	8,000	6.54
		5-20	2,945	1.89	8,000	5.13
		20-50	1,894	1.21	8,000	5.13
	Turbines	1-5	1,847	1.35	8,000	5.86
		5-20	2,945	1.64	8,000	4.45
		20-50	1,894	1.40	8,000	5.90
Natural gas	Boiler	1-5	1,847	No costs	8,000	No costs
		5-20	2,945		8,000	
		20-50	1,894		8,000	
	Engine	1-5	1,847	0.67	8,000	2.88
		5-20	2,945	1.06	8,000	2.88
		20-50	1,894	0.68	8,000	2.88
	Turbine	1-5	1,847	0.34	8,000	1.49
		5-20	2,945	0.55	8,000	1.49
		20-50	1,894	0.35	8,000	1.49
Other gaseous fuels	Boiler	1-5	1,847	0.72	8,000	3.11
		5-20	2,945	1.14	8,000	3.11
		20-50	1,894	0.74	8,000	3.11
	Turbine	1-5	1,847	No costs	8,000	No costs
		5-20	2,945		8,000	
		20-50	1,894		8,000	
	Engine	1-5	1,847	2.27	8,000	9.85
		5-20	2,945	3.63	8,000	9.85
		20-50	1,894	2.33	8,000	9.85

3.5.3 Step 3. Projection of MCP cost for each Member State

The effort required by each different Member States to meet the achievable set of ELVs in section 3.4 for new MCPs may be different. This is assessed in this section of the report.

The projected population of new MCPs per Member States is required in order to estimate the cost of achieving more stringent ELVs (than currently in the MCP Directive). This analysis has used the MCP population data developed in Amec (2016).

Limitation: due to timescales of the Amec report that gathered data on MCP population across EU, the data is available for EU27 Member States and Croatia was not included. This estimation, based in Amec data, could not deliver estimates for Croatia (HR).

The following assumptions were used in this population trend estimation:

- The energy supply/demand for combustion plants per country remain stable. This assumption is based on energy demand slightly increasing per year but there are greater shares of other energy generation approaches (such as renewables). These two changes lead to a stable combustion energy demand.
- The plant lifetime is assumed identical for all types of combustion plants.
- We have assumed that the existing population has a stable age distribution e.g. this is not the case for liquid fuels engines, many of them being rather old so that more new engines would be needed soon.
- We have applied an assumed MCP lifetime (30 years) to estimate plant turnover per year. This leads to 1/30th of the population requiring a new asset per year or circa one third of the MCPs requiring investment every 10 years.

Limitation: the final Amec (2016) report aggregates plant population data by fuel (with no distinction between technologies). The data was available in the underlying model but was not available for this contract. The following table was used in order to disaggregate plant types per technology for all Member States. The data available (in the Amec Final Report) does not provide a disaggregation per technology while the cost for abating emission in a turbine is different from cost of abating emissions in a boiler. Table 3-15 below describes the assumptions used to disaggregate the MCP population by MCP technology.

Table 3-15 Quotas of technologies per fuel and sizes

Fuel	Biomass			Other solid fuel			Liquid fuel			Natural gas			Other gaseous fuel		
Size (MWth)	1-5	5-20	20-50	1-5	5-20	20-50	1-5	5-20	20-50	1-5	5-20	20-50	1-5	5-20	20-50
Boiler	100	100	100	100	100	100	30	30	30	10	20	30	40	40	40
Engine							60	60	60	30	20	10	40	40	40
Turbine							10	10	10	60	60	60	20	20	20

Using the available data and those underlying assumptions a projection was made to estimate the cost per Member States of achieving a revised set of ELVs for new MCPs. The **overall cost** per country is mainly driven by the estimated number of new MCPs in that country: larger countries such as Germany, France or UK have a larger overall cost (for meeting a revised set of ELVs for new plants) than smaller countries.

Another indicator may be more useful to describe the efforts required per Member States: the average cost per new MCP was calculated dividing the overall cost for new MCPs to meet a more stringent set of ELVs by the number of forecasted new plants in that country. This is shown in Table 3-16. This indicator presents a higher value when there are more expensive plants to retrofit (e.g. solid fuelled boilers). This indicator will be lower when there is a high share of engines in that given Member States.

- Countries such as Finland, Poland or Romania have the highest cost per plant (>30 k euro/y) because they also have a higher share of boilers.
- Other Member States such as UK, Slovenia or Netherlands have a lower average cost (<20 k euro/y) because they have a lower share of boilers in their MCP population.

Table 3-16 Average cost per MCP to achieve ELV scenario in section 3.4 per Member State (K EUR/y/new plant)

Effort to meet revised ELVs					
Lower		**Medium**		**Higher**	
MS	Average cost (k EUR/y/new plant)	MS	Average cost (k EUR/y/new plant)	MS	Average cost (k EUR/y/new plant)
SI	14.1	EL	21.4	SE	24.4
NL	17.7	DK	21.5	LV	24.5
LU	18.3	BE	21.5	PT	24.5
CZ	18.8	SK	21.9	IE	24.7
UK	19.1	BG	21.9	EE	26.2
HU	19.9	LT	22.3	FR	27.0
IT	20.3	CY	23.5	RO	30.2
ES	20.4	MT	23.5	PL	34.9
AT	20.8	DE	23.9	FI	76.2

Note: Data for Croatia (HR) on MCP population was not available in the main information source (Amec, 2016).

3.5.4 Observations in relation to achievable set of ELV for new MCPs

- There is sufficient evidence from literature and questionnaires to prove that lower ELVs are achievable. There is a large number of pollutant-plant categories with lower ELVs than the MCPD ELV in one/various Member States and plant data from questionnaires.
- Data from literature (and regulatory documents) prove that combustion plant performance improves in the mid-term with time: new plant being built are more efficient and generate less emissions. Nevertheless, the questionnaires show that the MCP performance is driven by other factors (e.g. emission limit values already set in their permits, where they have one) and the majority of MCP categories show weak or no correlation with plant age.
- There are various plant types (some engines and turbines) with no assumed extra cost to meet this revised set of ELVs for new plants. Since these are new investments yet to be made, the operator would have freedom to select those MCP types (instead of choosing more expensive such as boilers) e.g. regardless of Finland having a large population of boilers, a new Finnish operator analysing a new MCP investment (under the revised ELV) could consider selecting a turbine.
- The information available and the tool to estimate the cost for Member States has a large number of limitations and several assumptions were made leading to high uncertainties.
- The average loads of these MCPs was assumed to be low and may be lower with further accelerated introduction of renewable energy investments. Low loads equate to low benefits, yet costs are typically based on plant size so are fixed irrespective of plant load.

4 Potential to set ELVs for CO on MCPs

4.1 Introduction

This section assesses the potential for setting ELVs for CO emissions.

The section is structured as follows:

- Section 4.2 describes contextual information from literature on CO emissions.
- Section 4.3 describes technologies to reduce CO.
- Section 4.4 describes impacts on human health.
- Section 4.5 describes evidence of MCP performance on CO from survey (questionnaires).
- Section 4.6 describes benefits on CO emission reduction.
- Section 4.7 describes observations in relation to achievable set of CO ELV ranges

4.2 Contextual information

4.2.1 CO emission dependence on combustion unit characteristics

The different combustion technologies (boiler, gas turbines and engines) present significant differences with respect to CO emissions. This variability is shown in various technical references (such as the LCP BREF). In particular, and based on LCP BREF data, older gas engines are likely to have relatively high CO emissions compared to gas boilers. Oil and gas-fired boilers are likely to emit less CO than solid fuel boilers. Regarding solid fuels, pulverised and grate boilers are likely to emit less CO than a fluid-bed boiler.

Table 4-1 shows examples of indicative performance for each of the combustion types. Fuel selection also has a clear impact on emission ranges.

Table 4-1 Indicative CO values for each combustion plant type (LCP data) at 50 MWth

Fuel	Type	Size (MWth)	Indicative CO emissions ranges in LCP BREF (mg/Nm^3)
Other solid	Boiler	50	30-140
Solid biomass	Boiler	50	30-250
Gas oil	Boiler	50	10-30
Natural gas	Boiler	50	5-40
Gas oil	Engine	50	50-175
Natural gas	Engine	50	30-100
Natural gas	G. T.	50	5-40

4.2.2 CO emission dependence with NOx emissions and efficiency

This section discusses findings on a CO-NOx correlation identified from literature review.

It can be challenging to minimise the generation of NOx and CO emissions in the combustion chamber at the same time. This section summarises this interdependence and the approaches to overcome it.

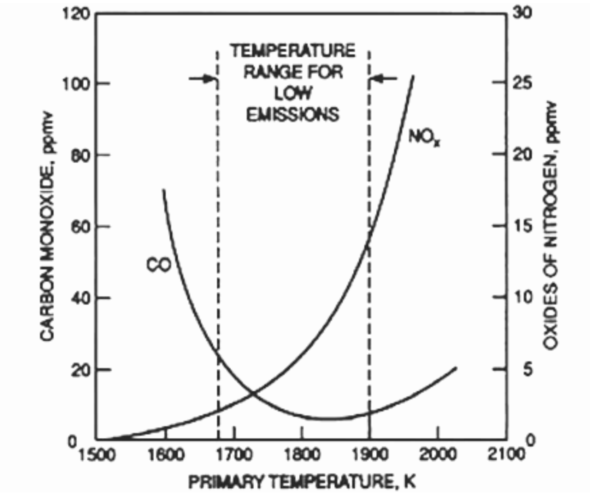
<u>Basic principle of combustion</u>: When burning hydrocarbons, the ideal reaction would result in the formation of carbon dioxide (CO_2) and water (if no sulphur or nitrogen compounds are present). However due to incomplete combustion processes (lower temperatures) carbon monoxide (CO) is also

formed, since CO_2 and CO form an equilibrium (Boudouard equilibrium) which is strongly temperature dependent.

Compromise on temperature control: Therefore, it is necessary to achieve sufficiently high temperatures in the combustion process to ensure a low formation of carbon monoxide. However, the nitrogen content (78 %) of combustion air also reacts during fuel combustion resulting in nitrogen oxides (NO_X). The content of nitrogen oxides formed is also highly temperature dependent, as with higher temperatures more nitrogen oxides are formed. The resulting NO_X emissions are therefore called thermal NO_X (which are not related to possible NO_X emissions resulting from nitrogen compounds present in the fuel). To control the emissions of CO and NO_X at the same time it is therefore important to perform the combustion in a controlled temperature window.

Figure 4-1 shows the correlation between the formation of CO and NO_X depending on combustion temperature (for a gas turbine). Due to the opposite temperature dependencies for the formation of the different pollutants, a specific temperature window has to be maintained to achieve a controlled combustion with low pollutant concentrations.

Figure 4-1: Effect of primary-zone temperature on NOx and CO emissions in a gas turbine (Lefebvre, A. H., 1998,)



Another parameter which directly depends on the combustion temperature achieved is energy efficiency. To achieve a high fuel utilisation, the combustion temperature should be as high as possible.

Air/fuel ratio: In the case of reciprocating engines there exist two major combustion modes to achieve the above-mentioned approaches:

- Stochiometric (close to 1 lambda, rich)
- Lean (larger 1.5/1.6 lambda)

For gas engines the primary approach to reduce NO_X formation is the lean-burn concept. Lean-burn combustion increases the air-to-fuel ratio to reduce the peak temperature of the flame and therefore reduces the thermal NO_X formation.

Due to the higher air ratio, higher compression ratios or peak firing pressures are possible, which result in higher efficiencies. However, lean mixtures may result in an incomplete combustion increasing the emissions of CO and unburnt hydrocarbon compounds.

An alternative way to achieve low emissions is to operate the engine in a lambda region close to 1 (stochiometric combustion). The primary emissions of NO_X and CO are higher than those from lean combustion but with a 3-way catalyst the emissions can be significantly reduced (below the level of lean combustion). However, the energy efficiency of the stochiometric combustion is lower than with the lean-burn concept. This is mainly a result of high pumping work, lower possible compression ratios and large heat losses. To overcome this drawback, it is possible to apply the recirculation of exhaust gas (EGR) which allows efficiencies which are comparable to the lean-burn technology (Saanum, I., Bysveen, M., Tunestål, P., & Johansson, B. (2007)[12]).

Example from MCP manufacturer: Engine manufactures (such as MWM) estimate that reducing NOx emissions from 500 to 250 mg/Nm^3 will lead to an increase in CO of 20-30% for most of their engine models.

Operator strategy: Therefore, for any engine or boiler there are generally trade-offs between low NO_X emissions, low CO emissions and a high energy efficiency. There are three main approaches to manage these trade-offs that may come into play, depending on regulations and economics.

- One approach is to **control for lowest NO_X** accepting a fuel efficiency penalty and possibly higher CO and hydrocarbon emissions.
- A second option is finding an optimal balance between emissions and efficiency.
- A third option is to **design for highest efficiency** and use post-combustion exhaust treatment to control emissions if required for permitting purposes.

The case study below helps to illustrate some of the potential trade-offs between NOx, CO and efficiency.

Illustrative example: gas engine. Optimal lean-burn operation requires sophisticated engine controls to ensure that combustion remains stable and NOx reduction is maximized while minimizing emissions of CO and VOCs. An added performance advantage of lean-burn operation is higher output and higher efficiency resulting from the higher compression ratios. Table 4-2 shows data for a large lean-burn natural gas engine and illustrates the trade-offs between NOx emission control levels and efficiency. In both cases (MAN and WARTSILA engines), in order to obtain the lowest achievable NOx levels, more than one efficiency percentage points are lost.

Table 4-2 Examples on higher NOx emissions for lower CO combustion regimes[13]

Data from combustion unit	Low NOx regime	High efficiency (low CO) regime
Unit model	Wartsila 18V34SG Pre-chamber Lean-Burn Gas Engine	
Size (MWth)	5.2	5.2
Engine speed (rpm)	720	720
Energy efficiency (%)	**40.7**	**42**
NOx emissions (ppm v 15% O_2)	49	92
CO emissions (ppm v 15% O_2)	361	227
Unit model	MAN 15 MWe, NM = 70	
Size (MWe)	15	15
Energy efficiency (%)	43.3	44.8
NOx emissions (mg/Nm^3)	75 (no SCR)	200 (SCR required)

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[12] Lean burn versus stoichiometric operation with EGR and 3-way catalyst of an engine fueled with natural gas and hydrogen enriched natural gas. In SAE Transactions Journal of Engines (3 ed., Vol. 116). [2007-01-0015] Society of Automotive Engineers. DOI:10.4271/2007-01-0015]

[13] Based on engine manufacturer's data – Wartsila 18V34SG Prechamber Lean-Burn Gas Engine

Data from combustion unit	Low NOx regime	High efficiency (low CO) regime
CO emissions (mg/Nm^3)	<100 (with catalyst)	<100 (with catalyst)

4.2.3 Cost of CO monitoring

The standard reference method (SRM) for monitoring of CO is the non-disperse infrared spectroscopy (NDIR) which is described in EN15058:2017. The costs of CO monitoring per stack generally show a wide range due to different factors, which include also:

- Nature of parameters
    - number of parameters to be measured (regarding type of installation)
    - special processes which require monitoring of additional parameters (e.g. SCR, SNCR)
- Economies of scale
- Measurement site
    - location of the measurement site (indoor/outdoor)
    - requirement of an air-conditioned room
    - distance and number of sampling points and analysers

Costs for continuous emission monitoring systems (CEMS) are reported in the range from approx.

- The Monitoring of Emissions to Air and Water from IED Installations (MON) REF provides cost for monitoring various pollutants in combustion plant: Capex ranging from 15 to 82 thousand GBP and Opex in the circa 6 thousand GBP. Combustion pollutants (NOx, CO, SOx, CH_4) are commonly measured by Fourier-transform infrared spectroscopy(FTIR) and the same device will be normally used to measure all of them. Very rarely would an installation only measure CO.
- EUR 30,000 to EUR 250,000 for the investment (CAPEX) and approx. EUR 10,000 to EUR 20,000 for the yearly operational costs (OPEX) (Mussatti, et. al, U.S. Environment Protection Agency[14]),

It should be noted that these price ranges for measurement systems provide measurements of different parameters and thus no specific price for the isolated measurement of carbon monoxide is available.

4.3 CO emission reduction technologies and measures

The primary measure to reduce CO emissions is to achieve a controlled and complete combustion. To control the relevant combustion parameters a suitable monitoring system (e.g. O_2, CO, CO_2) is necessary. Further to combustion control, primary measures can also be taken such as air staging or fuel staging.

Additional to primary measures, different end-of-pipe measures may be applied to reduce CO emissions. Those secondary measures generally include a catalytic process to propagate the oxidation of unburnt hydrocarbons (including CO).

The best technologies to reduce emissions of CO from MCPs are described in Table 4-3 below. Their cost and efficiency values will vary on a case by case basis and would also depend on the NOx control strategy. Since most of these techniques are applied in combinations with others, it is difficult to assign a precise efficiency range for each of them.

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[14] EPA/452/B-02-001; 2000, T.W. Chien , H. Chu , W.C. Hsu , T.K. Tseng , C.H. Hsu & K.Y. Chen

Table 4-3 Best technologies for CO reduction technologies

Technology	acronym	Used in best performers (questionnaires)	**Abatement efficiency (%)** *(2)*	Applicability restrictions
Air staging	(AS)	Biomass and natural gas boilers	Variable	Applicable to boilers
Fuel staging	(FS)	-	Variable	
Oxidation catalysts	(OC)	Natural gas and other gaseous fuel engines	Up to 90%	Engines and turbines. The applicability may be limited by the sulphur content of the fuel. The maximum flue-gas temperature is limited to about 560 °C.
Combustion optimisation	(CO)	Other liquid engines	Variable	Generally applicable

Data gathered from European MCPs in the questionnaires shows that:

- There are numerous MCPs that are not taking specific measures to reduce CO emissions;
- Fuel and air staging are the most common measures in best performing boilers;
- For engines, some best performers are using oxidation catalysts.

4.4 Summary of CO impact on environment and human health

Although CO emissions from petrol-engine road vehicles have been greatly reduced by the introduction of catalytic converters, road transport is still the most significant source of this pollutant (in most developed countries). People are more likely to be exposed to dangerous concentrations of CO indoors, due to faulty or poorly ventilated cooking and heating appliances. Cigarette smoke is also a major source of exposure[15].

CO affects the ability of the blood to take up oxygen from the lungs and can lead to a range of symptoms. The primary toxicological effect of carbon monoxide results from its very high affinity to human haemoglobin. Carbon monoxide has a binding affinity to haemoglobin which is over 200 times greater than that of oxygen[16]. Due to this competitive reaction the ability of haemoglobin to bind oxygen is severely affected and the oxygen supply of the body is significantly reduced.

- High level exposure: A high intoxication with CO can lead to death by suffocation[17].
- Low-level exposures to carbon monoxide are suspected to cause adverse effects for the heart and cardiovascular system, the central nervous system, and foetus and neonate.

CO can also contribute to the formation of ground-level ozone. There are other wider indirect impacts due to the fact that CO and unburnt hydrocarbons (e.g. methane) will follow the same trend. When CO emissions are high, there will also be higher GHG emissions leading to climate change impacts (with aftermath/consequences on human health and the environment).

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[15] NAEI, PHE Compendium of Chemical Hazards

[16] Toxicological Profile for Carbon Monoxide – U.S. Department of Health and Human Services – Agency for Toxic Substances and Disease Registry, 2012

[17] https://uk-air.defra.gov.uk/assets/documents/annualreport/air_pollution_uk_2017_issue_1.pdf

4.5 CO emissions analysis based on questionnaires

4.5.1 CO emission baseline

Table 4-4 provides a summary of the data from questionnaires compared with indicative values taken from the LCP BREF for 50 MW_{th} plants. Data on CO emissions is available for most plant categories. For plant categories with robust data sets, the average values of CO emissions are generally well below the indicative values (~85% of plants for which data was reported).

Table 4-4 Summary of CO emissions analysis from questionnaires

Fuel	Type	CO emission p25 -median (mg/Nm^3)	Technologies	Indicative CO reference (LCP BREF 50 MW) (mg/Nm^3)	MCP plants meeting indicative value (%)
Solid biomass	Boiler	65-141	(FS)	250	**72**
Other solid fuel	Boiler	34-98	Not reported	140	**57**
Gas oil	Boiler	(5, 33, 244)(2)		30	**33**
	Engine	54-78		175	**85**
	G. T.	(5, 8) (2)		No reference	
Other liquid fuel	Boiler	(2, 11) (2)		30	**100**
	Engine	57-82	(OC)	175	**87**
Multifuel	Boiler	(67, 278) (2)	Not reported	30	**0**
Natural Gas	Boiler	3-7	(AS)	15	**89**
	Engine	25-41	(OC)	100	**95**
	G. T.	4-8	(FS)	40(1)	**89**
Other gaseous fuel	Boiler	2-14	Not reported	35	**92**

Note (1) there is one Member state ELV of 100 mg/Nm^3 for CO in this plant category; (2) Raw data points available only (neither median nor p25 was derived)

4.5.2 Correlations between CO and key drivers in questionnaires

Root cause analysis: The complete data analysis for each MCP category includes a root cause assessment to identify key factors influencing performance. The correlation between CO emissions and selected key factors is summarised in Table 4-5. The data is not conclusive across most plant categories. There are a few isolated correlations such as bigger gas oil engines emitting more CO.

Table 4-5 Factors affecting CO emissions in data from questionnaires

Fuel	Type	**Age:** Do new plants emit less CO?	**Size:** Do small plants emit less CO?	**Loads:** Do plants operating at higher loads emit more CO?
Solid biomass	Boiler	No correlation		
Other solid fuel	Boiler	Yes (scarce data sets)	No correlation	
Gas oil	Engine		Yes (R^2:0.78)	No correlation
Other liquid fuel	Engine	No correlation		
Multifuel	Boiler			No sufficient data
Natural Gas	Boiler			No correlation
Natural Gas	Engine			

Fuel	Type	**Age:** Do new plants emit less CO?	**Size:** Do small plants emit less CO?	**Loads:** Do plants operating at higher loads emit more CO?
Natural Gas Other gaseous fuel	G. T. Boiler			

Legend: Green cells used when proven correlation; Yellow cells when potential correlation with scarce data

CO emissions in new plants: The data sets gathered in questionnaires provide information to determine whether "new plants" (defined in this project as those commissioned after 2016) have lower CO emission values. A summary of this comparison is presented in Table 4-6 below. Results are not statistically significant to support the hypothesis of new plants delivering lower CO emissions. The CO emission data from new plants is scattered around median performance (both higher and lower than CO emissions) for older plants. Only in new natural gas engines do the CO emissions seem to be lower (below average).

Table 4-6 Comparing CO emissions in new MCPs

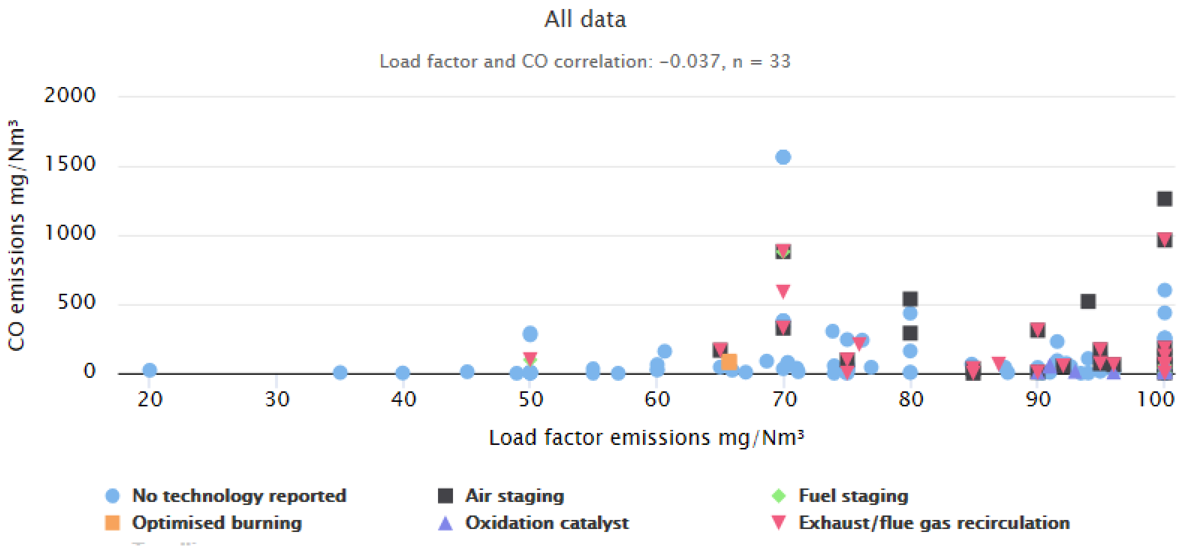
Technology	Fuel	New plants CO p25 –median (mg/Nm^3)	Existing plants CO median (mg/Nm^3)	Existing plants CO p25 (mg/Nm^3)	Indicative CO reference (LCP BREF 50 MW) (mg/Nm^3)
Boiler	Biomass	(43.2-229)(2) outlier 877	95.7	46	250
Engine	Gas Oil	No data	87	75	175
Boiler	Gas oil		No data		30
Engines	NG	(8-41)	45	22	100
Boilers	NG	(0.18-67)	6.8	3	15

(2) Raw data points available only (neither median nor p25)

Statistical data analysis has also been undertaken to determine whether there were correlations between CO, NOx and efficiencies across all MCP categories (where sufficient data was available). Full details of the analysis were included in the Final Technology Report.

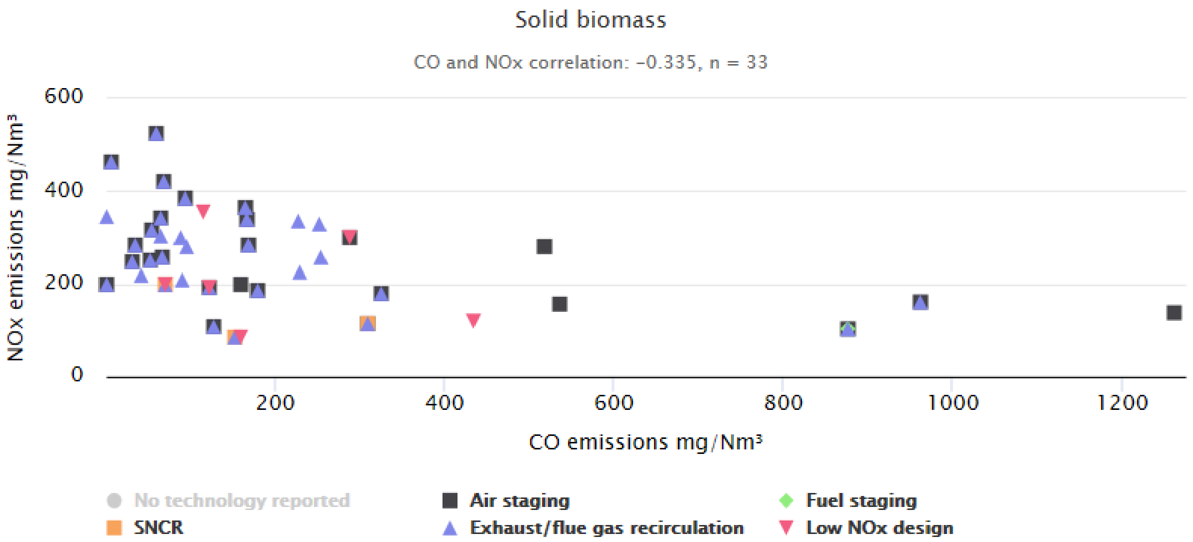
Plant load: Most data was collected with plants operating at 70% load or beyond. The figures generated included the identification of different abatement technologies. **No clear correlation can be derived from the overall data set on CO emissions versus plant load**. The same analysis has been carried out for each plant type / fuel category in a disaggregated manner with a similar outcome i.e. no clear correlation with load.

Figure 4-2 Correlation of CO emission vs plant load using aggregated data



<u>Correlation with NOx emissions</u>: no clear correlation was identified for the aggregated data set. In some plant categories, such as solid biomass boilers, higher NOx emission values were generated at lower CO emission levels. Figure 4-3 shows this weak (R^2 <0.4) correlation. This is consistent with literature reports of increased NOx emission associated with increased excess air levels on unabated boilers.

Figure 4-3 Correlation CO-NOx emission for biomass boilers



The combustion strategy applied in the plants that provided data cover a range of different practises. Some of them will control combustion aiming to minimise NOx with others aiming to increase energy efficiency. Some other plants will operate only to cover energy demand peaks or power supply cuts. These different operating modes and potentially other factors will influence NOx and CO emissions, but no clear correlation was determined at aggregated levels.

<u>Correlation with energy efficiency</u>: one could expect that lower overall energy efficiencies (monitored by “total fuel utilisation”) are achieved when the plant runs at incomplete combustion (higher CO emissions). The data gathered in the questionnaire cannot prove this hypothesis neither for the

aggregated data set nor for individual plant categories. More information is available in section 5.4 of this report.

4.5.3 Achievable CO ELVs based on data from questionnaires

Table 4-7 provides achievable CO ELVs based on the questionnaire data. Identical ELVs for new and existing plants are provided taking into account that CO emission data from plants commissioned from 2016 onwards was not significantly lower.

The numerical approach to provide the each achievable ELV range is based on the following statistical data analysis:

- The upper value of the range represents the median CO emission value of the corresponding plant category.
- The lower value of the range represents p25 of the CO emission data in questionnaires.

Table 4-7 shows the CO ELV achieved for each plant category. Generally speaking, these ELVs are similar to the indicative values selected in the LCP BREF for larger plant sizes and same plant categories. For some plant categories with scarce data, it was not possible to provide ELVs based on data from questionnaires.

Table 4-7 Achievable CO emission limit value based on data from questionnaires

Fuel	Type	Achievable CO ELV range (mg/Nm^3)	Comments	Indicative CO reference (LCP BREF 50 MW) (mg/Nm^3)
Solid biomass	Boiler	67-141		30-250
Other solid fuel	Boiler	34-98		30-140
Gas oil	Boiler	40-80	Scarce data	10-30
	Engine	54-78		50-175
	G. T.		Scarce data	
Other liquid fuel	Boiler		Scarce data	10-30
	Engine	57-82		50-175
	G. T.		Scarce data	
Multifuel	Boiler		Scarce data	5-30
	Engine			
	G. T.			
Natural Gas	Boiler	2-6		15
	Engine	25-41		100
	G. T.	5-8		5-40
Other gaseous fuel	Boiler	2-14		5-100
	G. T.	16-40		5-20

4.6 Estimation of cost and benefits

This section provides indicative monetary estimates, in terms of avoided emissions, potential carbon and air pollutant benefits of applying an achieved CO emission limit.

Illustrative example: Table 4-8 deploys emission reduction calculations for some MCP plant categories. These estimations have been done assuming an average load of 50% throughout the year. The example assumes that plants have a CO emission equal to the median value reported via the questionnaires. These estimations assume that the CO emission reduction achieved is 50% for combustion optimisation (CO) and 90% for oxidation catalyst (OC).

Table 4-8 CO emission reduction examples

Type of plants	Plant size (MW)	Baseline emission per plant (mg/Nm^3)	Baseline emission load per plant (t/y)	Emission reduction per plant (%)		Emission reduction per plant (t/y)	
				OC(1)	CO(2)	OC (1)	CO(2)
Gas oil engines	3	78	3.5	90	50	3.1	1.8
	12.5	78	14.7	90	50	13.2	7.3
	35	78	41.1	90	50	36.9	20.6
Other liquid engines	3	82	3.7	90	50	3.3	1.9
	12.5	82	15.4	90	50	13.8	7.7
	35	82	43.2	90	50	38.9	21.6

(1): OC: oxidation catalyst; (2) CO: combustion optimisation

The CO abatement cost is provided in Table 4-9. Oxidation catalyst (OC) costs are estimated for different MCP sizes. This information on catalyst was included in Technology Report but based only on one questionnaire. Cost data for combustion optimisation (CO) was not available. Applicability restrictions (from the Technology Report) have been taken into account and also the total annualised cost.

Table 4-9 Total yearly cost per plant on technology adopted

Technology	Cost (EUR/MW/y)	Plant size (MW)	Cost/plant (EUR/y)
Oxidation catalyst (OC)	5000	3	15,000
		12.5	62,500
		35	175,000

Table 4-10 provides an overview of costs versus benefits. There is no CO damage cost function available from the EEA or other European sources. However, these values are readily available in other regulatory frameworks such as traffic and mobility activities (UCLA Center for Health policy Research)[19]. The cost of abatement technologies is far larger in both cases than benefits from CO emission reduction. However, we cannot state that these measures are not viable because they also reduce other pollutants and these benefits are not accounted for here.

Table 4-10 Monetised benefits for one CO emission reduction (oxidation catalyst)

Type of plants	Emission reduction per plant (t/y)	CO damage cost (EUR/t)[18]	Benefits (EUR/y)	Benefits/Cost (ratio)
Gas oil engines	3.15	199	627	0.04
	13.23		2,633	0.04
	36.99		7,361	0.04
Other liquid engines	3.33	199	663	0.04
	13.86		2,758	0.04
	38.88		7,737	0.04

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[18] See table 5.104-8 in "Transportation Cost and Benefit Analysis II – Air Pollution Costs" https://healthpolicy.ucla.edu/Documents/Newsroom%20PDF/tca0510.pdf

4.7 Observations in relation to achievable set of CO ELV ranges

To date, the European regulatory focus has been predominantly on reducing NOx (and other pollutants) rather than CO emissions. As discussed in previous sections there is a trade-off between the two so that minimising CO emissions can lead to higher NOx emissions but also better combustion efficiencies (lower shares of unburnt fuel).

There are a number of observations in relation to achievable ELVs for CO emissions:

- **CO values in air quality measurements in the EU are seldom high:** the EU air quality limit of 10 mg/m^3 for CO has been in place since 1st January 2005 (maximum daily 8-hour mean). However, no EU country reported an exceedance of the CO air quality standard in 2014. The only exceedance reported in 2014 within the European Economic Area was at an urban industrial monitoring station in the former Yugoslav Republic of Macedonia. Average measured CO concentrations (across all EU measurement station types) declined 45% between 2000 and 2014.
- **Most values captured in the questionnaires remain below indicative values** (from LCP BREF for plants at 50 MWth). This could reflect the fact that operators are obviously willing to have a compromise of NOx emission and energy efficiency and not willing to lose unburnt hydrocarbons (to avoid higher operating costs) nor running plants at inefficient ratios. Energy efficiency data proves that most plants are interested in an optimised combustion operation, rather than sole focus on NOx minimisation.
- **CO health impact are lower than NOx health impact.** Since it is not possible to minimise both pollutants, a strategy to minimise NOx is preferred (driven by tighter NOx ELVs). If NO_X ELV are to be revised, then this will be a hurdle for setting CO limits.
- **CO is not the key factor for ozone generation**: Carbon monoxide is an ozone precursor but trends in CO air quality concentrations are not matched in ozone trends reflecting the fact that other pollutants such as NOx and VOCs are playing a more important role.
- **High cost of monitoring if continuous:** A key factor for CO emissions is that relatively small and localised changes in temperature and/or air supply can prevent complete oxidation and have a dramatic impact on CO emissions. This can cause very variable concentrations with concentrations fluctuating by multiple orders of magnitude within short periods. This variability can also mean that spot or short-term monitoring may be of limited benefit for assessing CO emissions. Use of continuous monitoring for CO provides more opportunity for operators to manage CO emissions effectively and should not have a significant impact on MCP monitoring costs.
- Indicative cost-benefit analysis indicates that abatement cost seems higher than emission reduction benefits (although impacts on other pollutants have not been accounted so the benefits are underestimates).
- **Measure of efficiency, useful to ensure energy efficiency and improve profitability:** CO is a key indicator of combustion efficiency (that is the completeness of oxidation of carbonaceous components in fuels); the overall efficiency of the conversion of energy in the fuel to provide useful energy is influenced by the combustion efficiency but generally other factors will have a greater influence. Such factors include the excess air level (which in extremes will also impact combustion efficiency), ambient temperature, exhaust gas temperature and the operation (duty) and configuration of the MCP (for example open cycle or cogeneration gas turbines). Nevertheless, as proven by low CO emission values from questionnaires, operators seem to be keeping energy efficiencies (and CO emissions) close to optimal values.

- **Minimise hazardous emissions:** CO is a key indicator of combustion efficiency and good combustion control is a primary control measure for other products of incomplete combustion including dust and non-MCPD pollutants such as Polynuclear Aromatic Hydrocarbons (PAHs).
- **Reduce citizen exposure to toxic gas:** Many EN Standards for smaller (residential) combustion appliances include monitoring of CO in exhaust gases as part of the appliance test for assessing efficiency and consumer safety reasons as CO is also a toxic gas.
- **Some Member States have proven that it is possible to set ELVs on** CO for some key plants type that generate higher CO emission values.

5 Potential to set EE ranges for MCPs

5.1 Introduction

This section assesses the potential for setting performance ranges for energy efficiency.

The section is structured as follows:

- Section 5.2 describes contextual information from literature on energy efficiencies.
- Section 5.3 describes technologies to maximise efficiency.
- Section 5.4 describes evidence of MCP performance on energy efficiency from survey (questionnaires).
- Section 5.5 describes cost and benefits related with energy efficiency optimisation.
- Section 5.6 describes observations in relation to achievable EE performance ranges

5.2 Summary of information from literature review on energy efficiency for MCPs

5.2.1 Regulatory instruments covering energy efficiency in combustion plants

A number of European mechanisms touch upon energy efficiency (EE) matters for combustion plants, these are summarised in Table 5-1. This overview shows that most of them do not cover the 1 to 50 MWth scope of the MCPD and do not set direct legally binding requirements (e.g. EU ETS).

Table 5-1 Overview of European regulations for EE on combustion plants

Instrument	Scope	Limit values	Comments
Industrial Emission Directive (2010)	Cover plants with >50MWth (or aggregated in common stack)	No limit values provided	Energy efficiency is a consideration within Best Available Techniques controls.
LCP BREF (2017)		Energy efficiency performance levels (BAT-EEPL) are reference but permit writers could impose in permit	Energy efficiency is a consideration within Best Available Techniques controls.
Energy Efficiency REF (2009)		No limit values provided	Reference document developed under IPPC directive by DG JRC
EU ETS (2009)	>20 MW (exclude biomass)	No limit values provided	The impact assessment determining the rules for harmonised free allocation reports different efficiencies for MCP configurations
Energy Efficiency Directive (2012 emended in 2018)	Not focused on power generation industries		The impact assessment of this directive includes some reference efficiencies to support the study

Instrument	Scope	Limit values	Comments
Eco design of energy using products (2009)	< 1MW		Smaller assets
Promotion of energy from renewal sources -Directive (EU) 2018/2001	Covers medium and large combustion plants (using biomass or other renewal)	No emission limit values	Sets criteria for different promotion features such as rules for financing renewable fuels
Harmonised EE reference values for separate production of electricity and heat (2011)	Combustion units other than CHP	EE values that vary with year of construction, fuel and corrected for climatic conditions	Reference values for both production of electricity and production of heat for each relevant fuel

5.2.2 Criteria for monitoring energy efficiency performance

There are a number of approaches used to describe the efficiency in combustion units. The energy efficiency definition needs to:

- Set a clear boundary where the energy efficiency metric takes place. We suggest defining this boundary around the combustion process. This approach leaves out of the scope those potential losses that occur in other industrial steps (e.g. electricity conversion).
- Be inclusive and applicable for every different energy use (e.g. central heating, electricity generation, etc).

The analysis used in the MCP information exchange was based on the approach agreed for the LCP BREF review whereby energy efficiency is defined as the ratio between the net produced energy (electricity, hot water, steam, mechanical energy produced minus the imported electrical and/or thermal energy, e.g. for auxiliary systems' consumption) and the fuel energy input (as the fuel lower heating value) at the combustion unit boundary over a given period of time.

In the questionnaires, annual average plant efficiency was provided, based on the lower heating value of the used fuel and taking account of all energy imports and exports across the unit. Given the importance of conditions related to energy efficiency, the questionnaire included questions on key parameters/conditions under which the information is provided.

The graphs used to summarise the efficiencies of each MCP plant type include the main energy efficiency types (electrical, mechanical, design efficiency, etc.). This was done in order to facilitate the energy efficiency comparisons between all different plant arrangements: e.g. CHP, combined cycles or mechanical drives plants, etc.

5.2.3 Improved plant design: technology projections to increase efficiencies

This section describes the improvement of MCP efficiency over time. Data from literature and also from questionnaires prove that energy efficiency in combustion units is **improving with time** in the long term. The largest share of energy efficiency performance **is determined by plant design** (not reliant on operator procedure or decisions). The Commission Implementing Decision of 19 December 2011 (establishing harmonised efficiency reference values for the separate production of electricity and heat) provides reference values that increase continuously with the year of construction of the unit.

5.2.3.1 Trends and expectations for efficiencies in new engines

Over time, efficiency has increased, capital costs have fallen, and emissions have declined in industrial engines. Significant private and public-sector investment is expected to result in additional incremental improvements in the next 30 years.

There are several classes of improvements in engines that will make them more suitable for on-site and distributed power generation:

- Efficiencies will improve through increasing pressure (Brake Mean Effective Pressure BMEP) and potentially with the use of thermal barrier coatings. Improved controls will allow lean combustion that optimizes both efficiency and emissions. Increased BMEP and engine speed will increase power output and correspondingly decrease cost per kW of the larger engines.
- Maintenance costs will be reduced as engine life is extended and maintenance intervals lengthened through the use of ceramics and other advanced materials, improved lubricants, and improved engine components.
- More effective integration of systems and controls will reduce the cost of basic engine packages by 10% to 25%. On-site cost of installation will be reduced by greater standardization of system design and auxiliary components. A modular approach with greater factory assembly is expected to greatly reduce site costs, particularly for smaller systems.
- The cost of installing CHP plants will decline, based on member states adopting streamlined siting, interconnection, and permitting procedures that allow for greater standardization of CHP components and packages. Electric utility interconnection costs are projected to be reduced by 50% for systems smaller than 500 kW and by 20% for systems larger than 3 MW.

The following Table 5-2 provides an estimation of these trends for a few engine sizes.

Table 5-2 Energy efficiency improvement projections for engines (The National Renewable Energy Laboratory)

Parameter	(unit)	Data from 2010	Projection 2020	Projection 2030
Unit	**1 MW engine CHP Lean burn**			
Total cost	(EUR/kW)	785	750	714
Elect. efficiency	(%)	38	40	42
Total CHP eff.	(%)	73	73	74
CO emissions	(g/G hp hr)	1.5	1.5	1
Unit	**5 MW engine CHP Lean burn**			
Total cost	(EUR/kW)	732	705	691
Elect. efficiency	(%)	41	43	45
Total CHP eff.	(%)	75	76	77
CO emissions	(g/G hp hr)	2	1.5	1

Suppliers data on energy efficiency: there are engine supplier brochures available providing data on energy efficiency since this has a high impact on customer asset selection (and profitability). Some of these documents show the positive evolution of efficiency with time. Some manufacturers (see Figure 5-1) show positive efficiency increase with loads for various models including competitors[19].

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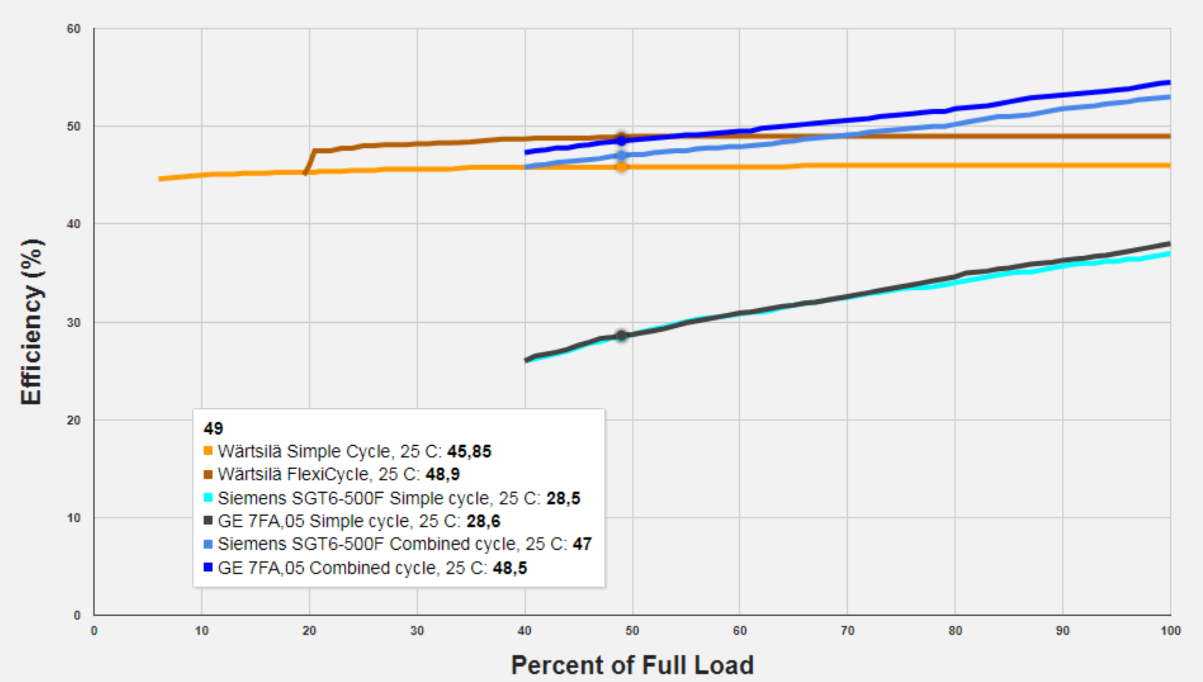
[19] https://www.wartsila.com/energy/learn-more/technical-comparisons/combustion-engine-vs-gas-turbine-part-load-efficiency-and-flexibility

Figure 5-1 engine supplier data on EE variation with loads



5.2.3.2 Trends and expectations for efficiencies in new turbines

Gas turbines performance has been improving with time. The use of gas fuels for combustion units is seen as a cleaner approach and this may have driven more investment in recent years.

Gas turbines smaller than 2 to 3 MW face intense competition from reciprocating engines on the basis of both cost and efficiency. Engine markets such as emergency generation sets and standby units provide sales volumes that afford economies of scale in engine manufacturing and service, further reducing costs of competing engine systems.

- Large improvements in performance are possible through the use of internally cooled nozzles and blades with axial flow expansion turbines.
- Performance of recuperated turbines can be improved by advances in recuperator materials and design methodology.
- Power-generation efficiencies could improve from their present level of the low 20s to levels in the upper 20s, and possibly lower 30s, with application of the technology in practical use on larger gas turbines.

Gas Turbines ranging from 3 to 10 MW face attractive prospects for increased sales and moderate investments in technology improvements. These turbines compete well with similarly sized reciprocating engines in many applications.

- Significant gains in efficiency and specific power are expected through higher turbine inlet temperatures and associated higher optimum pressure ratios.
- The introduction of ceramics or improved internal cooling of nozzles and blades, or a combination of the two technologies, can be expected in this size range depending on individual manufacturer's approaches and specific product requirements.

Gas turbines of more than 10 MW are of two heritages – industrial and aeroderivative. The aeroderivative machines are gas turbines made for aeronautical applications that are modified for stationary use. Their efficiency and performance are determined by the needs of the aeronautical market. Gas turbines of this size also can be expected to benefit from some of the technologies developed for the larger machines.

The use of ceramic hot-section components, nozzles, blades and combustors; or improved internal cooling of nozzles and blades; or a combination of the two technologies can be expected, depending on individual manufacturer's approaches and specific product requirements.

Several classes of improvements can be expected for all sort of gas turbines regardless of their size:

- System heat rates will decline (efficiencies increase) due to advances in turbine blade and vane design; improved tip sealing of rotating blades; and the use of advanced, high temperature materials such as monolithic ceramics and ceramic thermal barrier coatings. Improvements will occur over time, due in part to the diffusion of technology from aircraft turbines to those for stationary power, and the improvement may accelerate with the use of ceramic materials. With increasing temperatures, manufacturers will also increase pressure ratios and obtain corresponding increases in power and decreases in cost per kW.
- Emissions control will be improved with catalytic combustion or other combustion enhancements that allow more economic operation of gas turbine systems than is possible with exhaust gas-treatment approaches.
- More effective packaging and integration of systems and controls will reduce the cost of the basic components. Installation costs will be reduced by greater standardization of design and auxiliary components. A modular approach with greater factory assembly will greatly reduce site costs, particularly for smaller systems.
- The cost of installing CHP plants will decline, as states adopt streamlined siting, interconnection, and permitting procedures that allow for greater standardization of CHP components and packages. These changes in government policy will allow beneficial changes in technology and reductions in lead times.

Table 5-3 Energy efficiency improvement projections for turbines (The National Renewable Energy Laboratory)

Parameter	(unit)	Data from 2010	Projection 2020	Projection 2030
Unit	**5 MWth turbine CHP system**			
Total cost	(EUR/kW)	803	750	723
Elect. efficiency	(%)	30	33	35
Total CHP eff.	(%)	69	71	72
CO emissions	(ppm)	15	15	15
Unit	**10 MWth turbine CHP system**			
Total cost	(EUR/kW)	767	705	678
Elect. efficiency	(%)	32	34	37
Total CHP eff.	(%)	69	71	72
CO emissions	(ppm)	15	15	15
Unit	**25 MWth turbine CHP system**			
Total cost	(USD/kW)	755	705	680
Elect. efficiency	(%)	37	39	40
Total CHP eff.	(%)	73	73	74
CO emissions	(ppm)	15	15	15
Unit	**40 MW turbine CHP system**			
Total cost	(USD/kW)	680	660	640

Parameter	(unit)	Data from 2010	Projection 2020	Projection 2030
Elect. efficiency	(%)	39	40	41
Total CHP eff.	(%)	73	73	74
CO emissions	(ppm)	15	15	15

5.3 Technologies and measures to improve efficiencies

5.3.1.1 Generic measures to improve efficiency

There are a number of generally applicable measures that not only improve efficiencies but can generate impacts across a wider range of issues (e.g. reduce CO and increase efficiency); these are described in Table 5-4. Additional information on each technique can be found in the Technology Report. These measures are applicable to all types of unit: boilers, gas turbines and engines.

Table 5-4 Generic technologies to increase energy efficiencies in MCPs

Candidate best available technology	Description	Most commonly used
Advanced control system (ACS)	The use of a computer-based automatic system to control the combustion efficiency and support the prevention and/or reduction of emissions. This also includes the use of high-performance monitoring.	Gas turbines, engines and boilers
Combustion optimisation (CO) (Optimisation of burning)	Technologies taken to maximise the efficiency of energy conversion, e.g. in the furnace/boiler, while minimising emissions (in particular of CO). This is achieved by a combination of techniques including good design of the combustion equipment, optimisation of the temperature (e.g. efficient mixing of the fuel and combustion air) and residence time in the combustion zone and use of an advanced control system.	
(Boiler) Combustion unit design and size (CDS)	Good design of furnace, combustion chambers, burners and associated devices.	Boilers

The technologies presented in the above table can be disaggregated into individual retrofits, each one having a small contribution to the energy efficiency improvements such as:

- (ACS) using neural network or modern optimisation software 0,5-3 % efficiency can be gained
- (CO) proper calibration and maintenance of instruments and controls may lead to up to 3% improvement.
- (CO) soot blowing: elimination of fouling to improve heat transfer may lead to up to 2% improvement.

5.3.1.2 Specific technologies to increase energy efficiency

This section lists technologies that can improve the energy efficiency of MCPs. The following Table 5-5 provide descriptions for these proven measures. Additional information on each technique can be found in the Technology Report.

Table 5-5 Candidate best available technologies to increase energy efficiency for commercial MCPs

Candidate best available technology	Description	Most commonly used
Combined heat and power (CHP)	Cogeneration is the recovery of heat (mainly from the steam system) for producing hot water / steam to be used in industrial processes/activities or in district heating.	New plants

Candidate best available technology	Description	Most commonly used
	Additional heat recovery is possible from: the flue-gas; grate cooling; the circulating fluidised bed. The heat from the combustion plant (e.g. turbine, engine) flue-gases may be used for steam production in a heat recovery boiler (also called heat recovery steam generator) or be extracted partially (or sometimes fully) and used for steam supply to consumers, who can then use the steam in their own processes or for other purposes such as district heating or seawater desalination.	
Combined cycle (CC)	Combination of two or more thermodynamic cycles, e.g. a Brayton cycle (gas turbine/combustion engine) with a Rankine cycle (steam turbine/boiler), to convert heat loss from the flue-gas of the first cycle to useful energy by subsequent cycle(s).	New plants
Flue-gas condenser (GC)	A heat exchanger where water is preheated by the flue-gas before it is heated in the steam condenser. The vapour content in the flue-gas thus condenses as it is cooled by the heating water. The flue-gas condenser is used both to increase the energy efficiency of the combustion unit and to remove pollutants such as dust, SO_X, HCl, and HF from the flue-gas.	CHP boilers
Dry bottom ash handling (DBA)	Dry hot bottom ash falls from the furnace onto a mechanical conveyor system and, after redirection to the furnace for reburning, is cooled down by ambient air. Useful energy is recovered from both the ash reburning and ash cooling	Solid fuel boilers
Supercritical steam conditions (SCS)	The use of a steam circuit, including steam reheating systems, in which steam can reach pressures above 220.6 bar and temperatures of > 540°C[20].	Boilers
Wet stack (WST)	The design of the stack in order to enable water vapour condensation from the saturated flue-gas and thus to avoid using a flue-gas reheater after the wet scrubber.	Units with wet scrubbers.

5.4 Efficiency analysis based on data from questionnaires

The data collected in questionnaires contained energy efficiency values from 2017. Table 5-6 below summarises the energy efficiency values for each MCP type and compares with indicative reference values from the LCP BREF recently published. The complete data analysis can be viewed in the Technology Report.

For each plant category, the best performers (p75 to median) were compared with the indicative values provided in the LCP BREF for 50 MW_{th} plants (efficiencies increase with plant size). The main outcome of this review is that every plant type that reported data is operating inside the optimal efficiencies (as established in the LCP BREF).

Table 5-6 Energy efficiency data summary from questionnaires

Fuel	Type	Fuel utilisation (%)		Electrical efficiency	
		Survey: mean-p75	Indicative value[(1)]	Survey[(2)] mean-p75	Indicative value[(1)]
Solid biomass	Boiler	77-84	73-99	4-26	28-38

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[20] https://www.researchgate.net/publication/251667915_Analysis_of_small_size_combined_cycle_plants_based_on_the_use_of_supercritical_HRSG

Fuel	Type	Fuel utilisation (%)		Electrical efficiency	
		Survey: mean-p75	Indicative value(1)	Survey(2) mean-p75	Indicative value(1)
Other solid fuel	Boiler	86-90	75-97	Scarce data	31-44
Gas oil	Boiler	Scarce data	80-96	Scarce data	35-37
Gas oil	Engine	38-40		38-40	38-44
Gas oil	Turbine	Scarce data		Scarce data	25-44
Other liquid fuel	Boiler	Scarce data	80-96	Scarce data	35-37
Other liquid fuel	Engine	40-44	No value	38-40	38-44
Other liquid fuel	Turbine	25-44		Scarce data	
Multifuel	Boiler	88	89.5	Scarce data	78-96
Multifuel	Engine	Scarce data			
Multifuel	Turbine				
Natural Gas	Boiler	88-94	78-95	Scarce data	38-40
Natural Gas	Engine	65-91	56-85	38-42	35-44
Natural Gas	Turbine	47-62	65-95	21-37	33-60
Other gaseous fuel	Engine	65-68		37-39	
Other gaseous fuel	Turbine	Scarce data			

(1) Range from LCP BREF for 50 MWth existing plants; (2) Electrical efficiencies may be low for plants with other main aims (mechanical drive, district heating)

Further analysis was carried out to determine the factors influencing energy efficiency. Table 5-7 shows a summary for each MCP category. Green cells show a strong (R^2> 0.7) positive correlation with a given factor, yellow is used for weak correlations (R^2<0,7 or scarce data points).

- For two engine types and natural gas turbines, the efficiencies are higher at higher loads.
- For solid fuel boilers and other gaseous fuels, the new plants present higher efficiencies.

Table 5-7 Factors influencing EE in MCPs

Fuel	Type	**Plant age**: Do new plants have higher EE?	**Plant size**: Do large plants have higher EE?	**Plant load:** Do higher loads have higher EE?
Solid biomass	Boiler	No correlations		
Other solid fuel	Boiler	Weak trend	No correlations	
Gas oil	Engine	No correlations		
Other liquid fuel	Engine	No correlations		Strong correlation (only 5 data sets)
Natural Gas	Boiler	No correlations		
	Engine	No correlations		Strong correlation
	Gas turbine	No correlations		Strong correlation (6 data points)
Other gaseous fuels	Engines	Weak trend	No correlations	

5.5 Cost and benefits

5.5.1 Cost of measures to improve efficiency

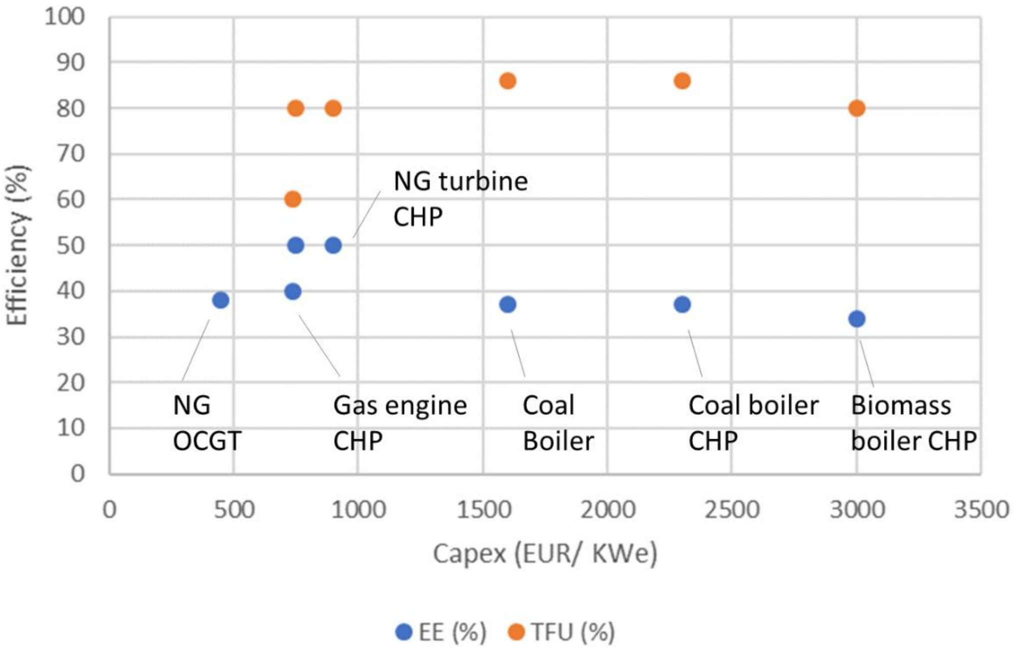
This section describes cost associated with measures to increase energy efficiency in MCPs.

5.5.1.1 Investment cost for new units

The main driver for EE performance of a combustion unit is the design. The final EE values will mostly depend on the investment selection stage e.g. the LCP BREF describes energy efficiency monitoring to be carried out after the first commissioning (or only after major plant retrofits). The total investment cost of combustion units is decreasing with time[21]. EE improvements incorporated by new designs are not generating a price increase in the purchase of new units (see also section 5.2.3 of this document for price trends).

New MCP technology selection is not driven solely by the aim of operator to maximise EE. Thus, fuels or technologies with lower EE may be selected as investment options driven by other factors (such as availability of fuel). There are no clear correlations between EE performance and Capex or Opex, see Figure 5-2 with some reference values i.e. a given MCP design may be selected to minimise Capex despite EE not being optimal.

Figure 5-2 Examples of MCP configurations: Capex vs EE and Total Fuel Utilisation (TFU) (DG JRC[22])



5.5.1.2 Cost of adopting best technologies or efficiency measures

It is difficult to estimate precisely the EE impact of many technologies that can improve MCPs performance. Some of them (such as advanced control systems or combustion optimisation) will have an impact in EE increases that are hard to isolate from other plant design features.

There are a number of these technologies that are only applicable to new plants (e.g. Combined cycle, supercritical conditions or CHP) and this limitation leaves little room for MCP retrofits in existing plants. One can thus compare the marginal capex required to achieve these extra EE gains. Some examples are provided below in Table 5-8 (values provided are averages values, but variability can be high

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[21] https://www.eia.gov/todayinenergy/detail.php?id=31912

[22] https://setis.ec.europa.eu/system/files/4.Efficiencyofheatandelectricityproductiontechnologies.pdf

depending on other design options). Table shows how EE options, such as combined cycles have higher Capex but these deliver higher EE.

Table 5-8 Examples of technologies selected for new plants to increase EE (DG JRC)[24]

Fuel	MCP type	Technology	Average Capex (EUR/kWe)	Average capex (M EUR/ 25 MWth plant)	EE (%)
Natural gas	Gas turbine	No technology (default configuration Open cycle)	450	29.61	33-41
		Combined cycle	750	49.34	46-54
		CHP	900	59.21	(1)
Solid fuels	Boiler	No technology (default configuration Pulverised open cycle)	1,600	105.26	31.5-41.5
		PC CHP	2,300	151.32	(1)
Biomass	Boiler	No technology (default configuration Pulverised open cycle)	2,000	131.58	28-38
		PC CHP	3,000	197.37	(1)

(1) CHP can save 3 to 20 % of total fuel utilisation (TFU) but numerous factors affect this EE increase including plant design and heat demand profiles.

Fuel choice or fuel blending can seldom be used to increase EE since some plants are designed to use a range of fuels. This approach would typically require negligible investment (Capex) but incur increased Opex. This is for example easier to carry out in other solid fuels boilers shifting to coal fuels with higher calorific value. This impact is shown on a coal fired boiler example in Table 5-9. Assuming that the boilers have identical performance (i.e. same ambient and flue-gas temperature, same excess air, etc.), different boiler efficiencies will be achieved based on heating value of the fuel.

Table 5-9 Impact of fuel quality on EE

Coal type	Coal cost 2017 (IEA) (USD/Tn)	Heat value [23] (MJ/kg)	MCP EE [24]	
			Electrical (%)	Boiler (%)
Hard black coal	55.60	>23	44.2	88
Sub bituminous	14.29	17.4-23	43	87
Lignite	19.51	<17,4	41.8	86

5.5.2 Benefits of energy efficiencies increase

There are three benefits that could be valued when increasing energy efficiencies:

(i) Reduction of fuel usage per energy generated: this is developed below in this section.
(ii) Reduction of CO emissions
(iii) Reduction of costs associated with CO_2 emission permits under ETS.

Point (ii) is not so relevant since existing emission values are already low (see section 4.6).

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[23] https://www.world-nuclear.org/information-library/facts-and-figures/heat-values-of-various-fuels.aspx
[24] https://ec.europa.eu/energy/sites/ener/files/documents/review_of_reference_values_final_report.pdf

Table 5-10 estimates the potential economic saving (benefits) at a plant level of increasing EE values for different plant types. Those estimations are based on fuel cost avoidance. There may be high volatility of cost prices in the short and medium terms, so this table only provides an illustrative example. Estimations have been done assuming 50% load average throughout the year (4400 h/y). Benefits (savings) can be significant for larger plants (e.g. 50 MWth).

Table 5-10 Estimation of savings when increasing energy efficiency in MCPs (Wartsila[25])

Fuel	Type	EE gain (%)	Fuel cost (EUR/MWh)	Savings (EUR/MW)
Other liquid fuel (HFO)	Engine	1	103	4120
Natural Gas	Engine	1	155	6200

5.6 Observations in relation to achievable EE performance ranges

To date, the European regulatory tools on energy efficiency for MCPs have been indicative and not legally binding.

There are a number of observations in relation to achievable EE ranges for MCPs:

- There are **many MCP types** and aggregating the whole spectra of plants into a limited set of plant types will be challenging given the large range of technical complexity e.g. gas turbine combined cycle may be labelled as one group, but one can find D, F and G-type turbines depending on the turbine inlet temperature (with significant differences in EE).
- **There are a number of MCPs that could be excluded from these requirements** due to the operational mode or low operational loads. This has been done in other Commission Implementing Decisions.
- **Some of the contributing factors to energy efficiency are complex** and should be taken into account when setting ranges e.g. the impact of load factor on efficiency varies from one technology to another.
- **EE for almost every technology is improving over time** and this is recognised by suppliers and regulators (e.g. Commission Implementing Decision 2011/877). Competition among supplier and technologies drives marginal innovations and optimisation of these devices. This fact supports the need to have a different (lower) efficiency reference value for new plants.
- **EE values provided via questionnaires show that most plants have efficiency ranges** inside BAT-AEPLs from LCP BREF. This is not surprising since all operators have a financial incentive to reduce operational costs.
- **The MCP sector is mature and data from regulatory and scientific literature is consistent on EE capabilities.** The literature survey on EE values and its comparison with questionnaire data confirms similar values. Data on EE per plant type is consistent and there are no challenges on setting indicative values because sufficient information is available to support a range selection for policy development.
- **EE monitoring is not complex or technically difficult.** There is clear consensus on the need to use an indicator that captures the different plant arrangements (mechanical drive, CC or CHP) and that is mainly measuring the plant design efficiency (monitored after commissioning).

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[25] https://cdn.wartsila.com/docs/default-source/services-documents/white-papers/wartsila-bwp---improving-power-plant-energy-efficiency.pdf?sfvrsn=ec29045_10

- **There are significant economic benefits** (associated with fuel savings) that justify operator interest in this matter, in keeping EE as high as possible. There are also certain environmental benefits related to the reduction of GHG emissions.
- **The technologies that improve energy efficiencies** also normally lead to lower emissions to air on key pollutants (e.g. CO) leading to further benefits.
- **Many of these MCPs are not operated by industrial operators (but located in in hospitals, commercial and residential developments, greenhouses, etc.)** but EE is relevant as it is an indicator of the main operational cost. Nevertheless, EE depends mainly on the design of the plants and this (EE ranges requirements) can be requested at assets purchase stage.

Appendices

Appendix 1: Tool to estimate costs of meeting a revised set of ELVs for new MCPs
Appendix 2: Technology Report

Appendix 1 –Cost estimate of the achieved set of ELVs for new MCPs

NewELVselection2019F.xlsx

Appendix 2- Technology Report

Report accessible here:
https://circabc.europa.eu/ui/group/06f33a94-9829-4eee-b187-21bb783a0fbf/library/f4bbf066-1905-4290-8ec2-3ef6507e10db

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