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Assessing the effectiveness of EU policy on large combustion plants in reducing air pollutant emissions

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European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark

Tel.: +45 33 36 71 00
Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

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([1]) http://www.aether-uk.com/CMSPages/GetFile.aspx?guid=14ca8d73-614e-42db-811d-738425f0b218 (accessed 19.11.2018)

Key messages

- Emissions of key pollutants from large combustion plants (LCPs) have significantly decreased in recent years. During the period considered in this report, 2004 to 2015, sulphur dioxide (SO_2) emissions decreased by 81 %, nitrogen oxides (NO_x) by 49 % and dust by 77 %.

- European policy on combustion plants, namely the Large Combustion Plants Directive (LCPD), accounts for most of these reductions, according to the detailed trend analysis performed and a statistical decomposition method that distinguishes the main drivers of individual emission trends.

- The implementation of this policy has played an important role in harmonising the environmental performance of LCPs across the EU and in aligning the levels of health and environmental protection that EU countries provide with regard to SO_2, NO_x and dust pollutants emitted by LCPs. While emission factors in 2004 varied strikingly among EU countries, much smaller (although still relevant) differences remain.

- These policy-driven reductions are a clear success story to build upon. Challenges however remain for the energy sector in terms of transforming it entirely so as to meet the present health and decarbonisation targets required by modern European society.

Executive summary

The Large Combustion Plants Directive (LCPD) was a core instrument of EU legislation, driving reductions in emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and dust between 2004 and 2015. It established a solid mechanism to better monitor these emissions through the annual reporting of inventories of emissions and energy input from combustion plants. Studying how and why it worked offers useful insight for policymakers and informs possible avenues for implementation of other environment policies, namely the Industrial Emissions Directive (IED).

The significance of large combustion plant (LCP) emissions, in particular those from electricity-generating installations, in total anthropogenic emissions of SO_2, NO_x and dust, as well as the transboundary nature of their negative impacts, required harmonised pan-European measures to tackle the problem effectively, efficiently and without distorting the internal energy market.

Emissions from large industrial sources remained among the most significant releases of the three abovementioned pollutants in the period studied (2004-2015) and still represent the largest source of such emissions in many European countries. However, during the LCPD time-frame, a very substantial reduction in LCP emissions was achieved, which contributed decisively to overall emission reductions.

Objectives and scope of this report

This report is a retrospective assessment of the European policy on combustion plants, with a focus on the LCPD. While it addresses the five key aspects of a policy evaluation, i.e. relevance, effectiveness, efficiency, coherence and European value added, the core of the analysis focuses on effectiveness.

In addition, the report explores the causal association between the observed changes, and the LCPD and broader EU policy landscape, by means of various methods, including a statistical technique known as decomposition analysis.

The scope of the analysis covers:

- all EU Member States (28 at the time of writing (EU-28));
- emissions of SO_2, NO_x, dust and, to a lesser extent, carbon dioxide (CO_2);
- the period between 2004 and 2015.

Within this scope, the purpose of this report is to examine the success level of EU policy on combustion plants in terms of addressing emissions of the three abovementioned pollutants, SO_2, NO_x, and dust, as well as some other associated benefits, namely those related to reductions in CO_2 emissions.

Key findings

During the time-frame of the LCPD, the sector dramatically transformed its environmental performance and overall emissions reduced accordingly. While this is clearly a success story, this report tries to identify areas in which the policy could have been more efficient or ambitious so that further benefits could have been reaped.

The LCPD did not operate alone. Multiple policy instruments affected and partially overlapped with the scope of the LCPD during the time-frame of its application, in particular the policies on integrated pollution prevention and control, air quality, climate mitigation and energy.

During the period considered, 2004-2015, this report identifies three different reduction trends, which can be summarised as follows:

- There was a sharp decline in emissions from 2007 to 2009. This can be partially explained by the emission limits imposed by the LCPD (2001/80/EC), which were binding from 2008. While the report is able to identify evidence of a causal relationship through statistical analysis, other drivers also certainly played a role. In particular, the financial crisis that started in 2008 had an effect on emission trends together with changes in pricing for certain fuel types and macroeconomic changes in Europe.

- Emissions then levelled off around 2010 followed by a short period of stability in emissions. This period can be attributed to the maturity of the policy; at that time, the process to replace the LCPD with the IED (2010/75/EU) had started.

- The third trend began in 2014, when emissions started to decrease again. This appears to be in anticipation of the stricter emission limit values imposed by this replacement policy, the IED, which fully came into force in 2016.

Combustion plants are costly and have long lifespans; therefore, investment decisions are affected by multiple factors. The LCPD has been successful in establishing an effective mechanism for operators to invest in the environmental performance of such plants. However, the paradigm of incremental improvements in fossil fuel plants is certainly no longer valid for a sector in which other policy objectives, namely those aimed at mitigating climate change, require rapid decarbonisation through energy efficiency and embracing clean energy sources.

The LCPD is a good example of how a piece of EU law, in combination with other EU instruments, either triggered investments in state-of-the-art pollution reduction measures, such as the pre-treatment of fuels, efficiency gains in the process and end-of-pipe pollution abatement techniques, or led to operators switching to newer, less polluting plants altogether.

The assessment shows a significant improvement in the implied emission factors (IEFs) of LCPs for SO_2, NO_x and dust, which indicates that the environmental performance of the sector has considerably improved. In other words, a decoupling of resource use (i.e. fuel use) and pressure on the environment (i.e. emissions) is apparent.

The LCPD also triggered a general harmonisation of these IEFs across countries. The LCPD started to operate when the EU was benefiting from significant enlargement, which also brought the challenge that the point of departure was very different across EU countries. In particular, those acceding the EU during the first years of LCPD implementation operated with significantly higher IEFs than the existing Member States and improved drastically during the LCPD time-frame, approaching, while not fully achieving, the IEF levels of the other EU Member States. While this is a clear success story, the report also identifies that the LCPD could have been more ambitious: its design, in combination with the Integrated Pollution Prevention and Control Directive, may have suffered from prompting, to a certain degree, a 'lowest common denominator' approach in the permitting of individual plants. This is particularly apparent for the emission limit values for nitrogen oxides and to a lesser extent dust, and for the design of derogation regimes and the accession treaty arrangements in relation to this Directive.

One of the challenges of policy evaluations is combining different lines of evidence to attribute a causal relationship between policies and changes to the reality they address. These changes are the result of highly complex interactions between factors, many of which are not related to policy design. This report uses a statistical technique, decomposition analysis, and supplements it with a literature review to disentangle the contributions of the main drivers of the changes in environmental performance. While the exercise has limitations, this approach identified strong signals that the improvement made by the sector was largely due to the implementation of EU policy.

The role of data in the analysis and knowledge gaps

This report was possible because of the availability of detailed information on the energy input used in the sector and on emissions over time, together with other background data sets (e.g. macroeconomic parameters). But the report was also largely limited by the quality, granularity and availability of data. The comprehensive and solid reporting mechanism established by the LCPD allowed a number of key parameters to be quantified; however, gap filling was also required and a number of calculations rely on high-level assumptions. In that regard, a number of specific knowledge gaps are identified and made explicit in the report.

Addressing these knowledge gaps could enable a more solid policy evaluation and inform the design of future policy interventions. This would also avoid the need for the resource-intensive use and processing of commercial data sets, and enhance transparency.

The LCPD is a success story

The LCPD is thus seen as a success story to build upon. It is a piece of EU law that delivered added value at European level and contributed to achieving the targets of international commitments. The LCPD is, therefore, an example from which European policymakers can learn from going forward.

1 Introduction

The EU Large Combustion Plants Directive (LCPD; Directive 2001/80/EC (EU, 2001a)) was a key instrument for addressing air pollutant emissions. There is solid evidence that the LCPD contributed to lowering these emissions. The EU 'impact assessment accompanying a revised EU Strategy on Air Pollution' (EC, 2013) summarised the contribution of EU versus national source legislation to compliance with ceilings set in the National Emission Ceilings Directive (NECD) for regulated pollutants. It concluded that for both sulphur dioxide (SO_2) and nitrogen oxides (NO_x), action was driven primarily by emission control measures for large combustion plants (LCPs), mainly in the LCPD. This was in combination with other EU legislation (e.g. the Fuel Quality Directive, 98/70/EC, and the Integrated Pollution Prevention and Control Directive (IPPCD, 2008/1/EC)) and national actions taken as part of NECD national programmes (EC, 2013).

Studying how and why the LCPD worked offers useful insight for policymakers and may inform decisions regarding possible avenues for implementing other related environment policies, namely the Industrial Emissions Directive (IED).

The **purpose of this report** is to examine the relevance and effectiveness of EU policy on combustion plants, and especially of the LCPD, in reducing industrial emissions of SO_2, NO_x and dust, while providing EU added value in comparison with national initiatives alone. To that end, this report looks into what the objectives of the LCPD were (Subsection 1.1.4) and to what extent these objectives were met effectively, efficiently and coherently between 2004 and 2015 (Chapter 4). The main assessment questions on which the report is based are outlined in Section 1.2.

The scope of the assessment is limited to the LCPD, including its specific interplay with the regulatory processes set under the IPPCD, and SO_2, NO_x and dust emissions from the combustion installations it covers. Other thematic policies and external factors that contributed to the emission trends and impacts of the LCPD are identified (see Figure 1.1), yet efforts concentrate on distinguishing the effects of the LCPD from these contextual factors.

The period assessed (2004 to 2015) corresponds to the time-frame in which countries were obliged to report annual emission data according to the LCPD. The data reported are most accurate for the period 2007-2015, when these inventories were well established. The year 2015 is also the last one in which the sector was regulated by LCPD. Thereafter, the LCPD had been replaced by Directive 2010/75/EU on industrial emissions (the IED; EU, 2010c).

This report is structured in the following way:

- Chapter 1 presents the background to the LCPD, the scope of the report and the main policy evaluation questions.
- Chapter 2 outlines the methodology followed.
- Chapter 3 presents the main findings of the report.
- Chapter 4 considers the findings in the context of evaluation, addressing the questions identified.

1.1 Description of the LCPD and its intervention logic

1.1.1. Background to the initiative

LCPs firing fossil fuels and/or biomass have been a main source of atmospheric pollutants — especially SO_2, NO_x and dust — but also carbon monoxide (CO), non-methane volatile organic compounds, greenhouse gases (GHGs) and heavy metals (e.g. mercury). Secondary pollutants, in particular ground-level ozone (O_3) and secondary particulate matter, are also formed following the release of primary air pollutants arising from LCPs.

In 1990, critical loads for acidification were exceeded across more than 32 million hectares of the then 15 EU Member States (EU-15). Industry was responsible for 95 % of all SO_2 emissions and 38 % of all NO_x emissions across the EU in that year (see also Chapter 3); for dust, many countries' emission data are available only from the year 2000 (EC, 1997).

The EU established combustion plant policy in the 1980s, with the aim of tackling the abovementioned problems of acidification and transboundary air pollution through a harmonised pan-European framework that would not distort the internal energy market. The directive on air pollution from industrial plants (Directive 84/360/EEC; EU, 1984) provided the first framework for environmental controls on the operation of air polluting sites and called for specific action by those sectors of major concern. It was succeeded in 1988 by Directive 88/609/EEC, which regulated air pollutant emissions from LCPs (the original LCP Directive; EU, 1988).

The **background** to the adoption of the 2001 LCPD continued to be the need to combat the anthropogenic emissions of acidifying pollutants and ozone precursors from industrial activities and, within industry ([2]), from stationary emission sources, which consist principally of LCPs. This was in line with the objectives of the Thematic Strategy on Air Pollution (EC, 2001).

The experience gained during the 1990s led to an overhaul of the policy on industrial sites to introduce a more integrated approach based on the concept of best available techniques (BAT). In terms of EU law, this crystallised in the IPPCD and the second LCPD (EU, 2001a).

While the IPPCD provided the overall framework to deal with environmental pressures across all main industry sectors, including the development of reference documents on BAT to serve as a guidance for permit conditions, the LCPD established specific rules and mandatory minimum requirements,

Box 1.1 Retrospective assessments

Retrospective assessments of policies are often defined as evidence-based judgements of the extent to which an intervention has been **effective** in meeting its initial targets, objectives and goals, and **efficient** in doing so; **relevant**, given the needs and objectives; **coherent**, both internally and with other EU policy interventions; and conducive to **EU added value**, in comparison with national measures alone.

Box 1.2 Large combustion plants

Combustion plants are any technical apparatus in which fuels are oxidised (i.e. combusted) in order to use the heat thus generated. In accordance with the LCPD, LCPs are plants with an installed capacity greater than 50 megawatts thermal energy (MWth) that generate heat and/or electricity. With 3 418 LCPs in operation in 2015, they are a common feature in the electricity and heat supply sectors, in oil refineries, in chemical industries and in iron and steel production, among others (EEA, 2017a).

LCPs emit a wide range of pollutants in significant quantities — especially SO_2, NO_x and dust — being responsible for a wide range of impacts on human health, ecosystems, the built environment and the climate.

([2]) Encompassing electricity and heat supply sectors, oil refineries, chemical industries and iron and steel production, among others.

including emission limit values (ELVs), for both new and existing LCPs. Both pieces of legislation were thus complementary. The IPPCD aimed to lead competent authorities to setting tighter limits than those in the LCPD.

1.1.2 Interactions with other policies

Increasing awareness of the negative impacts of transboundary air pollution and of climate change led to the adoption of further sectoral and thematic policies that also interacted with the LCPD, such as the following measures targeting air pollutants:

- the targeted reduction of emissions from all sectors by 2010, in the context of the Gothenburg Protocol (UNECE, 2012) and the NECD (EU, 2001b);
- the setting of limits for ambient air concentrations of SO_2 and other pollutants, under the Air Quality Framework Directive (Directive 96/62/EC) and its first daughter directive (Directive 1999/30/EC);
- the gradual tightening of content limits for sulphur in fuels, in the context of the Sulphur Content of Certain Liquid Fuels Directive (Directive 93/12/EEC, replaced by Directive 1999/32/EC).

These policies and measures led to emission reduction targets and/or emission ceilings for the EU-15 within a time-frame also judged to be relevant for the LCPD (see Table 1.1).

Box 1.3 Impacts of air pollution

Air pollution has significant impacts on the health of the European population, particularly in urban areas. It also has considerable economic impacts, cutting lives short, increasing medical costs and reducing productivity through working days lost across the economy. Europe's most serious pollutants in terms of harm to human health are fine particles (the smaller fraction of dust, below 2.5 μm in diameter), nitrogen dioxide (NO_2) and ground-level ozone (O_3) (EEA, 2017b).

NO_x and SO_2 are also involved, under certain conditions, in the production of secondary pollutants, O_3 or secondary particles. These are formed following the interaction between pollutants and other substances present in the atmosphere. Secondary pollution is often a more problematic driver of harm to human health and the environment than the original releases.

Table 1.1 Air emission reduction objectives/targets for the EU-15, coinciding with the time-frame of the LCPD

Policy/pollutant	Base year	Target year	Reduction (% of base year or absolute limit value expressed as maximum number of exceedances per calendar year)
UNECE-CLRTAP			
Sulphur dioxide ([a])	1990	2010	75 %
Nitrogen oxides ([a])	1990	2010	50 %
Ambient air quality limit values in first daughter directive (1999/30/EC)			
Sulphur dioxide	-	2005	50 μg/m³ (1 hour) (24)
Nitrogen dioxide	-	2010	125 μg/m³ (24 hours) (3)
Stage 1 PM_{10}	-	2005	200 μg/m³ (1 hour) (18)
Stage 2 PM_{10}	-	2010	40 μg/m³ (year)
			50 μg/m³ (24 hours) (35)
			40 μg/m³ (year)
			50 μg/m³ (24 hours) (7)
			20 μg/m³ (year)

Notes: ([a]) Targets from the Gothemburg Protocol (1 December 1999). The emission reduction target for the EU is shown, which corresponds with the overall effect of the different emission ceilings for each Member State.

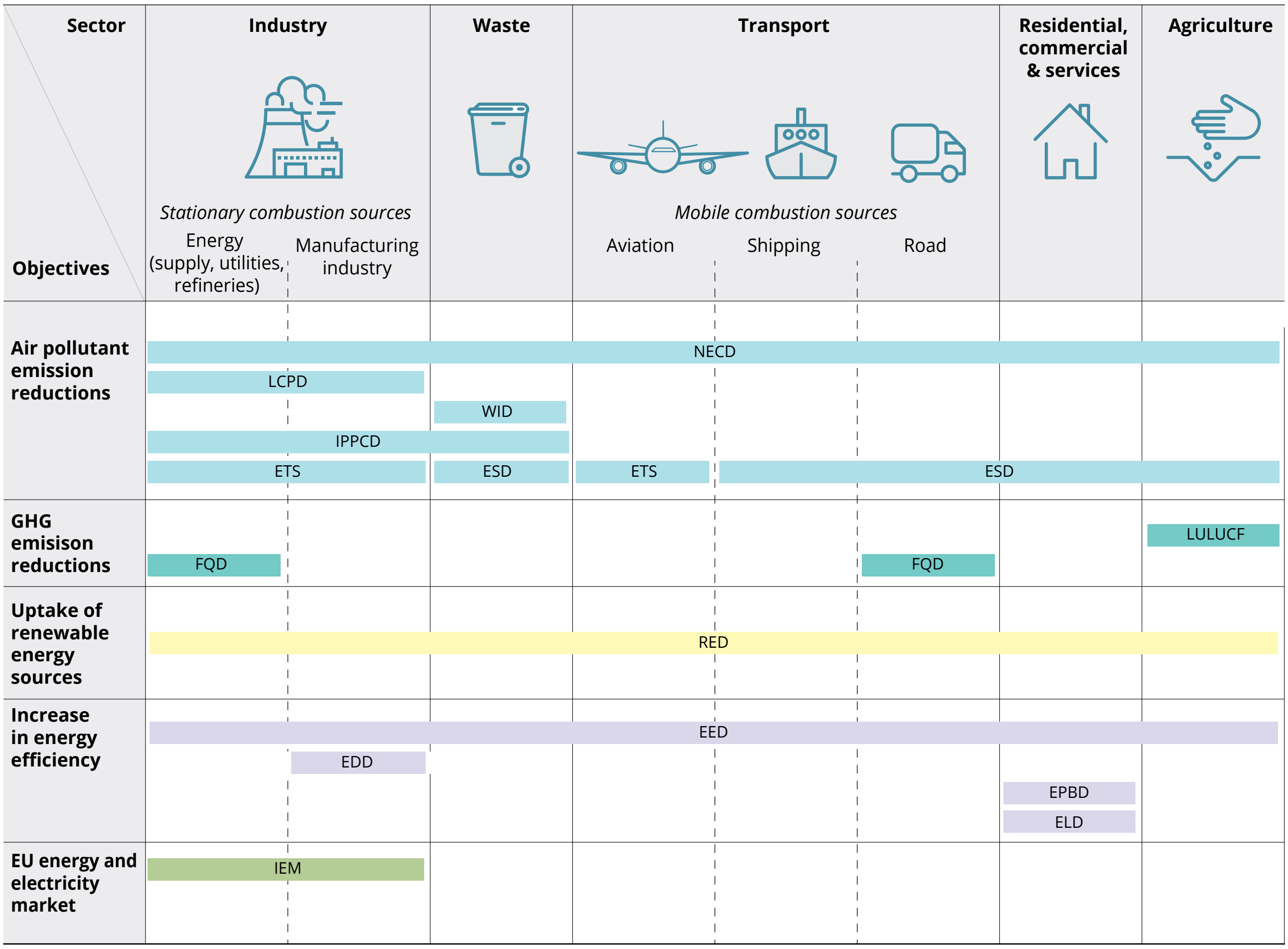
PM_{10}, particulate matter with diameter less than 10 μm; UNECE-CLRTAP, United Nations Economic Commission for Europe Convention on Long-range Transboundary Air Pollution.

Sources: EEA, 2000; Entec UK, 2005.

Figure 1.1 summarises the broader interactions between the LCPD and the other thematic policies that overlapped with its scope. Please refer to Sections 4.1 (Efficiency) and 4.4 (Coherence) for a discussion of these policy overlaps and their effects.

The LCP Directive has been fully repealed by the IED (Directive 2010/75/EU), as of 1 January 2016. This new piece of EU law integrates, in a single regulation, both elements contained in the LCPD and the IPPCD. This integration aimed also to improve the regulatory mechanism in depth ([3]).

Figure 1.1 Overview of interactions between various EU legal acts



Note: EDD — Ecodesign Directive 2009/125/EC; EED — Energy Efficiency Directive; ELD — Energy Labelling Directive 2010/30/EU; EPBD — Energy Performance of Buildings Directive 2002/91/EC; ESD — Effort Sharing Decision; ETS — Emission Trading Scheme; FQD — Fuel Quality Directive 98/70/EC; IEM — Internal Energy Market; IPPCD — Integrated Pollution Prevention and Control Directive; LCPD — Large Combustion Plants Directive; LULUCF — Land Use, Land-Use Change and Forestry; NECD — National Emission Ceilings Directive; RED — Renewable Energy Directive; WID — Waste Incineration Directive 2000/76/EC.

Source: EEA, adapted from Marcu et al., 2018.

([3]) This study does not tackle the new regulatory paradigm. Instead, it focuses on an *ex post* evaluation of the regime as it was until 31 December 2015.

1.1.3 Interactions with other drivers

In addition to policy interactions, a number of well-known factors can cause changes in emissions and in the corresponding environmental performance of LCPs ([4]). Generically, these factors can be summarised as follows:

- **Changes in the energy supplied by LCPs:** reasons for changes in the energy supplied by LCPs include changes in the overall **economic activity** (including fluctuations/changes in demand for energy from the residential and transport sectors) and in the **energy intensity of the economy**. Moreover, the fraction supplied by LCPs also depends on variations in the economy-wide **use of different energy carriers** (electricity, heat, petroleum products, etc.) and shifts in the relative **share of other technologies**, especially nuclear power plants, renewables and small combustion plants (< 50 MW thermal input).
- **Changes in the fuel mix used in LCPs:** the emissions of SO_2, NO_x, dust and CO_2 released by the combustion of a given quantity of fuel are strongly influenced by the initial fuel type. **Switching to cleaner fuels in LCPs** can significantly reduce emissions. Changes in relative fuel prices over the past decade were likely to have been a main driver for the observed trend to shift away from using fuel oil and coal, in favour of natural gas. This trend may have also been influenced by relevant legislation.
- **Changes in the efficiency of LCPs:** improvements in the thermal **efficiency of LCPs** can lower total emissions, because a smaller quantity of fuel is used to produce the same level of output (either electricity or derived heat sources).
- **Responses to more stringent industrial emissions legislation, especially the LCPD and the IPPC, and broader policies and measures adopted in the context of the NECD:** in response to stricter legislation, LCPs have introduced abatement technologies to lower their emissions of air pollutants to more restrictive levels, while old, or less efficient, plants may choose to shut down because of economic considerations. Together, these reasons affect the mass of air pollutants emitted per unit of fuel burned by LCPs — i.e. the specific **emission factors**.

The interaction of these drivers influences the overall emissions from LCPs. To facilitate their analysis, factors that come into play at the macroeconomic level can be grouped as follows:

- evolution of the overall **economic activity** between 2004 and 2015;
- **structure of the economy** and sectoral changes over time, such as a decline in heavy industry or in energy-intensive industries to the expense of the service sector;
- sectoral **energy consumption, intensity and changes** thereof, affecting the amount of final energy needed (per unit of value added in the case of economic sectors, and as final energy consumed over time in the case of the residential and transport sectors);
- **fuel mix** in the electricity supply sector and changes over time, including fuel switches driven by commodity prices (i.e. spot prices for fossil fuels) and efficiency gains (e.g. from coal to combined cycle gas turbines) and/or by national and/or sustainability considerations (nuclear power, renewable energy);
- trends in **electricity consumption by other sectors**, affecting electricity supply by LCPs;
- improvements in **transformation efficiency** over time, in line with technical progress and legislation;
- evolution of **fuel consumption in LCPs** over time;
- evolution of the **implied emission factors (IEFs) across LCPs** over time, per unit of burned fuel; this factor especially provides a strong signal about policy-driven improvements in the performance of LCPs, because a downwards trend is normally due to the adoption of abatement measures in response to policies ([5]).

1.1.4 The LCPD and its intervention logic

In 2001, the LCPD repealed the first directive that applied to large combustion installations (Directive 88/609/EEC). The LCPD aimed to restrict the maximum-permissible emissions of SO_2, NO_x and dust from LCPs in line with technical progress, while allowing flexibility (derogations) in cases

([4]) See, for example, McDowall et al., 2015; Rafaj et al., 2012, 2014a, 2014b.
([5]) Measures ranging from the installation of end-of-pipe equipment, such as filters, scrubbers and other devices, to implementing advanced combustion techniques and pre-washing fuels (coal) prior to combustion.

Box 1.4 Intervention logic

Taking most often the form of a narrative accompanied by a diagram, the 'intervention logic' is an important analytical tool to structure, conduct and communicate retroactive assessments of public interventions. Its main aim is to describe the envisaged logic of the intervention, or the sequence of events (in a 'cause-and-effect' relationship) intended to deliver the envisioned outcome. The intervention logic therefore serves as a blueprint for the careful, evidence-based evaluation of a policy intervention.

Source: EC, 2018a.

where full implementation could be considered disproportionately expensive in relation to the benefits.

The LCPD's **general objectives**, as laid out in its preamble (EU, 2001a), were:

- to combat acidification, eutrophication and ground-level ozone;
- to prevent the exceedance of critical loads of certain acidifying pollutants at any time;
- to further reduce human health risks due to air pollution;
- to support the Community and the Member States to meet the commitments, adopted under the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP), of combating acidification, eutrophication and ground-level ozone formation (UNECE, 1979).

The **sector-specific objectives** of the LCPD were:

- *To significantly reduce the emissions of SO_2, NO_x and dust from the large stationary combustion sources it covered across Europe.* This was to be achieved:

  (i) by differentiating plants and their legal regimes into three categories, depending on the year they commenced operation:

    a) **new-new plants** (licensed from 27 November 2002 onwards);

    b) **old-new plants** (licensed from 1 July 1987 to 26 November 2002);

    c) **existing plants** (licensed before 1 July 1987);

  (ii) and then applying more ambitious ELVs than the previous directives, tailored to these categories, as follows:

    a) *From the latest date of transposition of the LCPD (27 November 2002):*

      - for **new-new plants**, stricter ELVs for SO_2, NO_x and dust (as outlined in part B of Annexes III to VII of the LCPD);

      - for **old-new plants**, less strict ELVs for SO_2, NO_x and dust (as outlined in part A of Annexes III to VII to the LCPD);

    b) *As of 1 January 2008:*

      - for existing plants: less strict ELVs applicable to 'old-new' plants, with the possibility of opting for two new compliance options:

        ◊ the flexible operation of existing LCPs under a national emission reduction plan (NERP) establishing national ceilings and reduction targets for their SO_2 and NO_x emissions by 2003, in line with Annexes I and II to the LCPD;

        ◊ a set of applicable derogations under the LCPD (see Annex 2 for details);

  (iii) in accordance with other legislative processes, so as to ensure LCP-related emission reductions beyond the LCPD ELVs, by using permits to progressively implement the integrated approach based on BAT as provided for large stationary combustion sources under the IPPCD. This was to be achieved especially through:

    a) the adoption of a reference document on best available techniques (BREF) for LCPs (EC, 2006a) containing reference levels on the basis of which countries could specify ELVs in the permits of LCPs operating in Europe;

    b) the action by countries to grant new permits or revise existing permits by October 2007, according to the mechanism set out in Article 4 (new plants) and Article 5 (existing plants) of the IPPCD.

- *To improve the environmental performance of LCPs in terms of the regulated air pollutants:*

  This was to be achieved by implementing pre-, post- and during-combustion abatement measures. To that end, additional data concerning annual plant-level energy inputs had to be reported, together with the annual emission inventories for SO_2, NO_x and dust.

- *To improve information and knowledge regarding the emissions of key air pollutants from LCPs:*

  This was to be achieved by strengthening the provisions concerning the annual emission inventory for SO_2, NO_x and dust to include annual plant-level data from both new and existing installations, and to include data concerning energy input, in order to provide information on trends in emission factors ([6]).

- *To promote enhanced policy coordination and alignment of the levels of health and environmental protection at Member State and regional/local levels:*

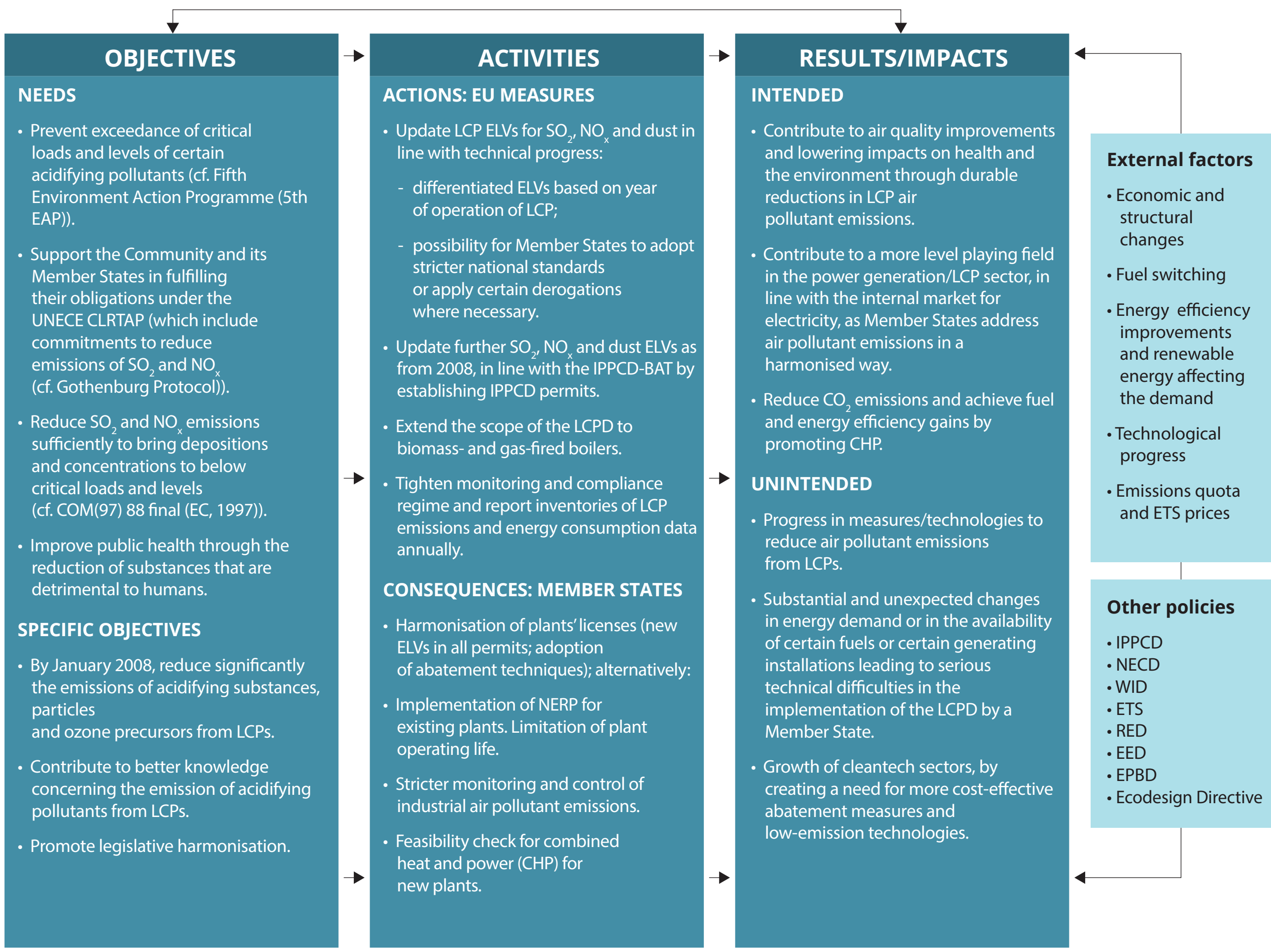
  (iv) by addressing differences in permissible emissions from LCPs and reinforcing the provisions regarding monitoring of plant-level emissions (including those from existing installations);

  (v) by updating the scope of the fuels covered and by addressing biomass as a source of energy and clarifying the relationship with the Waste Incineration Directive;

  (vi) by updating the provisions concerning abnormal operating conditions.

The intervention logic setting out the rationale for the LCPD is illustrated in Figure 1.2.

Figure 1.2 LCPD (2001/80/EC) intervention logic and impacts



([6]) The EEA has compiled and quality assured the historical time series into a single data set (EEA, 2018a). This data set, comprising LCP inventories, was the pillar of the analysis carried out for this report.

Table 1.2 Reported SO_2 and NO_x emissions, and baseline and hypothetical evolution in response to varying stringency options under the LCPD (EU-15 Member States)

Context	Emissions (kt)							
	LCP emissions, 2004		Total EU-15 emissions, 2004		LCP emissions, 2010		Total EU-15 emissions, 2010	
	SO_2	NO_x	SO_2	NO_x	SO_2	NO_x	SO_2	NO_x
Baseline (BL) pollutant emissions and % of total pollutant emissions	N.A.	N.A.	N.A.	N.A.	2 339 (36 %)	903 (13 %)	6 553	6 953
Reported (real) pollutant emissions and % of total pollutant emissions	2 871	1 537	4 839	10 019	886 (38 %)	918 (12 %)	2 326	7 413

Note: N.A., not available.

Sources: For BL pollutant emissions: IIASA, 1988; for reported emissions: LCP (EEA, 2018a) and CLRTAP emission inventories (CEIP, 2017).

1.1.5 Baseline

This report strives to address both the role of the EU intervention (i.e. whether or not the LCPD mattered) and, if possible, 'how much' it mattered ('What is the size of the changes in air pollutants emitted by LCPs as consequence of the LCPD?'). Elucidating the latter element requires an understanding of how the problem would have evolved in the absence of the initiative being evaluated — in this case, what would the baseline emissions of SO_2, NO_x and dust from LCPs have been without the adoption of the LCPD in 2001.

While data on air pollutant emissions from industry existed before the introduction of the LCPD, the EEA could not find an official EU baseline to indicate how emissions of these pollutants would have evolved in the absence of the LCPD. This is most likely because impact assessments were not common practice in the late 1990s when the LCPD was proposed. Later relevant impact assessments for legislative proposals covering climate change mitigation, air pollutant emissions and industry/LCPs unfortunately already account for the effects of measures contained in the LCPD in their baselines ([7]).

The International Institute for Applied Systems Analysis (IIASA) published a report before the adoption of the LCPD, which calculated for the then EU-15 a baseline development, according to which total SO_2 and NO_x emissions from LCPs in 2010 would have amounted to 2 339 and 903 kilotonnes (kt) respectively (expected shares of 36 % and 13 % of total SO_2 and NO_x pollutant emissions, respectively) (IIASA, 1988). In 2010, real emissions from LCPs amounted to 886 kt SO_2 (38 % of total SO_2 emissions) and 7 413 kt NO_x (12 % of total NO_x emissions) across the EU-15 Member States (see Table 1.2). A discussion about the real versus projected air pollutant emission reductions is presented in Subsections 4.1.1 and 4.1.2. In the absence of information (e.g. from complex reverse modelling simulations) that could allow the impacts of policies other than the LCPD to be discounted (see Figure 1.1), the above baseline scenario offers the best means to understand how SO_2 and NO_x emissions would have evolved in the EU-15 without the implementation of the LCPD.

1.2 Key assessment questions

Policy evaluation plays a key role in the decision-making process at the EU level and represents one of the pillars of the European Commission's Better Regulation programme (EC, 2015a). To better inform policymaking and the public, the EEA also evaluates policy, albeit in a different context and with a different mandate.

Anchored in the EEA's conceptual framework for policy evaluations (EEA, 2016a), this study aims to respond to the following key questions while focusing most strongly on assessing the effectiveness of the LCPD:

1. **Effectiveness:**

- Was the LCPD effective in reducing air pollutant emissions from the installations it covered?
- Was the LCPD effective in contributing to overall air quality improvements and lowering impacts on health and the environment?
- Did the LCPD trigger progress in terms of promoting more efficient combustion plants?
- To what extent can the observed changes be credited to the LCPD?

([7]) CAFE Scenario Analysis Report No 2 (IIASA, 2004) and Primes modelling underpinning the 2020 Climate and Energy Package.

- To what extent do the observed (direct and indirect) effects correspond to the objectives?

2. **Relevance:**

- To what extent were the objectives of the LCPD relevant to the need to reduce air pollution within the EU?

3. **Coherence:**

- To what extent was the LCPD internally coherent?

- To what extent was the LCPD complementary to and coherent with other EU initiatives in the field? Did it have synergies with them?

4. **Efficiency:**

- To what extent were the LCPD and its ELVs efficient means of reducing air pollutant emissions from LCPs?

- Were the LCPD and national implementation measures cost-efficient means of achieving EU and national objectives? Have the expected results been obtained at reasonable costs?

5. **EU added value:**

- What was the EU added value of the LCPD? (Could the objectives have been better achieved by action at EU level?)

- Would it have been possible to achieve the same results in the absence of the LCPD?

1.3 Main data sources

The report is based on several data sets of pollutant emissions, and energy and economy statistics, as described below:

- Reported data on large combustion plants covered by Directive 2001/80/EC (LCP inventories) (EEA, 2018a): following the reporting framework established by the LCPD, data on the energy input ([8]) and emissions from LCPs have been reported to the EU since 2004. The EEA has compiled and quality assured the historical time series to produce a single data set. This data set, known as the LCP inventories, provides the main pillar for the analysis conducted in this report. The SO_2, NO_x and dust emissions of LCPs are available from LCP database version 3.0 (EEA, 2017) for the years 2004 to 2015.

- EU emission inventories under the UNECE CLRTAP (CLRTAP emission inventories): in addition, in the context of the European Monitoring and Evaluation Programme (EMEP), under the CLRTAP, European countries compile emission inventories that cover most anthropogenic emissions and some emissions linked to natural sources (CEIP, 2017). Emissions from LCPs and other installations are reported as a subset of the emissions captured in these EMEP inventories. The CLRTAP emission data are available for the years 1990 (in some cases 1980) to 2015. They have been used in this report to illustrate the falling trends in emissions since 1990 (see Chapter 3) and were compared with emission data reported under the LCP inventories ([9]).

- Under the CLRTAP, emissions of SO_x are reported instead of SO_2. Differences are small because almost all SO_x emitted from combustion processes is in the form of SO_2. The CLRTAP also refers to total suspended particles (TSPs) instead of dust; dust emissions may be larger in some cases. TSP emission data were used for only the period 2000-2015, where total and sectoral trends are discussed, as data from 1990 to 1999 are not available for many countries. To improve readability, the terms SO_2 and dust were used as substitutes for SO_x and TSP throughout this report.

- With regard to sectors, CLRTAP emission data are shown as 'total', as well as 'industry' and 'stationary' emissions. **Industry emissions** cover emissions from 'energy industry, metal production, cement and lime production, mining and quarrying, chemical industry, manufacturing, waste industry (including water and sewage management), and distribution of electricity, gas, steam and air conditioning' ([10]). **Stationary**

([8]) The following fuel categories were differentiated in the reporting regime under the LCPD: biomass, other solid fuels, liquid fuels, natural gas and other gases.

([9]) For some years and countries, data are not available. Therefore, the following data were excluded from some of the analyses: (1) SO_x and NO_x: Malta 1990-1999 for total, industry and stationary emissions; Czechia and Slovakia 1990-1999 for industry and stationary emissions; Romania 1990-2004 for industry and stationary emissions; Greece 2015 for total, industry and stationary emissions; and Croatia 2004-2009 for LCP emissions; and (2) dust/TSPs: Romania 2000-2004 for total, industry and stationary emissions; Greece 2015 for total, industry and stationary emissions; and Croatia 2004-2009 for LCP emissions.

([10]) As defined in ETC/ACM, 2016. Other than for pipelines for the transmission of energy, energy used for transport in these industries, as well as agricultural activities, are excluded.

emissions cover emissions from energy industries (category 1A1) and from manufacturing industries and construction (category 1A2). The latter category also includes a sub-category of emissions from mobile combustion in manufacturing industries and construction (1A2gvii) that was excluded from the analysis.

- Eurostat energy and economy statistics: a wide range of data extractions from Eurostat were used to feed the various numerical analyses. Specifically, these data played a key role in constructing the decomposition analysis, the results of which are provided in Chapter 4.

2 Methodology

2.1 Methodology and assumptions

Limitations to the underlying data meant that quantitative analyses were not always possible. Answering the key assessment questions therefore relies on a combination of specific qualitative and quantitative methods. These are explained in the following sections.

2.1.1 Decomposition analysis for air pollutant emissions from LCPs

The observed evolution of the time series for SO_2, NO_x and dust emissions between 2004 and 2015 was deconstructed with the help of statistical techniques into a number of components that affected the original time series and that could reconstruct the observed evolution through additions and multiplications. The components identified were changes in **economic activity**, **structural changes** in the economy, changes in **energy intensity** in the end-use sectors, changes in the overall **energy mix** and changes in **emission factors** due to the diffusion of abatement technologies driven by environmental policies such as the Large Combustion Plant Directive (LCPD).

The decomposition comprised two separate identities (German et al., 2018):

- a detailed eight-factor identity, focusing on changes in emissions from **electricity-generating large combustion plants (LCPs)** only;
- a simpler five-factor identity, encompassing changes in emissions from **all LCPs**.

The most likely factors assessed in the detailed decomposition were:

Overall economic activity ('Activity (economic)') — this denotes the effect of changes in the whole-economy gross value added.

- **Economic structure ('Structure')** — this represents the effect of shifts in the balance of the economy towards sectors with higher or lower energy intensities, or reliance on electricity from LCPs. For example, a shift from a more manufacturing-based to a more services-based economy would act to lower emissions.
- **Sectoral energy intensity ('Intensity')** — this is either:

(i) within a particular economic sector, for which the effect of increases or decreases in final energy consumption per unit of value added is assessed; for example, a decrease in energy intensity in the manufacturing sector would act to lower emissions;

(ii) energy consumption not attributable to economic sectors ('Activity (non-economic)') — this represents the effect of changes in final energy consumption in the residential

Box 3.1 Decomposition analysis

Decomposition analysis is a statistical technique used to break down the various driving factors of a phenomenon and attribute a relative weight to each of these driving factors.

Decomposition analysis is widely accepted in policy analysis, where its use is increasing.

From the various statistical routines that can be used, this report uses the Logarithmic Mean Divisia Index (LMDI), which is a decomposition method based on the Shapley/Sun approach. It can be used to decompose an aggregate number into more than two underlying factors.

By identifying the individual contribution of the drivers to the overall changes observed, decomposition analysis in this report helps isolate the impact of those factors that were most likely driven by legislation.

and transport sectors, or through exports of electricity.

- **Energy mix in electricity generation ('Generation type')** — this characterises the effect of shifts in the method of generation of the electricity produced, both between non-combustion sources and combustible fuels, and between different types of combustible fuel.

- **Sectoral degree of electrification ('Electrification')** — this denotes the effect of shifts towards using electricity for a greater or smaller fraction of final energy needs in a given sector.

- **Generation efficiency ('Efficiency')** — this reflects the effect of increases or decreases in the transformation efficiency between the primary fuel type and electricity produced, for a given fuel type.

- **Share of fuel used in electricity production by LCPs ('LCP share')** — this denotes the effect of increases or decreases in the amount of fuel burning for electricity production that takes place in LCPs, compared with outside LCPs (e.g. in small-scale generators), for a given fuel type.

- **Emission factor** — this represents the effect of increases or decreases in the mass of pollutant emitted, per unit of fuel burned, for a given pollutant and fuel type. This factor provides the strongest indication of the impact of improvements in abatement technology or fuel quality.

The results of the detailed eight-factor identity provide insights into the drivers of emission trends among electricity-generating LCPs.

The results of the five-factor identity — in particular the influence of changes in emission factors — were used to assess the representativeness of the detailed decomposition results, and provide a more complete picture for countries for which electricity-generating LCPs account for a relatively low proportion of all LCPs.

The decomposition analyses were performed for the 28 EU Member States (EU-28) as a whole, as well as for individual Member States. The assessment looked at each pollutant in turn, outlining how different drivers have affected emissions from LCPs at the EU-28 level, then taking a closer look at trends within specific Member States to identify different behaviours over the study period.

2.1.2 Detailed trend analyses

In addition to the statistical decomposition approach outlined above, the effectiveness of the LCPD to drive environmental improvements at the plant level was also assessed through further specific analyses of trends in the implied emission factors (IEFs) for the key pollutants, generic emission trends, and energy decoupling. This analysis was carried out in the following ways:

- as trends in total emissions, distributed over LCPs that fall into different IEF classes;

- as an overview of how LCP IEFs have developed over time:

  (iii) by fuel type, in the EU and in the three country groups;

  (iv) in relation to LCP size, grouped by classes of capacity; and

  (v) by the industry sector to which the LCP belonged;

- as the evolution of the installation of abatement technologies at the level of LCPs;

- as a short assessment of LCP closure rates.

The evolution of LCP emissions by IEF classes

To determine whether or not the IEF of an LCP played a particular role in the observed emission improvements over time, the correlation between plant-level fuel use and pollutant emissions (i.e. the IEF) was investigated by subdividing LCPs into three intensity classes per pollutant, as shown in Table 2.1.

Table 2.1 Classes of LCP IEFs, per pollutant

Pollutant	g/GJ		
	Intensity class I	Intensity class II	Intensity class III
SO_2	> 1 000	200-1 000	0-200
NO_x	> 200	100-200	0-100
Dust	> 50	10-15	0-10

Source: EEA.

This grouping was performed for every year, based on plant-level data, with plants being allowed to move from one class to another if their respective IEFs changed over time.

The evolution of specific LCP IEFs

The evolution of specific LCP IEFs by fuel type

Trends in LCP IEFs per fuel type were explored to identify in more detail the role that specific fuel types played in contributing to overall trends in air pollutant emission reductions from LCPs.

Not all LCPs could be included in this particular calculation, since for plants fuelled by multiple fuel types an accurate determination of emission shares per fuel type would be impossible without an allocation method, the application of which would defeat the purpose of the analysis. Therefore, only single-fuel plants (defined as plants for which one LCP fuel represents more than 95 % of the total fuel input ([11])) have been analysed with respect to energy input, emissions and IEF. The share of total fuel input was calculated over the entire period for which data were available. Note that the developments in single-fuel plants are not fully representative of developments in the entire LCP stock. For example, plants co-firing biomass and fossil fuels were excluded.

The evolution of specific LCP IEFs in relation to LCP size (capacity)

To determine whether or not the size of an LCP played a role in emission improvements, the relationship between LCP size and IEF was investigated by subdividing LCPs into three capacity classes, as shown in Table 2.2.

The evolution of specific LCP IEFs by selected industrial sectors ([12])

To identify whether or not the industrial sector to which an LCP belonged influenced its environmental improvements over time, a comparison of IEF trends was performed between LCPs operating in the chemical industry, the energy sector, the iron and steel sector, and the paper and wood sector.

The assessment of LCP closure rates

The closure rates of LCPs were analysed to determine whether plants were retired because they had reached the end of their technical lifetimes or because of other factors not related to plant age. The Platts WEPP database ([13]) provides information on the first year of operation of a subset of LCPs, which makes it possible to determine the age of these LCPs. Assumptions on LCP lifetimes are made based on the EEA report *Transforming the EU power sector: avoiding a carbon lock-in* (EEA, 2016b). It was assumed that the average technical lifetimes are 40 years for LCPs fired by coal (and 'other solid fuels'), 35 years for natural gas and 40 years for oil/liquid fuels. The ages of 579 individual single-fuel LCPs could be determined, of which only 29 LCPs were considered closed ([14]).

2.1.3 Exploration of hypothetical scenarios of changes in emissions

A set of hypothetical scenarios were developed by the European Topic Centre on Air Pollution and Climate Change Mitigation (ETC/ACM) to provide insights into changes in LCP emissions by considering different ways in which the LCPD could have been implemented. EU policies on LCPs provided a range of possibilities in terms of implementation. On the one hand, the LCPD provided a legal regime that allowed for a number of derogations (see Subsection 1.1.4). On the other hand, LCPs were also covered by the Integrated Pollution Prevention and Control Directive (IPPCD). Therefore, LCPs also had to have an IPPC permit, which established more ambitious emission limit values (ELVs) based on emission levels associated with best available techniques (BAT-AELs) that ranged from the so-called upper-end BAT level to the lower-end

Table 2.2 Classification of LCPs by capacity (size)

MW_{th}	Capacity class I	Capacity class II	Capacity class III
LCPs	> 2 000	500-2 000	50-500

Source: EEA.

([11]) A figure of 95 % was chosen based on an inspection of the data in the LCP database (EEA, 2018a). It needed to be sufficiently high to take into account potential fuel switches of LCPs in time. The approach is the same as in AMEC (2009).
([12]) To which sector an LCP belongs is determined on the basis of the coupling of the LCP emission inventory data set with the European Pollutant Release and Transfer Register (E-PRTR) database.
([13]) Platts World Electric Power Plants database of 2015. The current owner of the dataset offers background information at https://www.spglobal.com/platts/en/products-services/electric-power/world-electric-power-plants-database (accessed 26 April 2019)
([14]) An LCP is considered closed if the energy input has been zero for the latest 2 or more consecutive years. One LCP that did not report energy inputs in 2015 and 2014 was only 4 years old in 2015 so was not considered closed.

BAT level (the maximum protection resulting in the most stringent ELVs).

By differentiating based on some of the legal possibilities, the following two illustrative scenarios were contrasted in Chapter 4 with the actual evolution of reported emissions:

- The **counterfactual** scenario, based on the premise that LCPs would not have improved their environmental performance over the period 2004-2015;
- The **BAT-lower scenario**, corresponding to the hypothetical situation in which all plants operated according to the lower-end BAT-AELs in the reference document on BAT (BREF) for LCPs (EC, 2006a).

The comparison was carried out to illustrate the benefits of implementing the LCPD in relation to a hypothetical 'no-progress' scenario, and to stress how much more substantial the benefits could have been had a deeper implementation of the two legal instruments — the LCPD and the IPPCD — been achieved in practice.

Literature review

To gain insights into aspects that could not easily be analysed through quantitative analysis, a broad range of articles, reports and studies were reviewed and assessed.

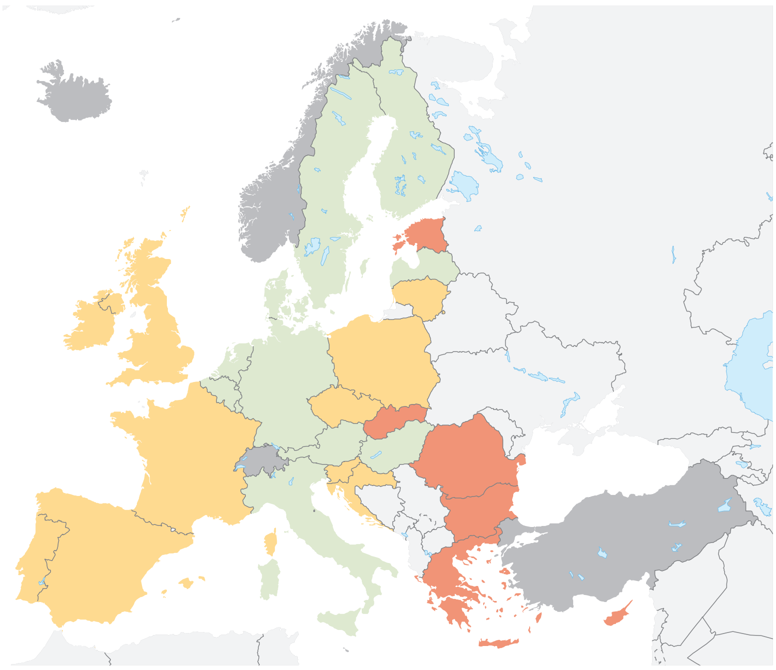
2.2 Geographical aggregation

Important disparities in the environmental performance of LCPs across the EU led to the structuring of the assessment according to **three country groups**, each group including countries with comparable average emission factors for SO_2, as shown in Figure 2.1:

- Group 1, **low** IEF ('LOW'): Member States with an average SO_2 LCP IEF that is below 50 % of the average SO_2 IEF of all LCPs in the EU;
- Group 2, **medium** IEF ('MEDIUM'): Member States with an average SO_2 LCP IEF ranging between 50 % and 200 % of the average SO_2 IEF of all LCPs in the EU;
- Group 3, **high** IEF ('HIGH'): Member States with an average SO_2 LCP IEF above 200 % of the average SO_2 IEF of all LCPs in the EU.

Of the total thermal input capacity of LCPs in the EU Member States in 2004 (1 235 GW_{th}), 47 % of this thermal input capacity was accounted for by LCPs in the LOW group, 43 % by LCPs in the MEDIUM group and only 11 % by LCPs in the HIGH group.

Figure 2.1 Groups of countries based on average SO_2 IEF



Source: EEA.

2.3 Uncertainties

Ideally, the assessment would have followed trends in emissions since 2001, by specific plant classes (existing, old-new and new-new plants), to reflect on the different regimes established for such classes under the LCPD. Unfortunately, a robust LCP data set is only available for 2004 onwards, as this was the year from which the LCPD reporting requirements were established. At the same time, the reporting of the specific legal regime of each LCP was not a mandatory requirement; it was reported in only some years of the period.

The LCPD inventories were subject to a series of quality assurance mechanisms that have reduced the number of errors in them. However, the present assessment led to the discovery of inconsistencies. In particular, the energy input of LCPs may not always have been reported correctly, as some data points are inconsistent with the declared capacities or the emissions reported for the same source, or imply a very low number of operating hours, which may not have been economical. To limit the impact of these potential errors, outliers were excluded from the energy input figures. Reporting countries have informed the EEA that such inconsistencies affect specifically the energy input data, rather than the reported emissions.

When assessing the evolution of pollutants from LCPs belonging to different IEF classes (see Subsection 3.3.2), the IEF could not be calculated for certain LCPs, namely those for which an energy input had not been reported. In such cases, the IEF class was set to 'unknown'. If the data reported for a particular year were of insufficient quality, the IEF class was also set to 'unknown'. The background studies to this report ([15]) provide more insight into how the data were processed.

The statistical decomposition analyses underpinning the assessment ([16]), presented in Chapter 4, show the change in key air pollutant emissions from LCPs, which would have occurred as a result of changes in that factor alone, if all other factors had remained constant over the period studied. This is referred to as 'the contribution of factor X to changes in air pollutant emissions'. The results of a dynamic assessment approach (e.g. econometric modelling) could have slightly diverged from the results of the decomposition analyses performed.

([15]) The work performed by the ETC/ACM is described in a non-published working paper that can be provided upon request.
([16]) http://www.aether-uk.com/CMSPages/GetFile.aspx?guid=14ca8d73-614e-42db-811d-738425f0b218 (accessed 19 November 2018).

3 Main findings

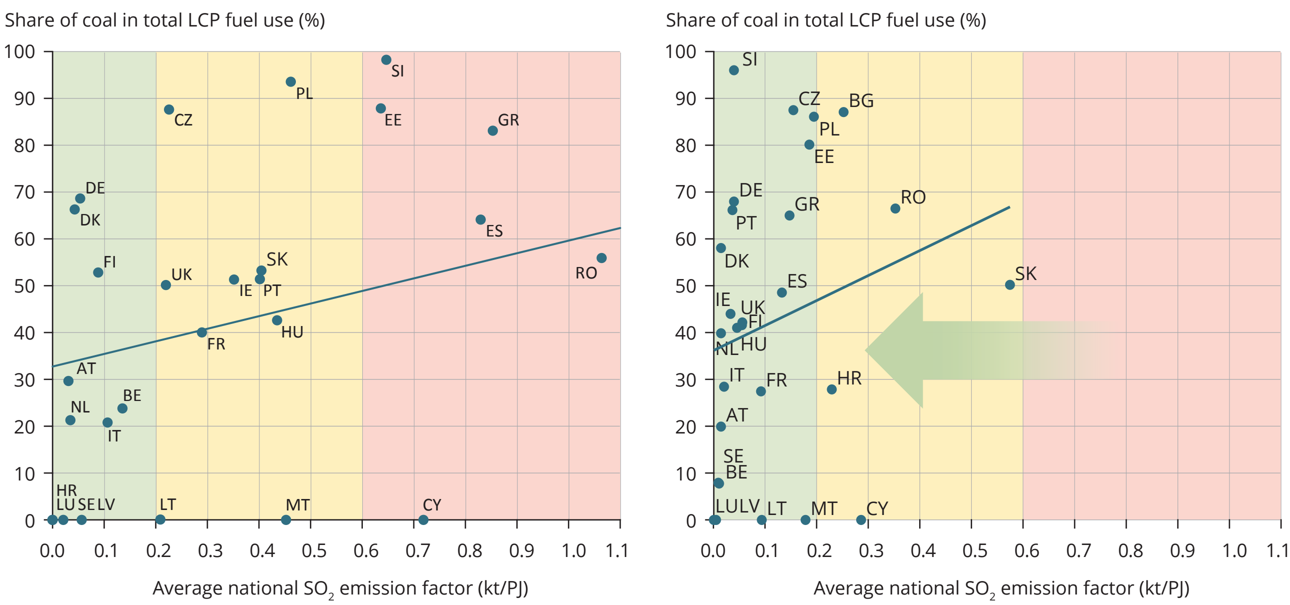
The following sections summarise the situation in 2015, as a result of implementing the Large Combustion Plant Directive (LCPD). The summary is in relation to the initial starting points (large combustion plant (LCP) emissions) across countries, and the trends, impacts and overall progress towards achieving the specific LCPD objectives (see Figure 1.2 for the intervention logic).

3.1 Varying environmental performance of LCPs before the entry into force of the LCPD

The environmental performance of LCPs varied strongly among countries around the time of entry into force of the LCPD. Taking SO_2 as an example — the pollutant whose effects were most relevant at the time because of the problem of acidification — average national implied emission factors (IEFs) differed by two orders of magnitude ([17]), as illustrated in Figure 3.1.

There are multiple explanations for these significant disparities. Specifically, the type of fuel used in LCPs played a very important role, with countries with high shares of solid (e.g. coal) and liquid fuels emitting more SO_2. Other significant disparities across countries when the LCPD came into force relate to the average age of the combustion plants, the quality of the fuels used and the existence (or lack) of abatement techniques to reduce stack emissions. These disparities in the environmental performance of LCPs led to the assessment being structured according to three

Figure 3.1 National average SO_2 IEF versus share of coal use, in 2004 (left) and 2015 (right)



Note: To better illustrate the diverging picture in 2004, Bulgaria was excluded in the left-hand graph because of its very high SO_2 emission factor (2.6 kt/PJ in 2004). Country codes: AT Austria, BE Belgium, BG Bulgaria, CY Cyprus, CZ Czechia, DE Germany, DK Denmark, EE Estonia, EL Greece, ES Spain, FI Finland, FR France, HR Croatia, HU Hungary, IE Ireland, IT Italy, LT Lithuania, LU Luxembourg, LV Latvia, MT Malta, NL Netherlands, PL Poland, PT Portugal, RO Romania, SE Sweden, SI Slovenia, SK Slovakia, UK United Kingdom

Source: EEA.

([17]) The ratio of the reported emissions of a given pollutant, in this case SO_2, to the aggregated energy input reported in the LCP inventories in the reporting year. The differences were not as dramatic for the other two key air pollutants, NO_x and dust.

country groups (see Section 2.2 for country group definitions):

- low IEF, group 1 (LOW);
- medium IEF, group 2 (MEDIUM);
- high IEF, group 3 (HIGH).

3.2 Main trends and impacts

3.2.1 Trends in LCP capacity and fuel use between 2004 and 2015

The total thermal capacity of LCPs across the EU increased by one tenth between 2004 and 2015 (from 1 235 GW_{th} to 1 361 GW_{th}). At the same time, the total fuel used by these LCPs (the **energy input**) decreased by almost one fifth (see Figure 3.2). Over the period, there was a visible decrease (of 21 %) in the energy input from fossil fuels (see Figure 3.3, left panel), while fossil fuels continued to represent over 95 % of all fuels used in LCPs (see Figure 3.3, right panel).

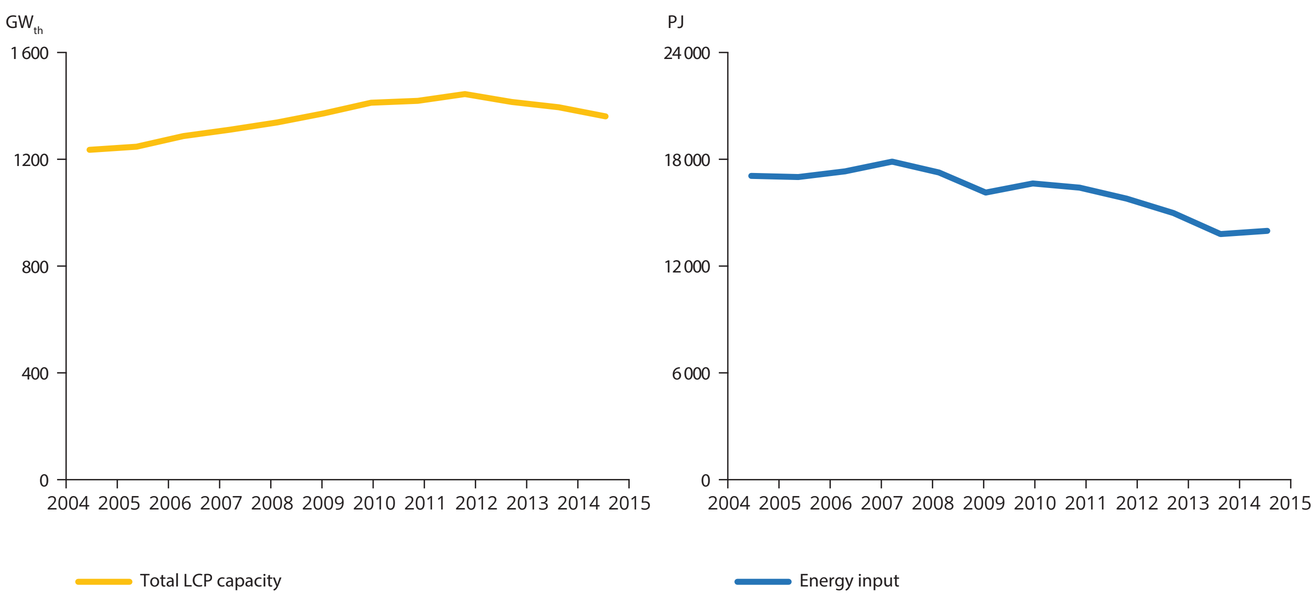
The left panel of Figure 3.3 shows changes in LCP inputs over time by fuel type, compared with the input level of each fuel type in 2004; the right panel shows the share of each fuel in the total LCP energy input in each year of the period. This comparison reveals an absolute decline over time in the level of solid fuels used in LCPs ([18]), while solid fuels remain the dominant fuel type in total LCP fuel use over the period, having decreased only marginally (by two percentage points, to 56 %) between 2004 and 2015. Specifically, the relative share of solid fuels used in LCPs decreased from 2004 to 2010 as the share of natural gas went up, but this trend reversed between 2011 and 2014.

The assessment of fuel consumption in LCPs across country groups reveals that solid fuels and natural gas were dominant between 2004 and 2015 in all groups. The shares of biomass and of other gases increased over this period, while the share of liquid fuels decreased in all country groups.

Nevertheless, differences are noticeable among the country groups: the LOW group had a consistently higher share of biomass, natural gas and other gases in total LCP fuel use. In contrast, the HIGH group used more solid and liquid fuels in its LCP sector, most likely explained by the larger proportion of older LCPs in these countries, as indicated in Subsection 3.3.1.

The evolution of key LCP air pollutant emissions is closely linked to the types and amounts of fuels used. This evolution is discussed in the following sections.

Figure 3.2 LCP capacity and energy input — evolution across the EU



Source: EEA, 2018a.

([18]) In the LCP inventories, the category 'solid fuels' includes all types of conventional coal.

3.3 Evolution towards the sector-specific objectives of the LCPD

3.3.1 Progress towards specific objective 1: to significantly reduce the emissions of SO_2, NO_x and dust from large stationary combustion sources in the EU

The main objective of the LCPD was to significantly reduce the emissions of SO_2, NO_x and dust from large stationary combustion sources (existing especially in the electricity and heat supply sectors) across Europe. For that, the LCPD mandated a stepwise compliance approach (see Subsection 1.1.4). In conformity with that staged process, this section illustrates the progress made in reducing the emissions of SO_2, NO_x and dust from LCPs:

- by considering the trends in LCP emissions (available since 2004) in the context of total and stationary emissions (available since 1990); and
- by illustrating the decrease in LCP emissions achieved by 2007 and then by 2015.

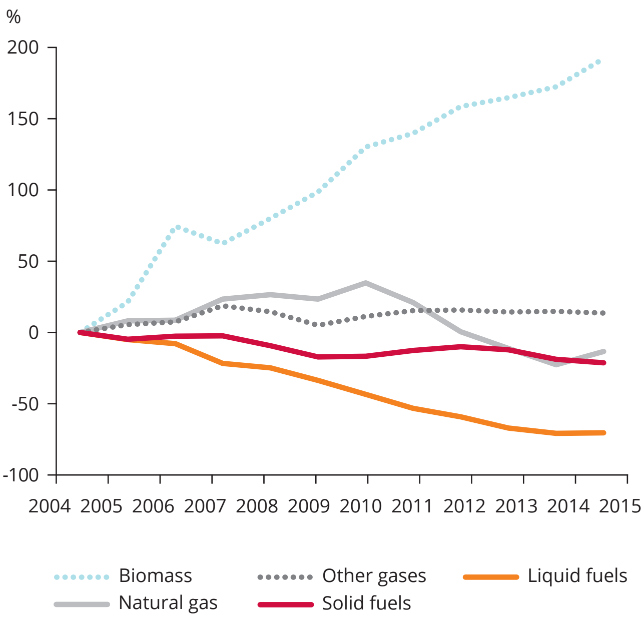
Trends in emissions of SO_2, NO_X and dust are presented for the 28 EU Member States (EU-28) and for the three groups of EU Member States.

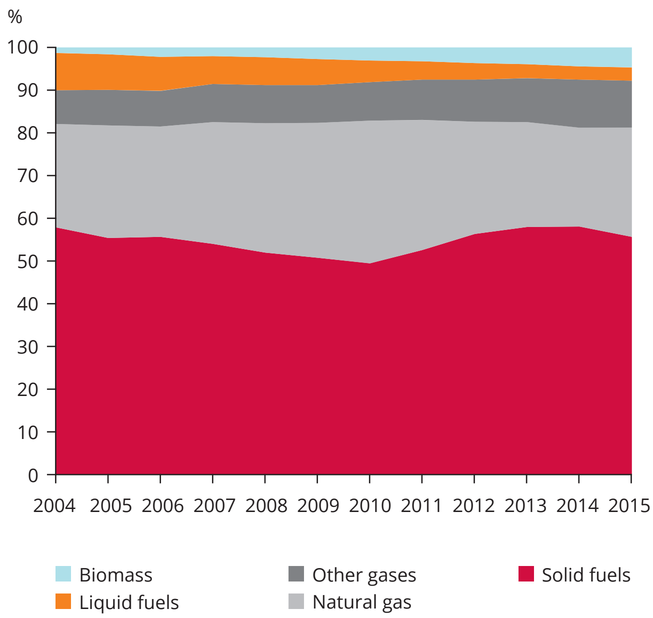
Adjusted trends in LCP emissions, stationary combustion emissions and total emissions

Total and sectoral air pollutant emissions have been reported under the Convention on Long-range Transboundary Air Pollution (CLRTAP) for every year from 1990 (see Sections 1.3 and Chapter 2). There is no recognised LCP sector under the CLRTAP. However, emissions reported under the CLRTAP **stationary combustion sector** include the vast majority of LCP emissions. Observations regarding the evolution of total CLRTAP emissions, CLRTAP stationary combustion emissions and, since 2004, LCP emissions can provide information about the role that reductions in LCP emissions have played in lowering stationary combustion and total air pollutant emissions.

The adjusted trends ([19]) in EU-level emissions show that there is a close correlation between LCP emissions and CLRTAP stationary combustion sector emissions. In addition, especially for SO_2 and for NO_x, the trend

Figure 3.3 **Change in LCP fuel type relative to 2004 (left panel) and annual share of each fuel in total LCP energy input (EU level) (right panel)**





Source: EEA, 2018a.

([19]) Under the CLRTAP, emissions of SO_x are reported instead of SO_2. However, differences between SO_x and SO_2 are small, because almost all SO_x emitted from stationary combustion processes is in the form of SO_2. The CLRTAP also refers to total suspended particles (TSPs) instead of dust, which the LCPD considers equivalent parameters.

analysis reveals a staggering reduction in CLRTAP combustion emissions, which exerts a depressing effect on total emissions. Dust emission trends also decreased during the period, but less markedly.

At the level of the EU-28, between 1990 and 2015, the share of CLRTAP stationary combustion emissions in total CLRTAP emissions fell for SO_2, NO_x and dust by 10 percentage points, 5 percentage points and 7 percentage points, respectively.

Between 2004 and 2015, in absolute terms and for the EU-28:

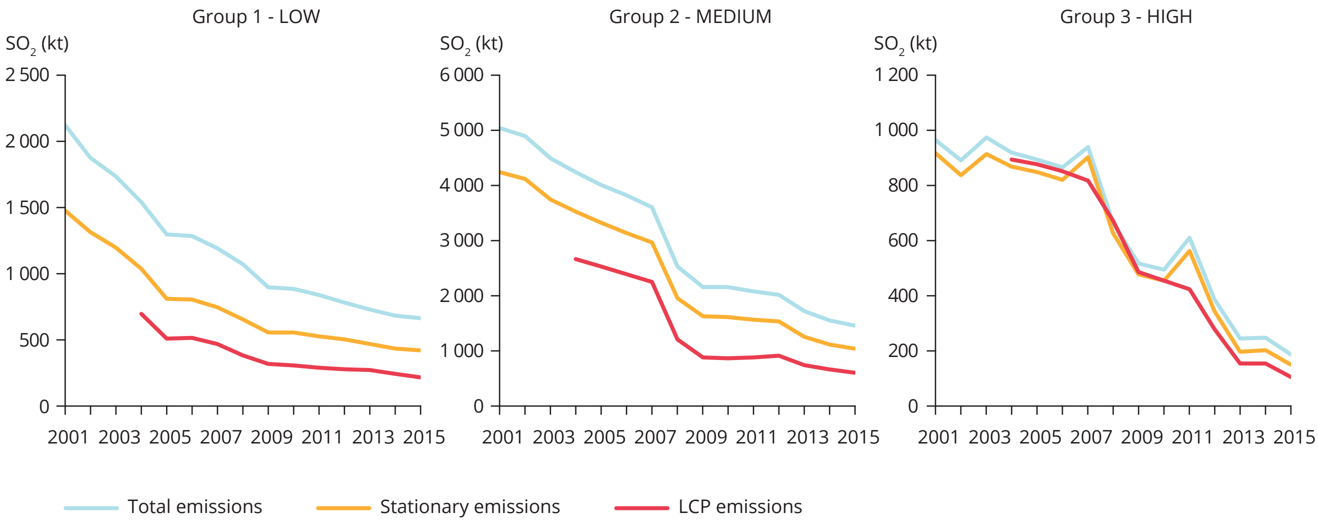
- Total SO_2 emissions decreased by 65 % (from 6 648 kt to 2 294 kt). The share of stationary combustion emissions in total emissions fell from 81 % to 70 %. Within the stationary combustion sector, LCPs accounted for the largest share of emissions, accounting for 79 % of all stationary combustion emissions in 2004, but only 58 % in 2015.
- Total NO_x emissions fell by 37 % (from 11 010 kt to 6 990 kt). The share of stationary combustion emissions of NO_x remained unchanged (29 % of total emissions in 2004; 28 % in 2015). Yet, LCP NO_x emissions accounted for 57 % of all stationary combustion emissions in 2004, but only 48 % in 2015.
- Total dust emissions decreased by 20 % (from 3 855 kt to 3 088 kt). The share of stationary combustion emissions in total emissions fell from 12 % to 7 % over the period. LCP emissions represented 46 % of stationary combustion emissions in 2004, but only 21 % in 2015.

Thus, while stationary sources, and in particular LCPs, remained among the most significant sources of SO_2, NO_x and dust emissions in Europe over the period 2004-2015, major emission reductions achieved by LCPs during this time reduced the share of stationary combustion emissions in total air pollutant emissions.

Similarly decreasing trends were observed for each country group and each air pollutant, albeit with variations in the pace and times at which the steepest reductions took place. Figure 3.4 illustrates this for SO_2 emissions. Certain fluctuations in the trends are visible primarily in the HIGH country group, suggesting the differing environmental performance of, and differing fuel types used in, plants across European countries.

Over the period 2004-2015, at the level of each country group and for the EU as a whole, the average annual pace of SO_2, NO_x and dust emission reductions was higher for LCPs than for stationary or total emissions. On average, annual SO_2, NO_x and dust emissions over the period (LCP-related and total emissions) fell fastest in the HIGH group and slowest in the LOW group — in line with observations that determined the initial country groupings (see also Table 3.2).

Figure 3.4 SO_2 emissions of country groups 1 (LOW), 2 (MEDIUM) and 3 (HIGH)



Notes: To provide a consistent picture (for 1990-2015 for CLRTAP data and 2004-2015 for LCP data), the following countries' emissions were excluded: Croatia, Czechia, Greece, Malta, Romania and Slovakia. The third graph represents three countries only and the scale is different from graphs 1 and 2. For a definition of country groups, see Section 2.2.

Sources: EEA, 2018a; CEIP, 2017.

Progress in accordance with the compliance timelines set by the LCPD ([20])

In the period 2004-2015, the reported LCP emissions in the EU-28 decreased by 77 % for SO_2, 49 % for NO_x and 81 % for dust, as shown in Table 3.1.

There are clear differences in the trends for these pollutants among the groups of Member States. In the LOW group, SO_2 emissions decreased by 69 % from 2004 to 2015; in the MEDIUM group, SO_2 emissions decreased by 75 %; and in the HIGH group (which initially had very high SO_2 emissions), SO_2 emissions decreased by 83 %.

Similar trends are also visible for NO_x and dust emissions from LCPs across the groups: the HIGH group recorded, on average, the greatest emission reductions over the period compared with its high initial emission intensity level, as analysed in the next section.

Under the LCPD, a two-step conformity regime deferred, until 1 January 2008, the obligation of 'existing plants' to comply with the LCPD emission limit values (ELVs) ([21]). Accordingly, at EU level, LCP emissions of SO_2, NO_x and dust fell at a slower rate, on average, between 2004 and 2007, than after 2007, when the oldest LCPs also had to become compliant (see Figure 3.5).

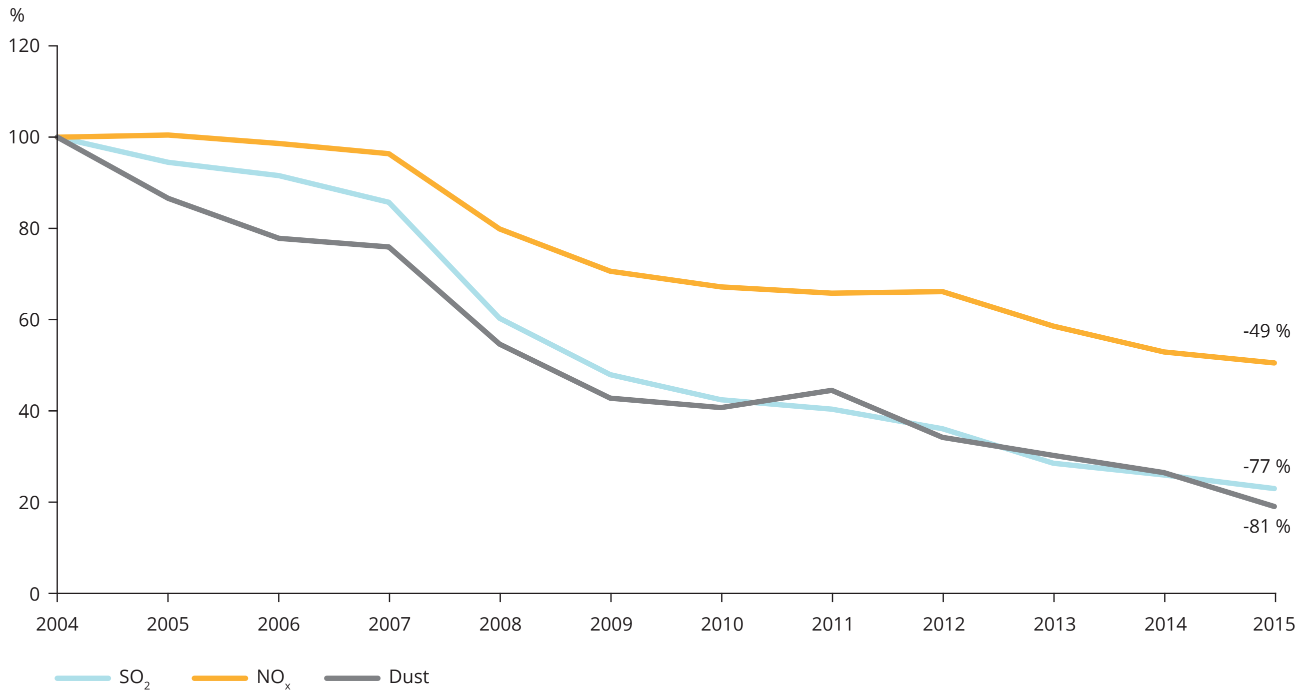
Table 3.1 LCP sector emissions in 2004 and 2015 and percentage decreases

Region	2004 (kt)			2015 (kt)			Decrease (%)		
	SO_2	NO_x	Dust	SO_2	NO_x	Dust	SO_2	NO_x	Dust
EU-28	5 356	2 159	286	1 231	1 090	54	-77	-49	-81
LOW	697	627	35	217	356	9	-69	-43	-73
MEDIUM	2 837	1 261	124	697	610	31	-75	-52	-75
HIGH	1 823	271	127	317	125	14	-83	-54	-89

Note: Croatia was excluded from the EU total because of a lack of data prior to its accession.

Source: EEA.

Figure 3.5 Indexed evolution of SO_2, NO_x and dust emissions from LCPs in the EU



Source: EEA, 2018a.

([20]) Data shown in this part are based on reported LCP emissions and they include all countries but Croatia.
([21]) 'Existing plants' denotes the oldest plants, licensed before 1 July 1987. All other plants had to comply with the ELVs by 27 November 2002, the latest date of enforcement of the directive. For details, please refer to Subsection 1.1.4.

Table 3.2 highlights notable differences among country groups as regards their average annual reductions in air pollutant emissions between 2004 and 2007, and thereafter. Until 2007, the LOW group had the fastest pace of average annual reductions for all categories of air pollutants. In contrast, in the other two groups the pace of emission reductions picked up only after 2007, when the oldest LCPs also had to become compliant.

These developments correspond to earlier observations regarding differences in fuel types and the uptake of abatement measures across LCPs belonging to the different country groups. They also point towards likely differences in the average age of LCPs across the country groups, with the HIGH and MEDIUM groups having larger shares of old, less efficient 'existing' LCPs than the LOW group, in line with other EEA analyses of combustion plants (EEA, 2016b).

3.3.2 *Progress towards specific objective 2: to improve the environmental performance of LCPs in terms of the regulated air pollutants*

The second specific objective of the LCPD was to improve the environmental performance of LCPs with respect to key air pollutants. To monitor progress towards this objective, the LCPD explicitly mandated

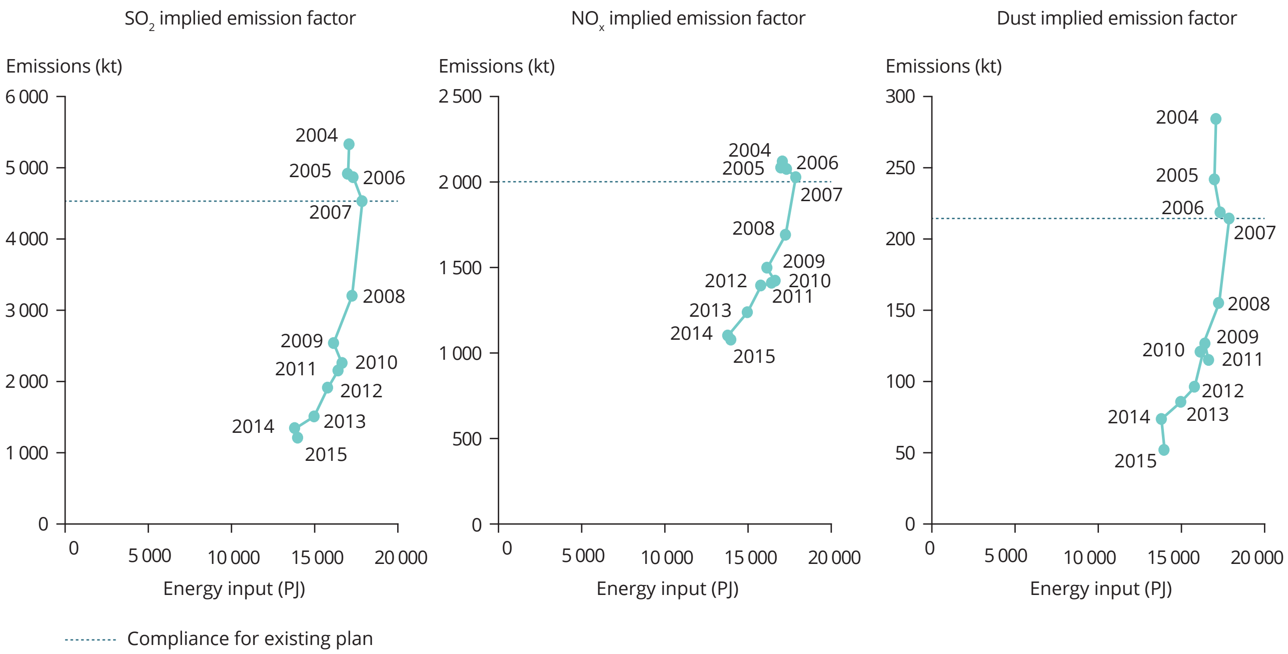
Table 3.2 Average annual pace of reduction in LCP pollutant emissions

Country groups	Average annual reduction rates (%)								
	LCP pollutant emissions								
	SO_2			NO_x			Dust		
	2004-2007	2007-2015	2004-2015	2004-2007	2007-2015	2004-2015	2004-2007	2007-2015	2004-2015
EU-28	-5	-15	-13	-1	-8	-6	-8	-14	-13
Low implied emission factor (LOW)	-12	-9	-10	-4	-5	-5	-13	-11	-11
Medium implied emission factor (MEDIUM)	-5	-15	-12	0	-9	-6	-7	-14	-12
High implied emission factor (HIGH)	-2	-19	-15	1	-10	-7	-11	-20	-18

Note: Croatia was excluded from the EU total because of a lack of data prior to its accession.

Source: EEA, 2018a.

Figure 3.6 LCP emissions versus energy input in the EU-28 (2004-2015; in kt/PJ)



Source: EEA, 2018a.

the reporting of annual plant-level fuel use data, in addition to plant-level emissions.

Together with the emission inventories, plant-level data on energy input allow the overall environmental performance of all LCPs to be calculated as the ratio of total LCP emissions to fuel consumption — the IEF.

The assessment shows that the LCP IEFs decreased significantly between 2004 and 2015 for all air pollutants, and especially between 2007 and 2008, when existing LCPs had to become compliant with the ELVs set under the LCPD.

Figure 3.6 depicts the evolution of the average IEFs over time. It shows that SO_2, NO_x and dust emissions from LCPs fell much faster than total energy input to LCP. Except in the aftermath of the economic crisis (2009-2011) when progress stalled, the improvement in the IEFs is relatively consistent over the whole period. The significant improvement in the IEF for each key pollutant indicates a relative increase in the environmental performance of the sector, that is, a decoupling of the use of resources (i.e. the fuel input) from the pressure on the environment (emissions of polluting substances).

Multiple drivers have caused this evolution, many of which are linked. The remainder of this chapter explores a number of important trends in detail. Chapter 4 then puts these trends and observations into context to explain the reasons for the falling LCP emission trends over the period analysed.

Evolution of EU-28 emissions by LCP IEF classes

The reduction in LCP pollutant emissions across the EU coincided with a shift towards LCPs operating in lower IEF classes ([22]):

- In 2004, 64 % of all SO_2, 44 % of all NO_x and 55 % of all dust emissions came from plants belonging to the highest IEF intensity class, class I, as illustrated in Figure 3.7.
- In 2015, these figures for plants belonging to this highest IEF class had fallen to 17 % for SO_2, 12 % for NO_x and 21 % for dust emissions.

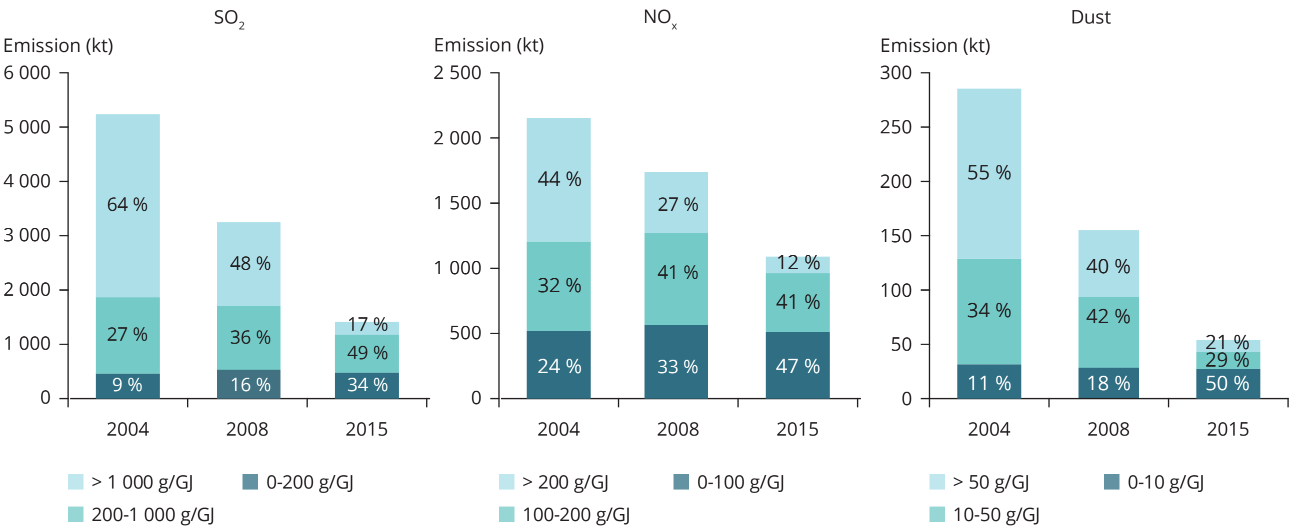
The rate of reductions was fastest around 2007 and thereafter.

The following explains the observed changes in LCP emissions per IEF class over time.

An LCP in the highest IEF class could have:

- improved its IEF, while remaining in the same IEF class;
- improved its IEF, then would move to a lower IEF class;

Figure 3.7 Evolution of LCP pollutant emissions per IEF class (kt/%, EU-28).



Source: EEA, 2018a; own calculations.

([22]) For information about the emission intensity classes please refer to Table 2.1, Classes of LCP IEFs, per pollutant.

- reduced its activity (energy input and corresponding emissions), while remaining in the same IEF class;

- closed down.

These explanations clarify, especially, the reduction in emissions in the highest IEF class for each pollutant.

To better understand the overall results, a specific analysis looked only at those LCPs that belonged to the highest IEF class in 2008. For these LCPs, the IEFs in 2008 and then in 2015 were assessed. The analysis shows that:

- LCPs having moved to a lower IEF class by 2015 accounted for 62 % of the overall reduction in SO_2 emissions and for around one third of the reduction in NO_x emissions from LCPs over the period.

- LCPs having temporarily or permanently stopped operating by 2015 (no energy input or emissions were reported in 2015) accounted for 52 % of the overall dust emission reductions and circa 30 % of the overall NO_x emission reductions from LCPs by 2015.

- LCPs having remained in the highest IEF class in 2015 accounted for 7 % of overall SO_2, 16 % of overall NO_x and 12 % of overall dust emission reductions over the period, thanks to a combination of reduced activity (and associated pollutant emissions) and a less marked improvement in the IEF of this group of plants.

Figure 3.8 shows the contribution of these three factors to the observed emission reductions in the highest IEF class.

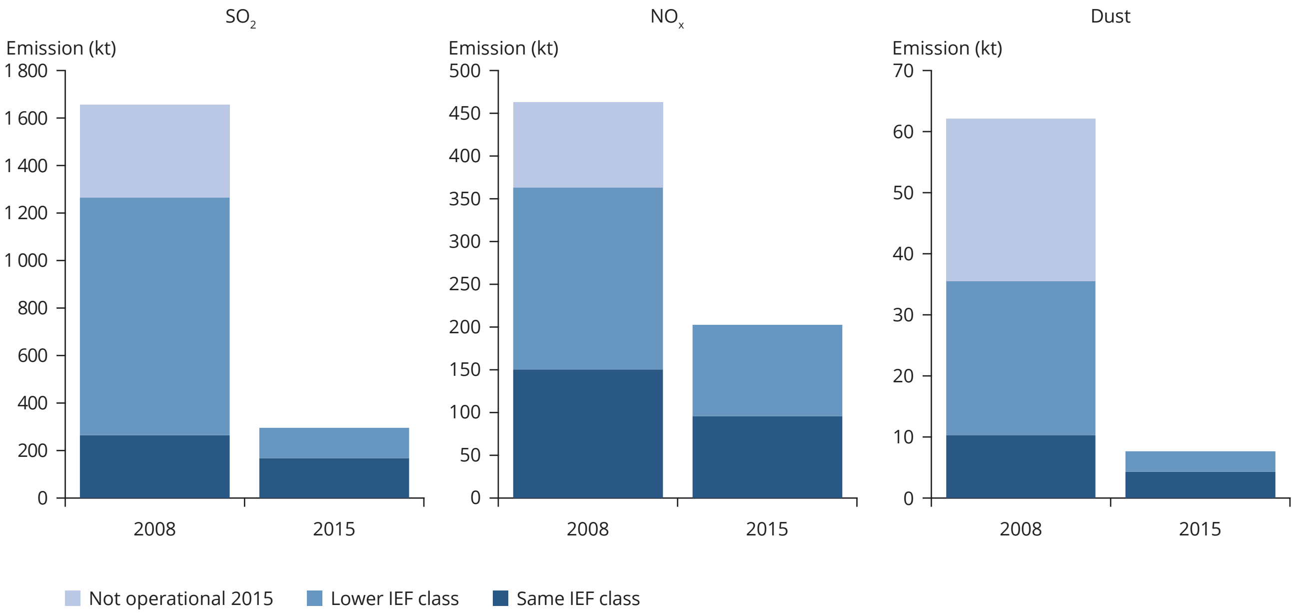
Overview of the development of LCP IEFs over time

Evolution of LCP IEFs by fuel type

The following figures show the development over time of fuel-specific IEFs for the substances SO_2, NO_x and dust:

- In 2004, the average IEFs for SO_2 for solid and liquid fuel-fired LCPs (482 g/GJ and 359 g/GJ, respectively) were relatively high, compared with other fuel types (3 g/GJ for natural gas-fired LCPs, 57 g/GJ for LCPs burning 'other gases' and 30 g/GJ for LCPs fuelled by biomass). The IEF for

Figure 3.8 Factors contributing to SO_2, NO_x and dust emission reductions between 2008 and 2015, for LCPs in the highest IEF class (EU-28)



Note: This graph shows the emissions in 2008 and 2015 from LCPs that belonged to the highest IEF category in 2008, for each pollutant separately.

Source: EEA, 2018a; own calculations.

SO_2 for single-fuel LCPs burning solid or liquid fuel improved most over time, in absolute terms. Nevertheless, in relative terms, there were similar improvements in IEFs for all fuel types among LCPs (between 61 % and 83 %).

- Similarly, for NO_x, the combustion of solid and liquid fuels accounted for the highest IEFs in 2004 (157 g/GJ and 116 g/GJ, respectively). The IEFs for NO_x for biomass (86 g/GJ), natural gas (47 g/GJ) and other gases (46 g/GJ,) were considerably lower. Unlike for dust or SO_2 emissions, the NO_x-related IEFs of single-fuel LCPs improved less over time. By 2015, IEFs had decreased by only 15 % (liquid fuels) to 39 % (natural gas) since 2004.

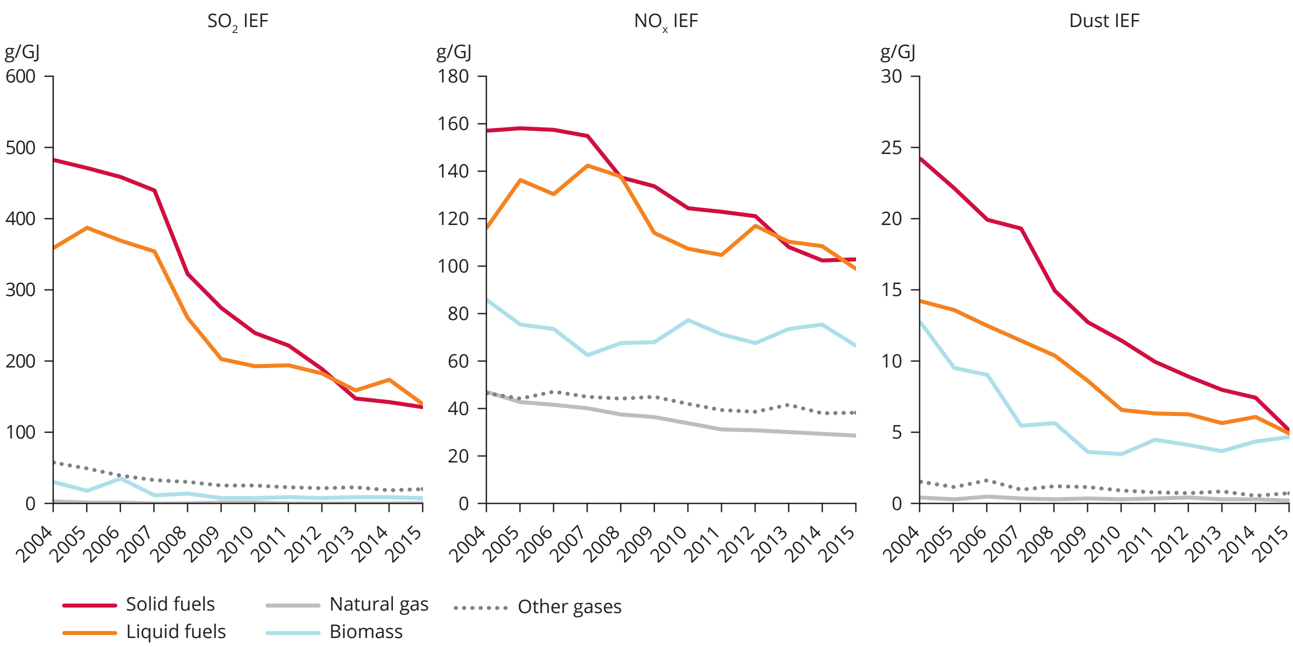
- As with SO_2 emissions, overall, the combustion of solid fuels is associated with the highest IEFs for dust (see Figure 3.9). In 2004, the IEF for dust for single-fuel plants using solid fuels, which include coal and brown coal, was 24 g/GJ. This was considerably higher than that of liquid fuels (14 g/GJ), biomass (13 g/GJ), other gases (2 g/GJ) and natural gas (0.4 g/GJ). In 2015, the IEF for single-fuel LCPs using solid fuels had decreased considerably (5 g/GJ) and by the same order of magnitude as for LCPs burning biomass or liquid fuels.

The results indicate that, over the period 2004-2015, the IEF has decreased for all combinations of fuel types and for all pollutants, but most prominently for LCPs fired by solid fuels.

Evolution of IEFs by size of LCPs (i.e. per capacity class)

Figure 3.10 illustrates that the IEFs for SO_2 and NO_x of LCPs in capacity class I (the largest plants, each > 2 000 MW_{th}) are relatively high. IEFs decreased between 2004 and 2015 for all pollutants and each LCP capacity class. On average, IEFs decreased fastest annually for LCPs in capacity class II (LCPs with capacities between 500 MW_{th} and 2 000 MW_{th}), but the average annual pace of reductions is quite similar across all three classes.

Figure 3.9 IEFs of single-fuel LCPs, by fuel type (EU-28)



Source: EEA, 2018a.

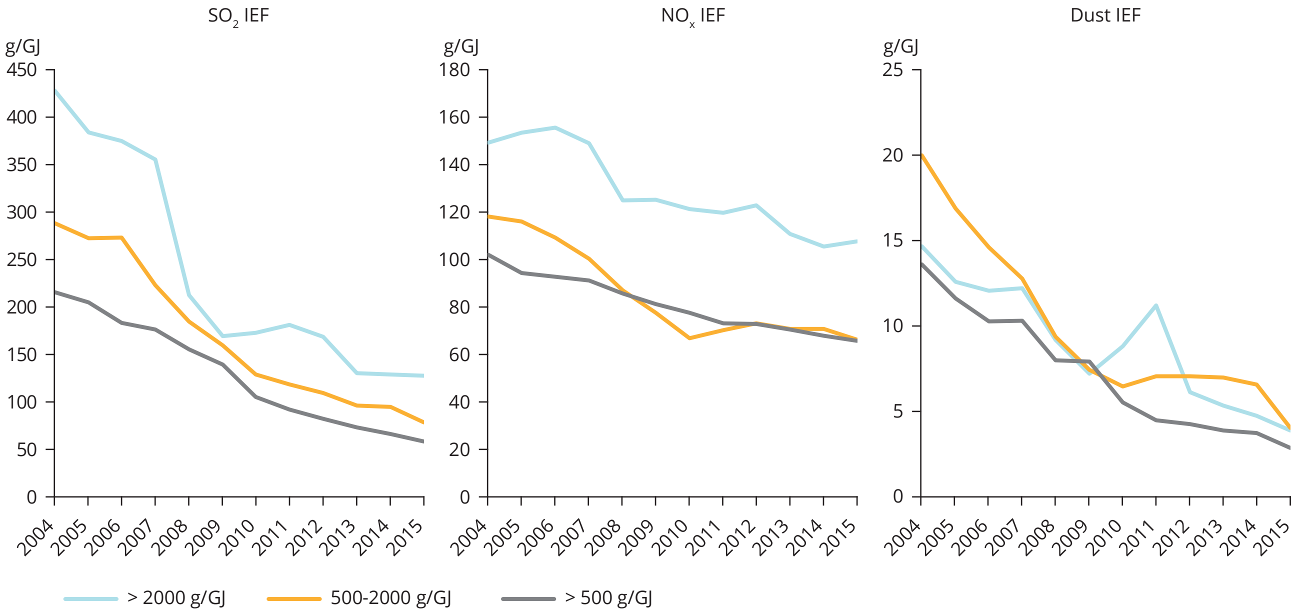
Evolution of IEFs by industrial sector

The IEFs of LCPs also vary in accordance with the specificities of the industrial sector to which the LCPs belong. Figure 3.11 shows results for the chemical industry, the energy sector, and the paper and wood processing sector. The trends indicate that differences between the IEFs of LCPs across these sectors became smaller over time. In the early years of the period 2004-2015, the chemical industry and the energy sector had clearly higher IEFs for SO_2, NO_x and dust. However, the IEFs of these sectors decreased more substantially than intensities in the paper and wood processing sector.

Closure rates

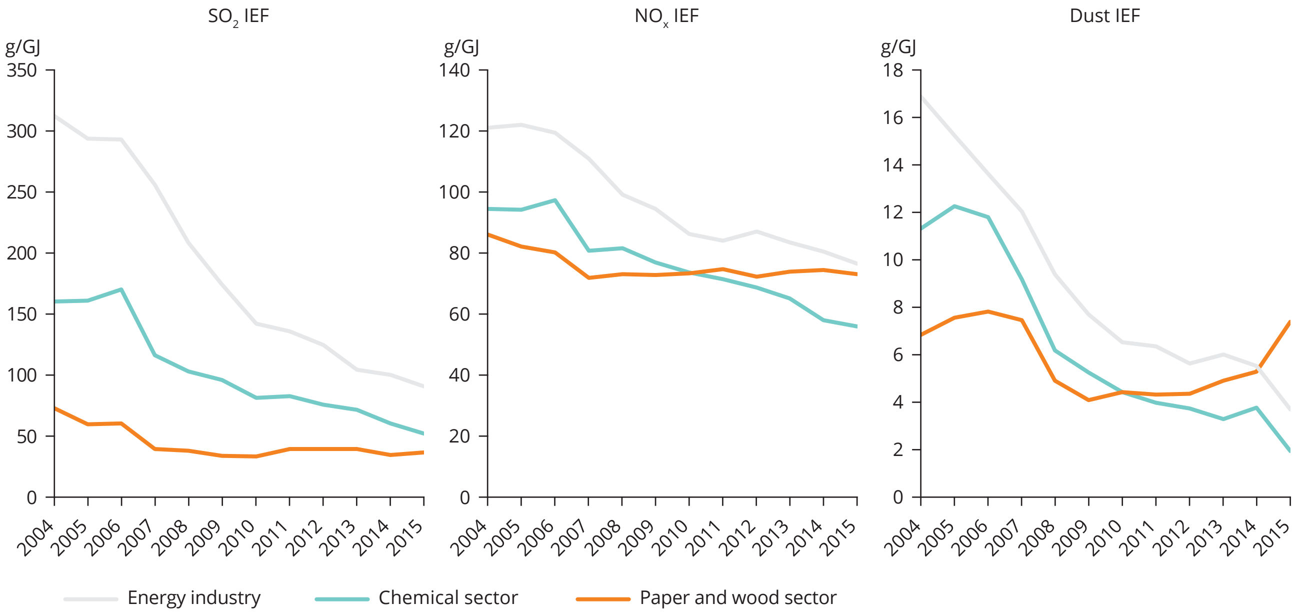
A significant proportion of the reduction in emissions between 2004 and 2015 in the highest IEF class for all pollutants was related to the number of LCPs that had stopped operating by 2015 (see Figure 3.8 and

Figure 3.10 IEFs of LCPs per capacity class (EU-28)



Source: EEA, 2018a.

Figure 3.11 IEFs for dust of LCPs in the EU-28, by sector (in g/GJ)



Source: EEA, 2018a.

Figure 3.12). To gain an understanding of whether plants were retired because of their old age (end of operating life) or other factors, the closure rates of LCPs were analysed. The Platts World Electric Power Plants (WEPP) database was used to determine the age of these LCPs. As in previous studies, the typical assumptions on average lifetimes were 40 years for solid fuels, 35 years for natural gas and 40 years for oil (EEA, 2016b). The age of 579 individual single-fuel LCPs could be determined, of which only 29 LCPs were considered closed. Twenty-six of the closed LCPs reported energy inputs until 2011 or later.

The assessment shows that LCPs fired by solid fuels closed at an average age of 43 years, LCPs fired by liquid fuels at an average age of 29 years and LCPs fired by natural gas at 37 years.

Based on this analysis, it could be concluded that a significant number the LCPs still in operation in 2015 were close to the end of their technical lifetimes (see also findings in EEA, 2016b):

- For LCPs firing solid fuels, 55 % of the plants in operation in 2015 were older than 40 years.
- For LCPs firing natural gas, 27 % were older than 35 years.
- For LCPs using liquid fuels, 49 % were above 40 years of age.

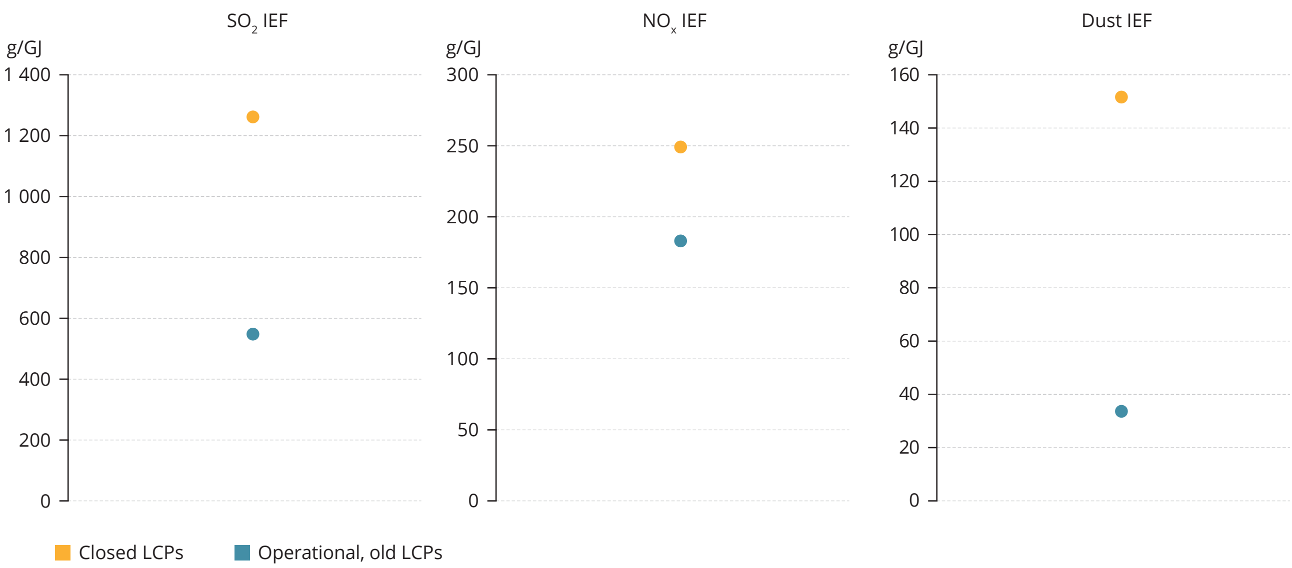
The number of single-fuel LCPs that closed down, and for which the age is known, is very small. For liquid fuel and natural gas (single-fuel) LCPs, the number is too small to perform meaningful comparisons. For solid fuel (single-fuel) LCPs, the total number of plants that closed down is 17. The IEF of these plants was compared with the IEF of other solid fuel (single-fuel) LCPs that were in operation in 2015. To prevent data from relatively young LCPs affecting the outcome of this comparison, only LCPs that were at least 40 years old in 2015 were included.

The analysis indicates that LCPs that closed down had, on average, considerably higher IEFs in 2004 than LCPs that continued to be in operation until 2015, even though the average ages of the LCPs were similar (see Figure 3.12).

3.3.3 Progress towards specific objective 3: to improve information and knowledge regarding the emissions of key air pollutants from LCPs

The LCPD established an EU-wide reporting framework for LCPs. The inventory, with 2004 as the first reporting year, covered plant-level data for total annual SO_2,

Figure 3.12 IEFs for SO_2 (g/GJ), NO_x and dust in 2004 in old (single-fuel) LCPs that closed down before 2015 or continued to be in operation in 2015 (EU-28)



Note: The LCPs included in this analysis are single-fuel 'other solid fuel' plants that either closed in the period 2005-2015 or were in operation until 2015.

NO_x and dust emissions, the total annual amount of energy input ([23]), as well as some key identification elements for each combustion plant. The inventory also collected the information that countries communicated to the Commission during the implementation of the LCPD, including the applicable derogatory regime per plant, or the legal status of each plant (see Subsection 1.1.4). The EEA took over LCPD reporting from reporting year 2013, and established a systematic reporting mechanism with both automated quality assurance on submission and post-submission checks assisted by experts.

While a number of air emission inventories were available at that time, the reporting framework set up under the LCPD was one of the first attempts to collect data on a plant-by-plant basis (i.e. data generated and reported at plant level and transmitted to the competent authorities). The only similar mechanism was the European Pollutant Emission Register (EPER) ([24]), established in 2000, and its successor, the European Pollutant Release and Transfer Register (E-PRTR) ([25]), which has collected data since 2007.

Annex VIII to the LCPD required operators to continuously monitor concentrations of SO_2, NO_x and dust from waste gases from each combustion plant with a rated thermal input equal to, or larger than, 100 MW, starting from 27 November 2002. Several derogations were allowed, such as for old plants operating less than 10 000 hours.

The LCPD inventory, however, lacked a number of key aspects that limited its contribution to improving knowledge:

- The narrow set of the reported fuel types led to significantly different fuels being reported in an aggregate form, without offering the possibility to determine their individual contributions to total energy input and ensuing emissions ([26]).

- Reported fuel types were not aligned to those used to derive the ELVs, an issue that became apparent when the reference document on best available techniques (BAT) for LCPs (EC, 2006a) established a wide diversity of fuel types as basis to determine BAT. Using the inventories as a proxy indicator for compliance would therefore require processing the data with external sources, which is resource intensive and may give rise to uncertainty.

- LCPs operate in a wide range of sectors (e.g. electricity- and heat-producing sectors, iron and steel works, the chemical industry, the refining industry) and their activity is often sector specific. The inventory did not collect precise information about the sectors in which the LCPs operated, which hampered the possibility to structure the analyses based on the economic activity performed.

- The legal basis of the inventory lacked details on certain parameter definitions, on calculation rules and, more substantively, on the definition of what constitutes a 'plant'.

- The inventory was established at a time when information technology was not as developed as it is today. The exchange of data between countries and the EU level was less systematic (e.g. based on paper submissions, Excel sheets, email exchanges). The current quality assurance mechanisms are now better developed than they were in the early years of the LCPD, thanks to the emergence of other data sources that enable cross-comparisons.

3.3.4 Progress towards specific objective 4: to promote enhanced policy coordination and alignment of the levels of health and environmental protection at Member State and regional/local levels

Significant disparities in the average environmental performance of LCPs across the EU Member States at the time of the adoption of the LCPD (see Section 3.1) indicate variations in the levels of health and environmental protection that countries provided with regard to SO_2, NO_x and dust pollutant emissions from these plants.

([23]) Energy input is expressed as net calorific value for five categories of fuels. For details, see Section 1.3.
([24]) Established as the reporting mechanism of the IPPCD, the EPER was superseded by the E-PRTR and is no longer available online. The data, of a similar scope to their successors, are fully integrated in the E-PRTR.
([25]) Established by Regulation No 166/2006, the E-PRTR collects data at facility level (one or more LCPs would be reported together if they belong to the same operator); the reporting of activity data (i.e. fuel input) is not mandatory. More information is available on the E-PRTR website: http://prtr.ec.europa.eu.
([26]) For instance, the category 'other solid fuels' contains a wide range of coals, compositions and calorific values that differ so much that it hinders a comprehensive understanding of the reasons behind the observed differences in IEFs per fuel type. Resource-intensive processing of external commercial data sets is needed to better understand and refine these fuel categories.

The LCPD sought to eliminate such discrepancies by mandating the application of harmonised, maximum ELVs across the EU. Countries with high IEFs (the HIGH group, i.e. usually countries with a higher share of old, less efficient 'existing' LCPs) could align gradually to the minimum EU-wide levels of health and environmental protection, following the sequential (two-step) conformity regime of the LCPD.

To facilitate a harmonised implementation of legal provisions and create a level playing field within Europe, information exchanges were organised between competent authorities dealing with the implementation of the LCPD as part of the Expert Group on Industrial Emissions (former Integrated Pollution Prevention and Control (IPPC) Expert Group) ([27]).

Among the EU policies that the LCPD interacted with (see Subsection 1.1.2), the most relevant was the IPPC Directive (IPPCD). It established a mechanism of permits based on the use of BAT, which allowed a degree of flexibility for competent authorities, enabling them to set conditions on a case-by-case basis.

Although this flexibility provided a sound approach for subsequent EU legislation on industrial emissions (EC, 2007a), its implementation in practice resulted in unjustifiably large differences in the ELVs set under the IPPCD across sectors. In contrast, the LCPD established a minimum set of mandatory ELVs for NO_x, SO_2 and dust, which acted as a safety net for minimum pollution abatement across the sector and prompted the alignment of environmental protection standards at European level with the binding minimum thresholds.

By introducing a mechanism that distributed minimum emission reduction efforts across EU countries and economic actors, the LCPD has played a central role in the achievement of the national and EU-wide commitments under the CLRTAP. Combustion sources were a key contributor to the emissions of the three regulated air pollutants falling under the scope of the CLRTAP commitments; the emission sources reduced their emissions at a pace higher than that of other sources (see Section 3.3.1).

3.4 Other quantitative impacts associated with the LCPD

3.4.1 Relevance of the LCP sector in Europe

LCPs are typical backbone infrastructures producing electricity and/or heat across the industry sector, including in the electricity and heat supply sector ([28]), oil refineries, chemical industries, the pulp and wood processing sector, and the iron and steel production sector. As such, LCPs play a vital role in the energy and industrial sectors and, more broadly, in socio-economic activity. In 2015, there were 3 418 LCPs across the EU-28.

While there are no official statistics on the contribution of LCPs to gross domestic product (GDP) and employment, values for the industrial sector (except construction) can be used as a proxy. As such, with a total contribution of EUR 2 022 billion in 2004 ([29]), industry represented 18.2 % of the EU's GDP at the start of the period. In 2015, the sector's contribution increased to EUR 2 573 billion and represented 17.4 % of the EU's GDP — a 0.8 percentage point drop in the share as the service sector became more relevant and as the share of industry decreased more prominently between 2008 and 2009, during the economic recession. Similarly, over 90 000 enterprises were active in 2015 in the electricity and heat supply sector — more than four times as many as in 2005 (EC, 2012, 2018b). Collectively, these enterprises led to the reported employment of 1.4 million people and an overall reported turnover of EUR 1.5 billion across the EU energy sector in 2015.

Socio-economic benefits of LCPs include opportunities for highly skilled employment, market shares for technology providers and plant operators, and opportunities for the export of abatement technologies, the air pollution control sector being seen as among the largest export sector of the EU's eco-industry (EUR 2.9 billion of annual sales in 2004, especially to China, with the main drivers for the development of environmental technologies in this sector being legal requirements) (EC, 2007b).

([27]) Register of Commission Expert Groups: http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetail&groupID=373 (accessed 19.11.2018)
([28]) Both for industrial purposes and for further distribution to end consumers.
([29]) At current prices.

4 Answers to the key questions

Chapter 4 outlines the main findings of the assessments of each of the evaluation questions set out in Section 1.2. Although most questions are addressed individually, those for which there are significant overlaps in the information and evidence provided have been grouped.

A number of generic factors has contributed to the overall reduction in air pollutants emitted by large combustion plants (LCPs) (see Subsection 1.1.3), including the uptake of plant-level emission abatement technologies in response to EU policies, in particular the LCP Directive (LCPD).

4.1 Effectiveness

The 2001 LCPD does not provide straightforward, measurable indicators against which progress towards its specific objectives can be assessed. Nevertheless, the analysis of trends in Chapter 3 provides sufficient evidence to measure the effectiveness of the directive. For the period 2004-2015, the analysis shows that:

- Air pollutant emissions from LCPs fell significantly for all key pollutants, irrespective of plant size, plant type, fuel type and location across the EU;
- Air pollutant emissions from LCPs represented the main share of total air pollutant emissions;
- Annual emissions of SO_2, NO_x and dust from LCPs decreased, on average, more rapidly than the overarching trends of these pollutants.

This allowed LCPs to play a major role in reducing total air pollutant emissions, in line with the objectives of the Thematic Strategy on Air Pollution (EC, 2013). The following sections put these findings in relation to each key question.

4.1.1 Has the LCPD been effective in reducing air pollutant emissions from the installations it covered?

Comparison with baseline emission levels (EU-15)

Regarding the then 15 EU Member States (EU-15), the baseline projections carried out for the LCPD indicate that, without further measures, SO_2 emissions from LCPs would have amounted to 2 339 kt in 2010 (see Table 1.2). In reality, across the EU-15, LCP emissions of SO_2 fell from 2 871 kt in 2004 to only 886 kt in 2010. Similarly, according to the baseline, NO_x emissions from LCPs in 2010 would have amounted to 903 kt across the EU-15 without the LCPD. In reality, LCP NO_x emissions fell from 1 537 kt in 2004 to 918 kt in 2010, which means that 2010 LCP NO_x emissions were marginally higher than the projected baseline levels.

The comparison suggests that, by 2010, the LCPD had significantly reduced LCP emissions of SO_2 across the 15 Member States (actual SO_2 emissions were 62 % lower than the projected baseline level). Yet, despite the real fall in LCP NO_x emissions between 2004 and 2010, the LCPD may not have had a real impact on this reduction in NO_x emissions (actual LCP NO_x emissions were 2 % higher than projected baseline NO_x levels for 2010). This could mean that abatement measures for NO_x pollutants from LCPs (such as the uptake of low-NO_x boilers) evolved much slower than estimated in the baseline.

Comparison with hypothetical scenarios (EU-28)

Emissions of SO_2 and dust from power plants decreased by more than three quarters (81 % and 77 %, respectively), and emissions of NO_x by roughly one half (49 %) between 2004 and 2015, largely as a result of emission intensity improvements (see also Subsection 3.3.1 ('Progress in accordance with the compliance timelines set by the LCPD'), 4.1.3 and 4.1.4).

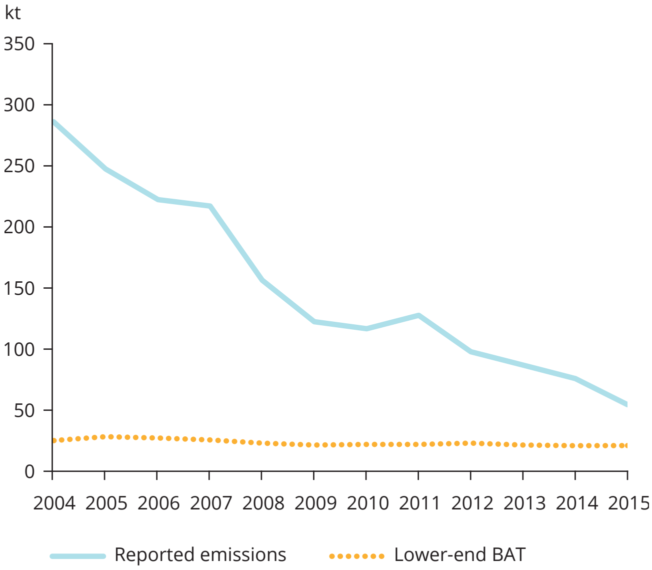
EU policies on LCPs provided a range of obligations, including compliance with minimum requirements (LCPD) and the application of more ambitious emission levels associated with best available techniques (BAT-AELs) as defined under the Integrated Pollution Prevention and Control Directive (IPPCD). To benchmark the evolution of real LCP emissions across the 28 EU Member States (EU-28), two different hypothetical historical LCP emission scenarios for the EU-28 were built, based on the different ways in which LCP policies could have been implemented: full implementation of the IPPCD BAT-AELs and no further improvement in the environmental performance of LCPs. Findings from this comparison are outlined below.

Had all plants in the EU-28 operated exactly in accordance with the lower-end BAT-AELs, total LCP emissions would have fallen more significantly by 2015 than they actually did, by 93 % for dust, 98 % for SO_2 and 82 % for NO_x. In contrast, had the environmental performance (the implied emission factors (IEFs)) of LCPs not improved over the period, LCP emissions across the EU-28 would have decreased by only 41 % for dust, 27 % for SO_2 and 29 % for NO_x. This indicates that the LCPD has been effective in reducing air pollutant emissions from the combustion plants it covered. Moreover, it shows that most of the real LCP emission reductions achieved were due to the improved environmental performance of the plants rather than other factors, such as plant closures.

However, the better implementation of a combination of obligatory minimum emission limit values (ELVs) under the LCPD and the BAT-AELs under the IPPCD would have led to even more significant LCP emission reductions across the EU-28. Figure 4.1 compares the real LCP emissions for dust with those corresponding to a hypothetical situation in which all LCP plants in the EU-28 had complied with lower-end BAT-AELs (BAT-lower scenario). Had all plants operated exactly in accordance with the lower-end BAT-AELs, total LCP dust emissions would have been only 21 kt in 2015. Hence, while real dust emissions from LCPs have gone down considerably over the period 2004-2015, in 2015 they were still higher than the BAT-AEL levels, suggesting that there would have been room for further reductions by implementing best available technologies.

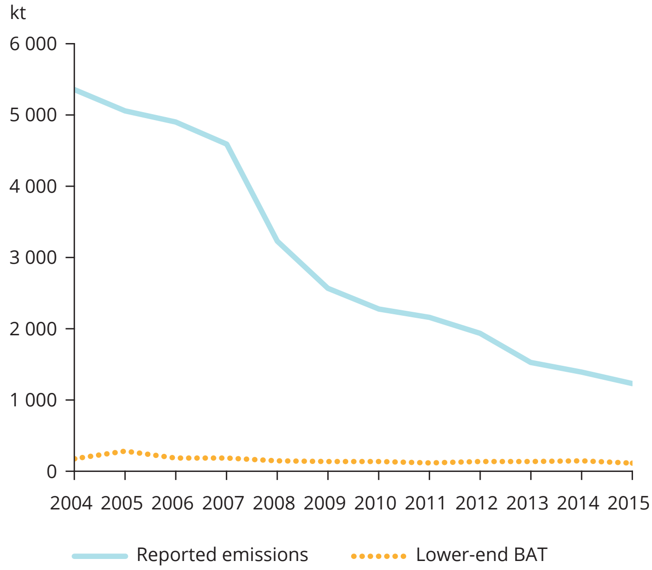
Figure 4.2 makes it possible to compare the real SO_2 emission levels from LCPs across the EU-28 to emissions corresponding to the BAT-AELs in the 2006 reference document on best available techniques (BREF) for LCPs (EC, 2006a). It shows that had all plants operated exactly in accordance with the lower-end BAT-AELs, total SO_2 emissions would have been only 114 kt in 2015. Hence, while real LCP emissions of SO_2 had gone down considerably by 2015, they were still higher than the BAT-AELs and there would have been room to further reduce these emissions through best available technologies.

Figure 4.1 Reported dust emissions from LCPs in the EU-28 (solid line) versus lower-end BAT levels (dotted line)



Source: EEA, 2018a; own analysis.

Figure 4.2 Reported SO_2 emissions from LCPs in the EU-28 (solid line) versus lower-end BAT levels (dotted line)



Source: EEA, 2018a; own analysis.

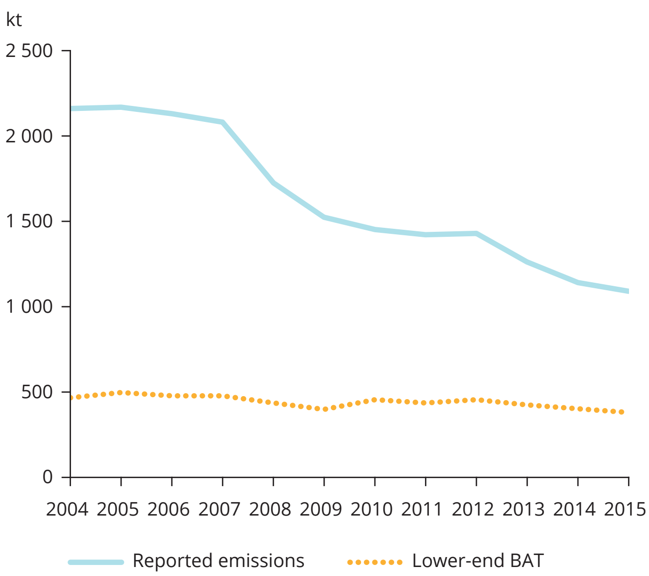
Finally, Figure 4.3 compares the reduction in real LCP NO_x emissions across the EU-28 to levels for NO_x corresponding to the 2006 LCP BREF BAT-AELs (EC, 2006a). The figure shows results for the hypothetical situation in which all plants in the EU-28 had complied with lower-end BAT-AELs (BAT-lower scenario). Had all plants operated exactly in accordance with the lower-end BAT-AELs, total NO_x emissions would have been only 114 kt in 2015. This indicates that real LCP NO_x emissions in 2015 were still higher than the 2006 BREF BAT-AELs and there would have been room to further reduce NO_x emissions from LCPs by implementing best available technologies.

4.1.2 *Has the LCPD been effective in contributing to overall air quality improvements and lowering impacts on health and the environment?*

All Member States show falling trends for total and LCP-related air pollutant emissions at the national level. The downwards trend in SO_2 emissions since 2004 in the three country groups, depicted in Figure 3.4, illustrates the significant correlation between the trend in LCP sector emissions and the trend in total air pollutant emissions.

The analysis of adjusted trends in Subsection 3.3.1 also reveals that the contribution of LCP emissions to total stationary combustion emissions fell considerably over time for SO_2, NO_x and dust. For each country group and for the EU as a whole, the average pace at which LCP emissions fell yearly was higher than the pace recorded for stationary and for total emissions, respectively.

Figure 4.3 Reported NO_x emissions from LCPs in the EU-28 (solid line) versus lower-end BAT levels (dotted line)



Source: EEA, 2018a; own analysis.

Taken together, these trends imply that the emission reductions delivered by LCPs were the most relevant driver of total air pollutant emission reductions and of emission reductions in the stationary combustion sector.

Comparison with baseline emission levels (EU-15)

As shown in Subsection 4.1.1, real SO_2 and NO_x emissions from LCPs decreased considerably across the EU-15 between 2004 and 2010.

When comparing projected (baseline) LCP emissions as a percentage of total emissions (EU-15) with the reported data for 2010, it is apparent that the projected and actual LCP emissions as percentages of total emissions are very similar (see Table 1.2):

- According to the projected baseline, LCP emissions would have accounted for 36 % of total SO_2 emissions and 13 % of total NO_x emissions in 2010.
- According to reported data, actual LCP emissions accounted for 38 % of total SO_2 emissions and 12 % of total NO_x emissions.

In conjunction with the observed marginal change in NO_x emissions (total and from LCPs), this may indicate that abatement measures to combat NO_x pollutants from LCPs evolved much slower, in reality, than had been estimated in the baseline.

4.1.3 *Has the LCPD triggered progress in the promotion of more efficient combustion plants?*

Improvements in the overall IEFs were the basis of historic total reductions in air pollutant emissions from LCPs, as illustrated in Subsection 3.3.2. The adoption of plant-level emission abatement measures as a result of the LCPD explains much of the observed improvements in the environmental performance of LCPs (62 % of the overall reduction in SO_2 emissions and around one third of the reduction in NO_x emissions by 2015, for the subset of LCPs analysed in Subsection 3.3.2). In contrast, the temporary or permanent closure of LCPs made less of a contribution to the observed improvements in environmental performance (accounting for half of overall dust emission reductions and one third of NO_x emission reductions from the subset of LCPs assessed in Subsection 3.3.2).

Evolution of EU-28 emissions by LCP IEF classes

An analysis of the trends in LCP air pollutant emissions shows clearly that the reduction in LCP emissions across the EU coincided with a shift towards LCPs operating in lower IEF classes ([30]). Reductions took place at a faster rate after 2007, which also coincided with the stepwise compliance regime under the LCPD (see Figure 3.7 and Figure 3.8). Three factors played a determinant role in reducing the air pollutant emissions from these plants:

- The most important factor was the shift of LCPs to lower IEF classes by 2015.
- The second most important factor was LCPs temporarily or permanently stopping operating by 2015.
- The least important factor was LCPs having remained in the highest IEF class by 2015.

Overview of the development of LCP IEFs over time

Evolution of LCP IEFs by fuel type

The development over time of fuel-specific IEFs for the substances SO_2, NO_x and dust indicates that the IEFs decreased for all combinations of fuel types and for all pollutants (see Figure 3.9):

- The IEF for SO_2 for single-fuel LCPs burning solid or liquid fuels improved most over time, in absolute terms. Nevertheless, in relative terms, for all fuel types, LCPs see similar improvements in IEFs (between 61 % and 83 %).
- Unlike dust or SO_2 emissions, single-fuel LCPs' NO_x-related IEFs improved less over time, as also illustrated in Subsection 4.1.1 in relation to the baseline projections. In 2015, IEFs decreased by only 15 % (liquid fuels) to 39 % (natural gas) compared with 2004.
- By 2015, the IEF of single-fuel LCPs using solid fuels had decreased considerably (5 g/GJ) and was in the same order of magnitude as the IEFs for LCPs burning biomass or liquid fuels.

Evolution of IEFs by size of LCP (i.e. per capacity class)

IEFs decreased between 2004 and 2015 for all pollutants and each LCP capacity class, but the average annual reduction rates were quite similar across all three classes (see Figure 3.10).

Evolution of IEFs by industrial sector

Trends indicate that differences between IEFs of LCPs across these sectors became smaller over time. The chemical industry and the energy sector had clearly higher IEFs for all air pollutants, but their environmental performance improved more significantly than that of the paper and wood processing sector (see Figure 3.11).

Closure rates

To determine whether plants were retired because of their old age (end of operating life) or because of other factors, LCP closure rates were analysed.

LCPs fired by solid fuels and natural gas closed at an average age that was higher than typical average operating lifetimes, whereas LCPs fired by liquid fuels closed earlier on average than the typical average lifetimes. For solid-fuel (single-fuel) LCPs, only 17 plants in total had closed down.

The analysis reveals that the IEFs of the plants that had closed were, on average, considerably higher in 2004 than that of LCPs that continued to be in operation in 2015, despite the similar ages of the plants (see Figure 3.12). This confirms that, foremost, it was the most-polluting old LCPs that were decommissioned.

Installation of abatement technologies

The report *Technical support for developing the profile of certain categories of Large Combustion Plants regulated under the Industrial Emission Directive* and the so-called 'SR18 database' behind the report (EC, 2017) provides useful estimates concerning the pollution abatement technologies installed in LCPs. For every unit for which installed abatement technologies were not already indicated in the Platts-WEPP database, the presence of an abatement technology was inferred based on typical technology- and fuel-specific efficiency ranges. This made it possible to assess how many plants have improved their environmental performance by retrofitting.

Of the 349 single-fuel LCPs with 'biomass' or 'other solid fuels' fuel types with a capacity of more than 300 MW_{th}, there was information on the abatement technique (directly known or based on typical efficiency ranges) and the installation date for three quarters of the LCPs (261) in the SR18 database. For one quarter of the LCPs,

([30]) For information about the emission intensity classes please refer to Table 2.1, Classes of LCP IEFs, per pollutant.

information on abatement technology was missing in the SR18 database ([31]).

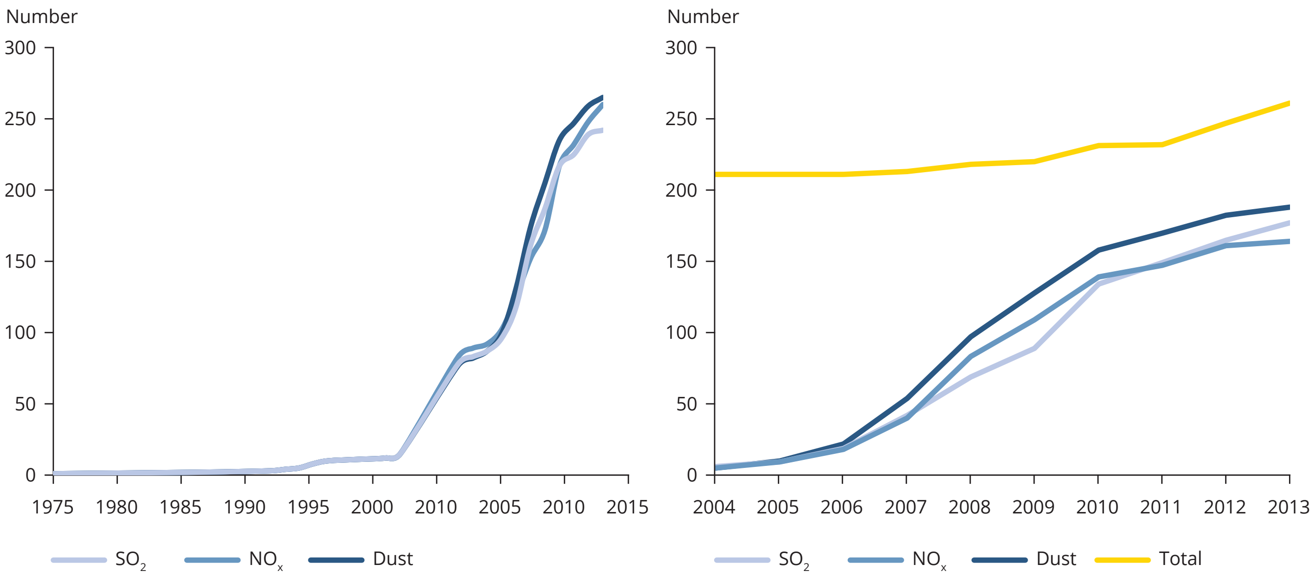
The assessment found that roughly half of these LCPs had installed abatement technologies for dust (183 LCPs), NO_x (171 LCPs) and SO_2 (159 LCPs) emissions between 2004 and 2013. The rates of installation peaked during the 2007-2010 period. The historic time series also show that abatement technologies were being installed from 2000 onwards, but especially during the 2004-2013 period (Figure 4.4).

That the emissions of all pollutants fell especially because of the decrease in the IEFs of LCPs, and especially from LCPs in the highest IEF classes, has already been shown. A cross-comparison over time of the IEFs of individual LCPs for which information on the existence of abatement technologies is available is illustrated in Figure 4.5. This shows that:

- LCPs that installed these technologies before 2004 ('old abatement') had a lower median IEF than LCPs that took abatement measures later ('new abatement') or did not take them at all ('no abatement') ([32]). LCPs that installed abatement technologies before 2004 did not improve their IEFs as much as the other LCPs did over time (especially for NO_x and SO_2).
- On average, LCPs that did not install abatement technologies for certain pollutants still improved their IEFs between 2004 and 2013. However, the rate of improvement appears to have been lower than for LCPs that did install abatement technologies.

These developments could be explained by LCPs belonging to the 'no abatement' group for one pollutant, but having installed an abatement measure for other pollutants that would also affect the emissions of the pollutant not targeted by the abatement measure, for instance SO_2 scrubbers that can also affect dust emissions. Second, other smaller emission-reducing measures, which are not categorised as an abatement technology may have been at play (e.g. optimisations of the burner to reduce NO_x emissions). Finally, even though the analysis includes only a homogenous subset of LCPs (large, single-fuel plants with biomass

Figure 4.4 Cumulative number of single-, solid-fuel LCPs (left) that installed SO_2, NO_x and/or dust abatement technologies (right) during two time-frames in the EU-28: 1975-2013 and 2004-2013

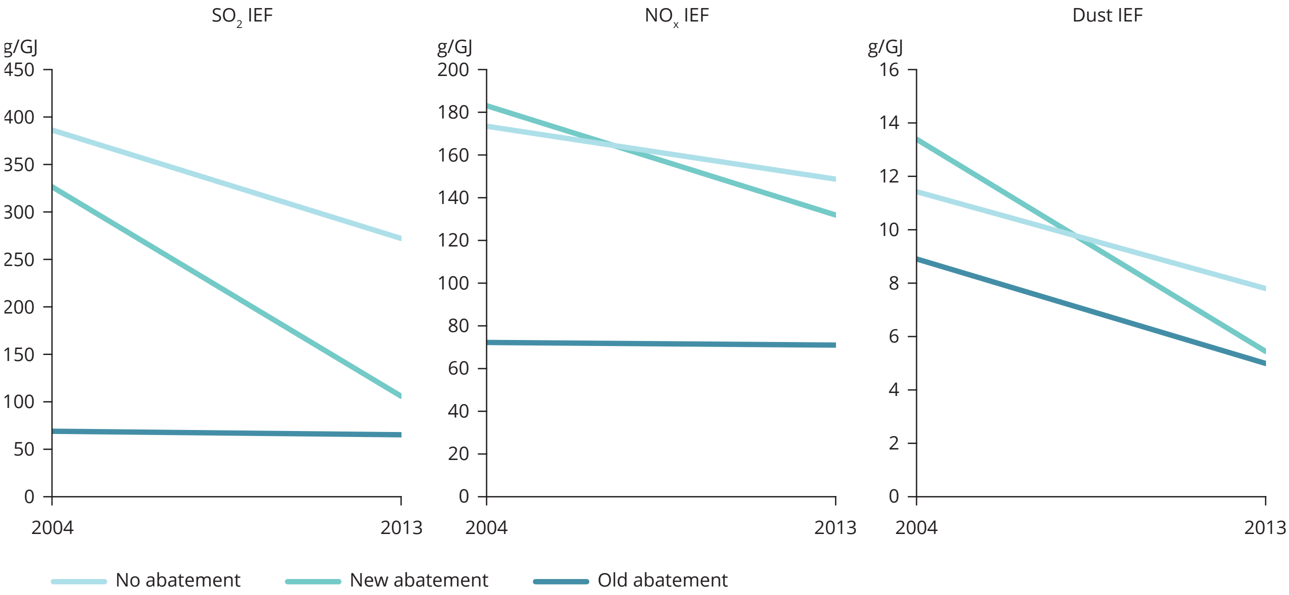


Sources: EU, 2016; EEA, 2018a; own analysis.

([31]) For only a small fraction of these 88 LCPs there is a consistent time series for the period 2004-2013, which could explain why these are missing in the SR18 study. For instance, LCPs might have closed down or the capacity of the LCP might have changed. Only four LCPs in the LCP database that meet the criteria (more than 300 MWth and single-, solid-fuel plants), with reported energy input and emissions in 2004 and 2013, were not included in the SR18 study. Abatement technologies were installed between 1975 and 2019. The analysis of the SR18 study included *ex post* data up to 2013, and projections for *ex ante* years from 2015 to 2019. For the current analysis, only *ex post* data up to 2013 were considered.

([32]) 'No abatement' means that for a given pollutant no abatement technology was installed in the period 2004-2013, although a technology could have been installed to abate the emissions of other pollutant(s).

Figure 4.5 Changes in median LCP SO_2, NO_x and dust IEFs between 2004 and 2013 (EU-28)



Source: EU, 2016b; EEA, 2018a.

or solid fuels), the switching of fuels, for example to fuels with a lower sulphur content, may have had a mitigating effect on SO_2 emissions as well (i.e. pre-combustion abatement).

4.1.4 To what extent can the observed changes be credited to the LCPD?

Main drivers of the falling trends in LCP emissions

To find out how strongly the emission limits of the LCPD influenced the observed LCP emission reductions, a set of possible key drivers were quantified through macro-level decomposition analysis (see Chapter 2). Such an attribution had not been possible in previous LCP studies. Two statistical identities were formulated and then assessed:

- a detailed, eight-factor identity, focusing on changes in emissions from **electricity-generating LCPs**;
- a simpler, five-factor, identity, encompassing changes in emissions from **all LCPs** (for control purposes mainly).

For the EU level, the detailed assessment indicates that the most important factor in reducing emissions of SO_2, NO_x and dust from electricity-generating LCPs was the **improvement in the IEF** ([33]) achieved by LCPs between 2004 and 2015. In contrast, despite certain fluctuations, neither the economy nor structural shifts between sectors played determinant roles in reducing the air pollutant emissions from these LCPs over the period.

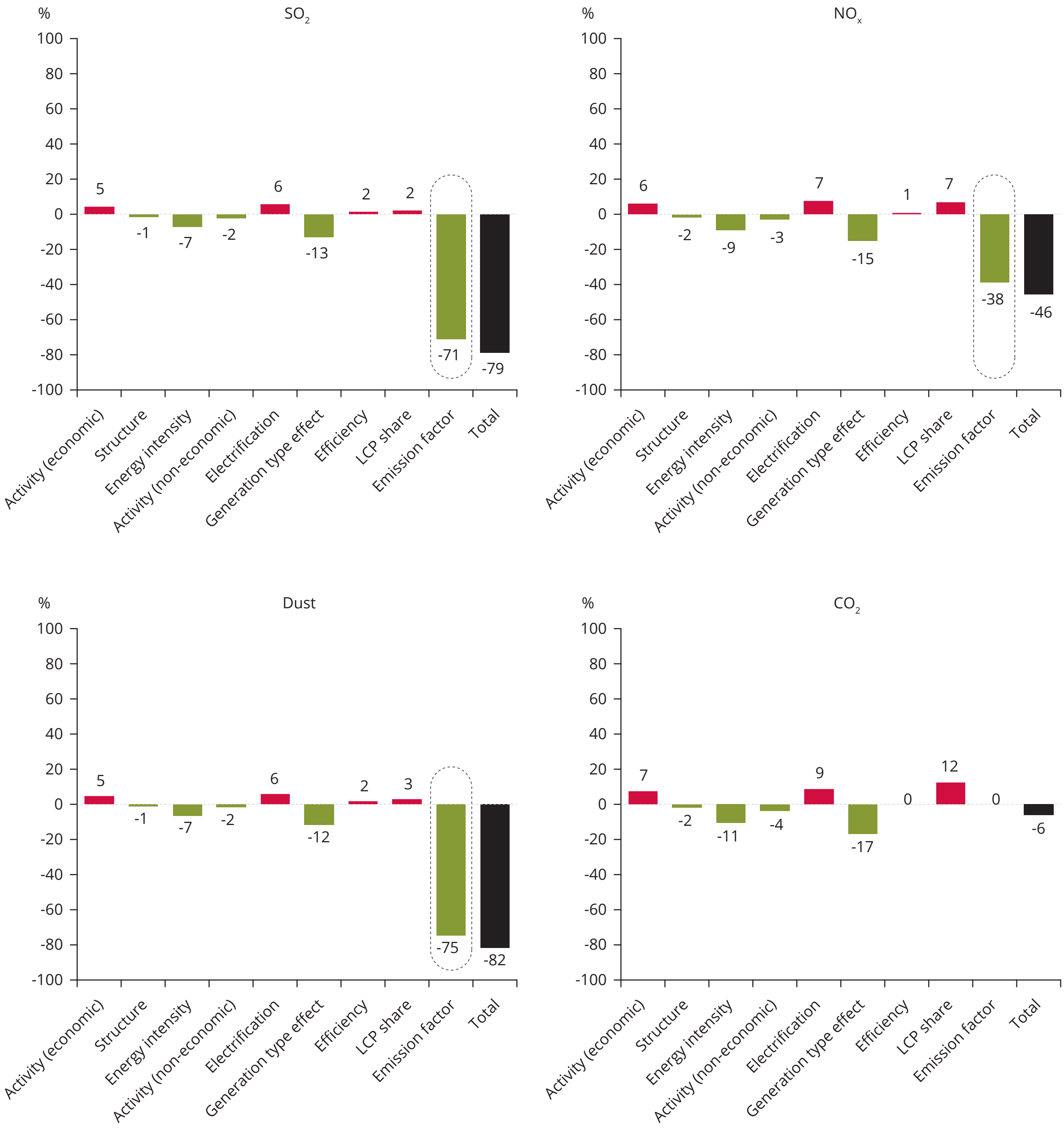
Typically, the improvement in the IEFs at the EU-28 and national levels corresponds to the installation of abatement equipment, cleaner technologies and/or the use of more environmentally friendly fuels (of the same type) in individual LCPs. Because such measures often translate into higher economic costs for operators, they would rarely occur in the absence of legal requirements. However, the fleet turnover, where cleaner plants replace more polluting ones over time, can influence the IEFs too. The results of the macro-level analysis cannot disentangle these drivers, the latter requiring an analysis of plant-level data, as outlined in the next subsection. A micro-level analysis for selected LCPs, described in more detail below, confirmed that attributing the policy effect to this factor in the identity is sound.

At the EU level, the improvement in the IEFs seems to have played the main role in the reduction of SO_2 and dust emissions from electricity-generating LCPs, alone causing a drop in emissions of 71 % (SO_2) and

([33]) That is, the quantity of pollutant emitted per unit of fuel consumed for a given pollutant and fuel type.

75 % (dust), had all else remained equal (see Figure 4.6). Somewhat less strong, but still the most important single driver for NO_x, the IEF improvement accounted for a 38 % decrease in the emissions of power-generating LCPs between 2004 and 2015.

Figure 4.6 Contribution of each factor in the detailed decomposition to changes in total emissions of SO_2, NO_x, dust and CO_2 between 2004 and 2015, as a percentage of 2004 emissions, for electricity-generating LCPs (EU-28)



Note: Factors tending to increase emissions of all pollutants (red bars in the figure): an overall increase in economic activity, an increase in the degree of electrification of energy consumption, a slight reduction in transformation efficiency and an increase in the share of fuel burned within LCPs as opposed to elsewhere. Together, these would have raised emissions by 22 %, 15 %, 15 % and 28 % for NO_x, SO_2, dust and CO_2, respectively, between 2004 and 2015. However, this was more than offset by changes in other factors causing emissions to decline (green bars), namely economic structure, sectoral energy intensity, energy consumption from the residential and transport sectors, the energy mix in electricity generation, and emission factors.

Source: EEA.

The EU-level decomposition analysis also revealed that:

- For all three air pollutants, the IEFs improved mostly because of improvements in the environmental performance of power plants burning solid fuel (coal), both at the national and at the EU level.

- The IEFs improved mostly between 2007 and 2008, leading to the most rapid fall in the emissions of SO_2 and dust from electricity-generating LCPs at this time. This corresponds with the two-step conformity regime under the LCPD, whereby 'existing LCPs' had to comply with stricter limits by 1 January 2018. It also overlaps with other policies and macroeconomic drivers, whose interactions are assessed below.

At the Member State level, the importance of the IEF effect varied from country to country. For example, in Bulgaria — where the IEFs for SO_2, NO_x and dust were among the highest in Europe in 2004 (see Figure 3.1) — improvements in the IEFs of national electricity-generating LCPs led to significant reductions in all air pollutants emitted by these plants. In contrast, countries whose IEFs were already low in 2004 (e.g. Germany) saw relatively small improvements over time, given that they had less scope for additional improvements and, in a few cases, recorded even a slight worsening of their IEFs between 2004 and 2015. For some pollutants, IEFs worsened in, for example, Latvia, Luxembourg and Sweden, but this applied to very low quantities of emissions, generally across the whole period, so it did not result in major changes in national emissions from these plants. Only in Slovakia did a worsening of the IEF for SO_2 have a large impact on SO_2 emissions from electricity-generating LCPs, but this is likely due to very specific national circumstances ([34]).

As shown in Figure 4.6, other important factors affecting LCP emissions at the EU level (and also at the level of individual Member States) were changes in the energy mix of electricity generation, in the energy intensity of the economy and in the degree of electrification in final energy consumption:

- At the EU-level, there was a general **reduction in the energy intensity of economic sectors**, which contributed to a decrease in emissions from power-generating LCPs of between 7 % and 11 % for all four pollutants (SO_2, NO_x, dust and CO_2). This was mainly driven by a reduction in the energy intensity of the industrial sector.

- Acting in the opposite direction (i.e. increasing emissions), there was an overall **rise in economic activity** at the EU level, contributing to a small increase of between 5 % and 7 % in the emissions of all air pollutants from LCPs. In addition, there was an increase in the degree of **electrification of all sectors**, which increased the demand for electricity from these LCPs. It led to a rise of between 6 % and 9 % of EU emissions from these LCPs, depending on the pollutant.

- Finally, shifts in the energy mix of electricity generation (**generation type**) helped to reduce emissions from electricity-generating LCPs by 13 %, 15 %, 12 % and 17 % for SO_2, NO_x, dust and CO_2, respectively, across the EU. The main driver of this effect was a small decline in the use of 'other solid fuels' in electricity production (31 % share of generation in 2004, compared with 25 % in 2015), but a reduction in liquid fuel burning was also significant, being the main driver in certain countries, such as Ireland. A corresponding increase in the share of electricity from non-biomass renewables and nuclear sources was seen, alongside a small increase in the share of biomass in the energy mix.

Summary of the micro-level analysis

Where signals are most clear, an analysis at the individual LCP level allows more detailed investigation of the drivers identified than the national- (macro-) level decomposition analysis. Such analysis has allowed verification of the conclusion that **some observed changes in emissions were clearly a response to industrial emissions legislation** (e.g. installation of abatement technologies to comply with the ELVs from the LCPD or switching fuel to biomass). However, many complex situations at the individual plant level mask signals that are easier to discern at the national level.

This analysis is heavily dependent on the accuracy of the LCP inventory data: while this data set has been quality assured, many **reporting accuracy issues remain** such as continuity of the plant identifiers (referred to as ID's) and errors in fuel classification.

At the macro level, as shown in the previous section, improvements in the IEFs were the most significant driver of reduced emissions from electricity-generating LCPs. The review of selected micro-level data (i.e. individual LCPs) has shown this change to be driven by the improved environmental performance of LCPs burning various types of coal (termed 'other solid

([34]) This is believed to have been due to the high SO_2 emissions at the LCP Slovenské elektrárne (a.s. ENO granulacné kotly), which were particularly high for 2015. This plant dominates SO_2 emissions in Slovakia, masking declines in SO_2 emissions from smaller electricity-generating LCPs.

fuels' in the LCP reporting database), predominantly around the period 2007-2008. This strongly points to a response to the LCPD and its step-wise compliance regime.

The second most significant driver of reduced emissions identified at the macro level was fuel switching, as electricity generation shifted away from LCPs that burn solid fuel to, partly, more biomass-burning LCPs and, primarily, to LCPs that use non-biomass renewables at the European level.

In general, the micro-level analysis has identified three groups of electricity-generating LCPs, each having opted for a different response to the LCPD:

- LCPs that installed an abatement technology to comply with the ELVs under the LCPD and continue operating;
- LCPs that switched fuel types to comply with the ELVs under the LCPD and continue operating;
- LCPs for which plant closures and changes in groups of electricity-generating LCPs owned by large companies appears to have played a role.

Assessing the effect of industrial emissions policies

The assessments carried out in Chapters 3 and 4 show that the improved environmental performance of LCPs was the most important driver for the reductions in key air pollutant emissions from all types of LCPs (including power plants). As confirmed by the above decomposition analyses and substantiated by others (Berghmans and Alberola, 2014), the economic crisis played only a secondary role in the reduction of air pollutant emissions from LCPs.

In theory, the main EU policies that aimed to improve the environmental performance of LCPs were industrial emissions policies (in particular the LCPD) and the EU Emissions Trading System (ETS), which covers in particular emissions from combustion installations with a rated thermal input exceeding 20 MW (i.e. nearly all LCPs). While the EU ETS aims specifically to reduce greenhouse gas (GHG) emissions, these reductions are also likely to result in reductions in SO_2, NO_x and dust. The LCPD and the EU ETS practically address the same sources, regulating the same types of emissions over the same time-frame (Hood, 2013).

At the EU level, emissions of SO_2, NO_x and dust fell fastest, on average, between 2007 and 2008. For coal-burning LCPs, the largest emission reductions were observed over the period 2004-2015.

The increased use of biomass in plants covered by the LCPD also contributed to emission reductions, although to a lesser extent than achieving compliance with LCPD limits did. Where biomass replaced solid fuels, the SO_2 and carbon intensity of electricity-generating LCPs improved. The EU ETS incentivised, at least partially, this increased use of biomass, because emissions from biomass burning are not accounted for under the scheme. The uptake of biomass was further incentivised by other policies and measures implemented by Member States to meet renewable energy targets set by the Renewable Energy Directive (RED), such as Renewable Obligation Certificates in the United Kingdom.

Figure 4.7 represents the decreasing trends in LCP air pollutant emissions between 2004 and 2015, together with the main policy and macroeconomic drivers during that period. Because of their overlapping nature, the majority of the interactions between the LCPD, other policy instruments and broader drivers cannot be treated in full isolation from each other.

Nevertheless, the assessments and the literature review presented in this report support the following interpretation of the main reasons for the observed decrease in air pollutant emissions from LCPs. Within the overall period from 2004 to 2015, two main phases can be identified: 2004-2007 and 2008-2015.

During the period 2004-2007, the effects of the LCPD were predominant over those of the first phase of the EU ETS.

The LCPD affected air pollutant emissions between 2004 and 2007 in two key ways:

1. through the installation of abatement technologies so that plants could comply with the LCPD ELVs by 2008;
2. through the closure of inefficient LCPs that were unable to meet the LCPD ELVs.

The analyses of IEFs in Subsection 3.3.2 and earlier in this section confirm that the main drivers for the observed reductions in LCP emissions over the period were improvements in the environmental performance of LCPs (the IEFs), the switch in LCP fuel from solid to natural gas (as illustrated in Figure 3.3), together with the decommissioning of ageing LCPs.

The EU ETS is likely to have had a less important effect on emissions during its first trading period (2005-2007). This learning phase was essentially designed to prepare for phase 2 (2008-2012), when the EU ETS 'would need to function effectively to help the EU meet its

Kyoto targets' (EC, 2016). The first release of verified emissions data in April 2006 showed that the number of allowances available to EU ETS operators was higher than necessary to cover verified emissions, and that this situation would remain until the end of the first trading period. Consequently, the price of allowances dropped abruptly, and it remained close to zero until the end of 2007, as these phase 1 allowances could not be used for compliance during the second trading period (EEA, 2018b). Therefore, spot market carbon prices during the first trading period did not incentivise emission reductions further below the ETS cap. However, the much higher price, during that period, of allowances for the second phase may have already influenced operators' decisions regarding the necessary CO_2 abatement to be achieved before or during the second trading period.

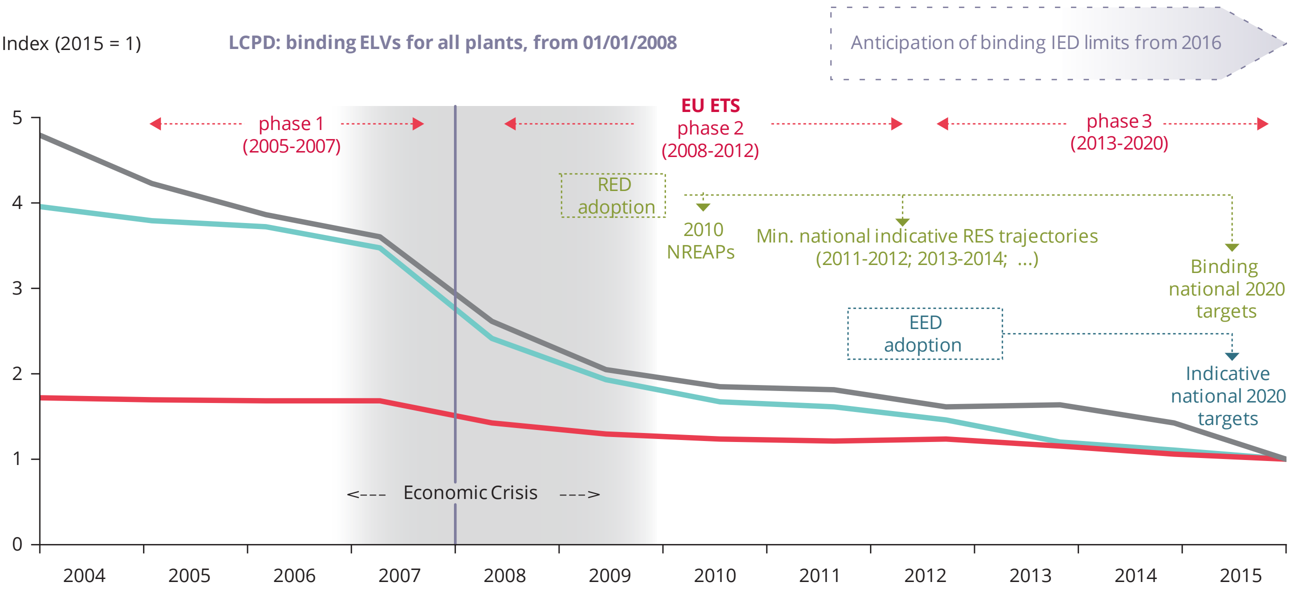
Other factors also contributed to the decrease in LCP emissions over the 2004-2007 period: a gradual shift to renewables in the energy mix (since 2005) and the onset of the eurozone crisis (in 2007) (Berghmans and Alberola, 2013; IEA, 2016). Together, they weakened somewhat the demand for energy from LCPs compared with commercial expectations, contributing to the decommissioning of the least-performant plants.

Overall, the most robust evidence concerning the relative effects of various drivers of air pollutant emissions from LCPs between 2004 and 2007 points towards a predominant effect of the LCPD over other factors, which occurred in the context of increasing trends in LCP capacity and energy use (see Figure 3.2).

During the period 2008-2015, in addition to the EU ETS, the LCPD increasingly overlapped with a number of energy policies, in particular the RED (EU, 2009) and the Energy Efficiency Directive (EED) (EU, 2012).

A number of studies show that phase 2 of the EU ETS (2008-2012) was unable to trigger innovation investment that was sufficient in itself to have led to the observed reductions in SO_2, NO_x, dust and CO_2 emissions from LCPs (CECILIA2050, 2013; Berghmans and Alberola, 2014; I4CE, 2015; Fujiwara, 2016). After more stringent caps were set for the second trading period, verified emissions exceeded the supply of allowances in 2008, resulting in a carbon allowance price of around EUR 20. While this may have contributed to the observed switch from solid to gaseous fuels in LCPs (see Figure 3.3), it only lasted for a short time. After 2008, activities covered by the EU ETS were greatly affected by the economic recession, with the result that the supply of allowances exceeded verified emissions between 2009 and 2012. Coupled with a fixed supply of allowances (set by the EU ETS cap), the European Emission Allowance (EUA) price fluctuated between EUR 10 and EUR 15 per EUA in 2009 and was reduced to around EUR 7 per EUA by the end of the second trading period. A company survey conducted on behalf of the European Commission confirmed that

Figure 4.7 Trends and main drivers of key air pollutant emissions from LCPs, 2004-2015



Note: NREAP, National renewable energy action plan; RES, renewable energy sources.

Source: EEA, 2018a; own analysis.

ETS allowance prices during that period, while playing a supportive role in many business decisions, were not key drivers of abating emissions for most companies (EC, 2015b).

The unfolding economic crisis in Europe and the global downturn in 2008 were macroeconomic factors that drastically reduced the activity level across all EU sectors (Berghmans and Alberola, 2013; EC, 2016). They partially explain the steeper fall in LCP air pollutant emissions in 2008, and in 2009 and thereafter, because of the slower than expected economic recovery.

The rebound in the competitiveness of coal-fired energy supply from 2009 to 2012 contributed to increased activity from such LCPs after 2010 and to a reduction in the rate of air pollutant (and GHG) emission reductions from all LCPs during that period, as visible in Figure 4.7. This is ascribed to strong demand for natural gas in Asia, until 2013, which 'kept European gas prices high, despite weak demand' (IEA, 2016), and to the fall in international coal prices in the context of US coal exports (following the emergence of shale gas production) against weaker global demand (Berghmans and Alberola, 2013).

Domestically, decreasing carbon allowance prices after 2010 rendered the EU ETS unable to counterbalance the favourable coal-to-gas price ratio (IEA, 2016), triggering coal-fired plants to increase operations so as to maximise profits (Berghmans and Alberola, 2013; Fujiwara, 2016). The switch by LCPs to solid fuel use after 2010 is illustrated clearly in Figure 3.3. In this context, the derogation for old plants operating less than 10 000 hours under the LCPD is likely to have curbed the maximum activity level of such plants, offsetting their emissions. This is because existing LCPs that 'opted-out' ([35]) from applying the second, more restrictive, compliance step of the LCPD closed at various times during the period 2008-2015, leading to steady improvement in the IEFs of the remaining LCPs and thereby reducing air pollutant (and GHG) emissions. That 'anticipated power plants that have their time of use limited by the LCPD tend to emit less CO_2 than the others' was also demonstrated by other studies (Berghmans and Alberola, 2014).

Directly or indirectly, energy legislation such as the RED, the EED, the recast Energy Performance of Buildings Directive (EPBD) (EU, 2010b), the Ecodesign Directive, as well as other instruments, such as the Fuel Quality Directive, decreased the demand for fossil-fuel-based energy, especially after 2010 (EEA, 2018a, 2018c, 2018d, 2018e). This reinforced the effects of the LCPD on less efficient plants, although it also weakened the effects of the ETS in cases where the interactions had not been factored into the emissions cap ([36]) (European Parliament, 2013; Marcu and Elkerbout, 2015). Part of the decommissioning of older LCPs identified in this study (see Subsection 3.3.2) needs to be seen within this broader context of policy interactions.

From 2013 to 2015, allowance prices under the ETS (phase 3, from 2013 to 2020) remained low (EUR 3-EUR 8 per tCO_2e (EEA, 2018b)), providing an insufficient signal to drive low-carbon abatement. Owing to market participants' perception of continued low emission allowance prices, 'most ETS-compliant companies in the power sector have stalled investment in newer and low-carbon gas-fired plants while maintaining operation of the existing coal and lignite-fired plants, which have lower operating costs' (Fujiwara, 2016).

Therefore, decisions taken during the period 2013-2015 by operators not to invest in, reduce operations at or close earlier than planned certain LCPs, were primarily driven by considerations over ageing plant capacity, less optimistic energy demand projections across the EU (slow economic recovery from the crisis, and energy efficiency and renewable energy policies) and the prospects of stricter air pollution regulations by 2016 ([37]) (IEA, 2016).

The interaction of the drivers over the whole period, 2004-2015, is also illustrated in Figure 4.6 for electricity-generating LCPs (a similar analysis was carried out for all LCPs). Factors that tended to increase emissions of all LCP pollutants (red bars in Figure 4.6) were:

- an overall increase in economic activity;
- an increase in the degree of electrification of energy consumption;
- a slight reduction in the transformation efficiency;
- an increase in the share of fuels burned within LCPs, as opposed to elsewhere.

However, these drivers were more than offset by changes in other factors causing emissions to decrease (green bars in Figure 4.6), namely:

([35]) Opt-outs had to be carried out in accordance with provisions in Article 4(4) of the LCPD.
([36]) The overachievement of renewable energy targets and the effects of other energy policies that aimed to reduce overall energy consumption (such as the EED and the EPBD) were most likely not factored into the initial cap-and-trade approach of the EU ETS.
([37]) Under the Industrial Emissions Directive (IED) (EU, 2010c).

- economic structure;
- sectoral energy intensity;
- energy consumption from the residential and transport sectors;
- the energy mix in electricity generation; and
- most notably improvements in the IEFs (energy performance) of LCPs.

Over the period 2004-2015, for all LCPs, total LCP fuel use fell by one fifth. Paradoxically, total thermal LCP capacity increased by one tenth across Europe, concomitantly (see Figure 3.2). According to the International Energy Agency (IEA), the latter resulted from misguided investment decisions taken by affluent utility companies during the period 2004-2007, drawing on very optimistic demand projections before the eurozone crisis (IEA, 2016). The oversized total capacity of LCPs became yet another factor that exerted downwards pressure on the average full-load hours operated by LCPs. It reduced the average energy input available to all plants and made them less economically attractive, thereby reinforcing the downwards pressure on fossil fuels that was already being exerted by energy policies (displacement due to renewables and decreasing energy demand). This has resulted in the decline in the level of fossil fuel use in LCPs (solid, liquid and gaseous fuels) since 2004 (see Figure 3.3, left side).

In conclusion, while multiple interactions led to the significant decrease in air pollutant emissions from LCPs over the period 2004-2015, the largest part of the reduction was primarily driven by the improvement of the environmental performance of LCPs in response to the LCPD and its step-wise compliance regime, before macroeconomic drivers and other EU energy and emissions control policies, such as the EU ETS.

4.1.5 To what extent do the observed (direct and indirect) effects correspond to the objectives?

The effectiveness of the LCPD with regard to its two key policy objectives — (1) to significantly reduce the emissions of SO_2, NO_x and dust from large stationary combustion sources across the EU; and (2) to improve the environmental performance of LCPs for the regulated air pollutants — has been presented in detail above. Disparate lines of evidence were integrated through diverse methods into a meaningful analysis that shows that the effects of the LCPD fully correspond to its main objectives.

This section discusses the effects of the LCPD with regard to its other objectives — (3) to improve information and knowledge regarding the emissions of key air pollutants from LCPs; and (4) to promote enhanced policy coordination and alignment of the levels of health and environmental protection at Member State and regional/local levels.

Effectiveness with regard to improving overall information and knowledge regarding LCP emissions

Under the previous LCPD, plant-level reporting of SO_2 and NO_x emissions by Member States was mandatory only for very large, existing plants (pre-1987 LCPs) above 300 MW_{th}; for plants between 50 and 300 MW_{th}, national reporting was carried out on an aggregate basis. In contrast, the 2001 LCPD mandated the reporting of plant-level data for every plant that fell within its scope. It thus significantly extended the available pool of information on air pollutants emitted by combustion plants.

Prior to these inventories, the EU did not have any information framework that could provide comparable data for LCPs across all Member States, at this level of granularity. While some countries had established national reporting mechanisms prior to the reporting framework set up under the LCPD, most EU members did not have consistent data collection processes at the plant or at the installation level.

Statistical inventories, such as the Convention on Long-range Transboundary Air Pollution (CLRTAP) inventory (UNECE, 1979) or the GHG reporting mechanism (EU, 2004), while covering data from earlier dates (1990 being the first year with solid data for both data sets), offered no insight into the individual sources of these emissions. This presented considerable limitations to the possibility to analyse environmental performances for specific technologies and fuel types. It also implied a much lower level of detail with regard to the geographical distribution of the emissions.

By complementing these sources, the LCP inventories have offered a more detailed and close-to-the-source set of information, which helped increase the understanding of the environmental challenges related to the LCP sector. For instance, the requirement to continuously monitor emissions of SO_2, NO_x and dust from combustion plants with a rated thermal input equal to or larger than 100 MW (conform Annex VIII to the LCPD) enabled the provision of data with a higher time resolution and improved statistical reliability and comparability across the EU:

- Readings from continuous emissions monitoring systems are likely to have contributed to the development of advanced algorithms for monitoring combustion dynamics for the purposes of boiler tuning and short-term process control, thereby improving the overall efficiency of combustion processes (Zhou, 2017; Emerson et al., 2018).

- In specific local settings, where environmental risks linked to the key industrial air pollutant emissions played a significant role in local air quality and human health, the requirement for continuous monitoring may have played an important role in identifying particular causes for abnormal levels of combustion-related air pollutant emissions, such as high emissions during start-up and shutdown plant operations (Suess et al., 2009), or in enabling swift detection of non-compliant plants.

- Finally, the requirement for continuous monitoring may have played an important role in ensuring higher public confidence at the local level.

Over the years, the LCP inventories were intensively used to inform decision-makers and the public. The European Commission published three progress reports on the implementation of the LCPD ([38]). The EEA maintains two indicators, which draw on the LCP inventories (EEA, 2017d, 2017e). Furthermore, LCP inventory data were used for a wide range of EEA reports. Researchers also benefit from the data sets, as they provide, for example, input data for analyses, scenario work and model calibration.

The fact that emission data are provided together with key design parameters (nominal capacity) and fuel input, allow for the calculation of emission factors at different aggregation levels that can be used to challenge the emission factors that are offered by literature. This report has used the LCP data set in a variety of ways and connected it with other data sets, proving several use cases of the LCP inventories that clearly support a sound, policy-relevant knowledge base.

While the EEA is not aware of any analysis on the specific objective of the LCPD to achieve an 'improvement of information and knowledge regarding LCP emissions', there are strong indications that this data set is of particular use to a wide range of stakeholders.

Shortcomings of the data in LCP inventories and recommendations for analysis

While the LCP inventories were a clear step forward in terms of expanding the knowledge base at European level, a number of shortcomings regarding the reported data were identified. Specifically, the use of the LCPD inventories and the European Pollutant Release and Transfer Register (E-PRTR) data during the current assessment showed limitations and quality issues, from which the recommendations described below were drawn.

Characterisation of the plant

The LCP inventories provide the nominal capacity of each plant and their fuel mix. This is very limited information in terms of its contribution to understanding the operation and environmental performance of the plants or making projections about their future. Additional elements that could improve the characterisation of the plant are the following:

- Start date of operation: the types of equipment installed in combustion plants have relatively predictable lifespans and traceable performance levels depending on age. This issue has been legally addressed and the current reporting mechanism, under the Industrial Emissions Directive (IED), already requires this field to be provided by operators.

- Type of combustion plant: plants operate using a wide range of technologies. This information is not collected by EU-level public data flows. Some commercial databases compile information of this kind but it is generally incomplete. Addressing this issue, while respecting commercial secrecy, would enable a better analysis of the environmental performance of the sector and reduce the uncertainties.

- Abatement technologies installed: there are limited comprehensive data sets in the public domain detailing LCP abatement technologies and the date of their installation. Consequently, for this study, it has been necessary to identify trends and changes within the LCP inventories and then to investigate selected examples to see if these changes were driven by industrial emissions legislation. A **comprehensive data set of abatement installations** would allow quicker identification of sub-populations where abatement technologies have been installed and a broader comparison with the reductions in reported emissions of specific LCPs. This requirement is not provided for by the IED or any other piece of EU law but could be considered in future reviews of legislation. Alternatively, a future study could compile such information

([38]) The three reports are available on the European Commission website at http://ec.europa.eu/environment/archives/industry/stationary/lcp/implementation.htm.

from competent authority permits and related determinations and correspondence. Given the likely range of accessibility to such information, it is recommended such work initially focus on selected countries. Consultations with inspectors at competent authorities, perhaps as part of a formal Eionet consultation, should yield useful insights. The identification of the effect of abatement technologies was limited because of a lack of data regarding which LCPs are subject to controls, and the impact of variable fuel input. The clear identification of LCPs subject to abatement is therefore only possible when fuel input remains relatively consistent, in turn allowing the identification of a large proportional shift in the IEF. With more detailed data on the control technologies, it may be possible to isolate the effect of variable fuel input, or to understand the relative impact this has on emissions.

- Emissions of CO_2: a final limitation to the reported LCP data is the lack of monitoring data for CO_2 emissions or a consistent link to a trustworthy database of such data (e.g. the data reported to the CO_2 ETS), which necessitated the use of default CO_2 emission factors from the Intergovernmental Panel on Climate Change (IPCC) in the macro-level analysis presented in this report. While abatement technology to reduce CO_2 emissions is not currently widely applied, carbon capture and storage may play a significant role in the near future, increasing the need to monitor CO_2 emissions.

- Output of combustion: the public data sets at EU level do not require information on the electricity generated or the heat provided by each individual LCP. This would allow a more robust comparison of the macro- and micro-level analyses. If the requirement is not established legally, this data compilation could be done through review of company reports and electricity regulator reports among other sources. It would then be possible to relate the electricity generated by specific LCPs with electricity generated by all LCPs and by all sources within a country.

Aggregation level

The LCP inventories collect data at plant level, meaning one or more combustion units that discharge their gases through a common stack. This is a relatively detailed level of aggregation, as the E-PRTR, for example, compiles data at facility level, which could encompass several combustion plants but also other activities in an industrial complex, as soon as they are operated by a single owner.

While the EEA recognises the efforts made by reporters to provide data at plant level, combustion plants comprising several units with different boiler/chamber types result in a significant loss of accuracy, and collecting information at unit level would be more useful. The analysis presented in this report at the micro level identifies several groups that exhibit responses in reported data that could be attributed to the LCPD. However, such analysis also identifies several limitations to LCP reporting. First, single power stations tend to be split into several units, each reported on separately. This means that analysing any trends observed in the data will require research at the individual unit level, whereas permit data, and therefore data pertaining to controls or other environmental reporting, tend to apply to the entire station. In addition, the reporting on individual units may show interrelated responses to one another, relative to the status of each unit, the connectivity between units and the overall power demand required of the power station. This complicates the identification of specific trends.

Operation regimes

Combustion plants are operated in very different regimes, and their degree of flexibility could be significantly higher for some plant types (e.g. plants operating with natural gas). Establishing whether the plants operate on a base-load regime or other regimes is significant to analysing their environmental performance. The current LCP inventories did not collect, on a mandatory basis, data on the number of operating hours, data that are now compiled under the IED regime. This parameter alone does not allow an understanding of the load regime but can be used as a proxy.

Second, observations within reported data may be influenced by economic decisions made by the ownership of the station, specifically where one operator owns several strategic LCPs within one country (a 'fleet'). An operator may choose to close down or change the role of plants in its fleet; for example, some plants run continuously to provide a 'base load' of electricity, while others run only during periods of peak electricity demand (see Chapter 3). Plant closures and changes in plant roles, therefore, may be due not solely to the impact of the LCPD or the motivations of the country, but to the strategic economic decisions made by a key operator, which in select cases may span across several countries. It is this relationship that is currently not well defined within LCP reporting. This limitation affects the analysis at the country and the individual LCP levels. Consultations with operators and competent authorities may yield insights into the broader context for operational changes in multiple electricity-generating LCPs across one or more countries.

Fuel types and content of key substances

The LCP inventories collect data according to five categories. While some of them are standard commercial fuels (e.g. natural gas) whose composition, calorific value and other defining aspects are homogenous, others contain a series of very different fuels (e.g. other solid fuels). At the same time, the categories established for the inventories are not in line with those of the requirements established in the annex to the LCPD or the BAT identified in the Integrated Pollution Prevention and Control (IPPC) process.

While this aspect is partially addressed by the IED, which establishes more categories and, importantly, separates coal from other forms of solid fuels, the categories are not defined and the inventory would benefit from a clear definition of what falls into each category as well as using the 'other' categories to better identify the fuel that is actually being used in the operation of the plants.

The fuel types are normally delineated on the basis of their physical state and net calorific value, but they may differ in the content of their key substances in environmental terms, namely sulphur and mercury. Compiling information on the concentration of these in the fuel input could facilitate analyses similar to the one presented in this report.

Effectiveness with regard to promoting enhanced policy coordination and alignment of the levels of health and environmental protection at Member State and regional/local levels

In 2004, Member States and country groups differed considerably with regard to the environmental performance of LCPs with the same fuel type. This is indicative of different levels of health and environmental protection being provided at that time across Europe. For dust, NO_x and SO_2, differences in IEFs in early years of the LCPD were particularly large (see Figure 3.1).

To ensure that all EU citizens receive the same high level of environmental protection, the LCPD addressed the differences through maximum allowed ELVs from LCPs. It also reinforced the provisions regarding monitoring of these air pollutant emissions at plant level.

Provisions for equivalent plant-level monitoring of key air pollutant concentrations were set in Annex VIII to the LCPD, along with the obligation to use specific European Committee for Standardization (CEN), International Organization for Standardization (ISO) or other relevant standards. Similarly, the LCPD reinforced provisions regarding the inspection and enforcement mechanisms used to ensure compliance.

In doing so, the LCPD contributed to the harmonisation of environmental and health standards across the EU. This is important, as SO_2, NO_x and dust emissions affect especially vulnerable groups in society, who may be subjected to higher levels of, or more prolonged, exposure to pollution because of proximity to emission hotspots and various social, economic and lifestyle factors (EEA, 2018f).

The transposition of the LCPD into national legislation resulted in a set of coordinated national measures and policies. In response to them, the average environmental performance of LCPs improved significantly over time, for most pollutant and fuel combinations and in all country groups (LOW, MEDIUM and HIGH; see Section 2.2 for definitions of these groups). The largest improvements took place in the groups that had the least environmentally performant LCPs at the time when the LCPD was adopted (the MEDIUM and HIGH groups), as illustrated by the IEF trends for solid-fuel-firing LCPs in Figure 4.8. These improvements resulted in the convergence of average Member State IEFs, and thus the harmonisation of overall health and environmental protection levels, across the EU-28.

Similarly, policy coordination as a result of the LCPD triggered modernisation across the industrial sectors and resulted in the harmonisation of the environmental performance of these sectors by 2015 (see Subsection 3.3.2 and Figure 3.9).

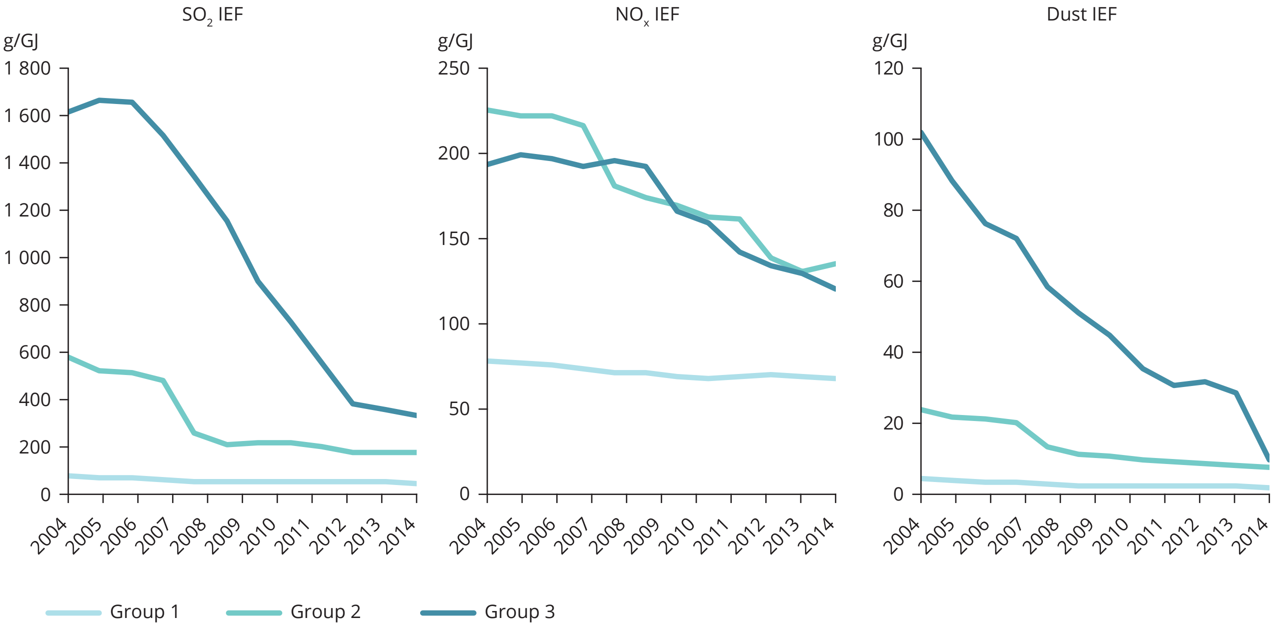
By harmonising provisions regarding minimum ELVs from LCPs in conformity with the subsidiarity principle, the LCPD also led to a level playing field, as it effectively prevented uncoordinated national policies and measures that could have negatively influenced the functioning of the European single market.

4.2 Efficiency

4.2.1 To what extent were the LCPD and its ELVs efficient means of reducing air pollutant emissions from LCPs?

The analysis performed for this report did not include specific elements on efficiency because of resource

Figure 4.8 Converging IEFs for single-fuel LCPs burning solid fuels (EU-28)



Source: EEA, 2018a.

constraints. Analysing the cost-benefit ratios for a sector with the complexity and variety of the power plant sector also requires data with a granularity that was not available to the EEA in the context of this work.

The European Commission has performed studies of this kind in the past, in relation to the implementation of the LCPD and the interface with the policy on IPPC. The study on *ex post* estimates of costs to business of selected pieces of EU environmental legislation (EC, 2006b) assessed, for selected countries and plants, the overall balance between the costs of implementation and the societal benefits of the LCPD. It was concluded that, in general terms, there were indications that the costs would be compensated by the benefits. However, the study's scope, data constraints and methodology did not offer a solid result.

More recently, the European Commission conducted a study (EC, 2017) that thoroughly assessed the balance between the costs and benefits of implementing the IED and the new BREF that replaced the previous version (EC, 2006a), that is at the core of this study. While this recent study for the European Commission focused on the new policy, it found that the benefits are much higher than the costs of implementation. By analogy, the findings of the current study indicate that the benefits related to the implementation of the LCPD — a policy that was substantially less ambitious than the IED — far outweighed the costs of legal implementation, thus contributing to the cost-efficiency of the LCPD.

4.2.2 Were the LCPD and national implementation measures cost-efficient means of achieving EU and national objectives? Have the expected results been obtained at reasonable costs?

The two-step timeline for compliance was purposefully introduced by the LCPD to reap immediate benefits of technical progress, in the cases of newer plants and plants under construction, while old plants were granted time to progressively phase in technical upgrades (see Subsection 3.3.1, 'Progress in accordance with the compliance timelines set by the LCPD').

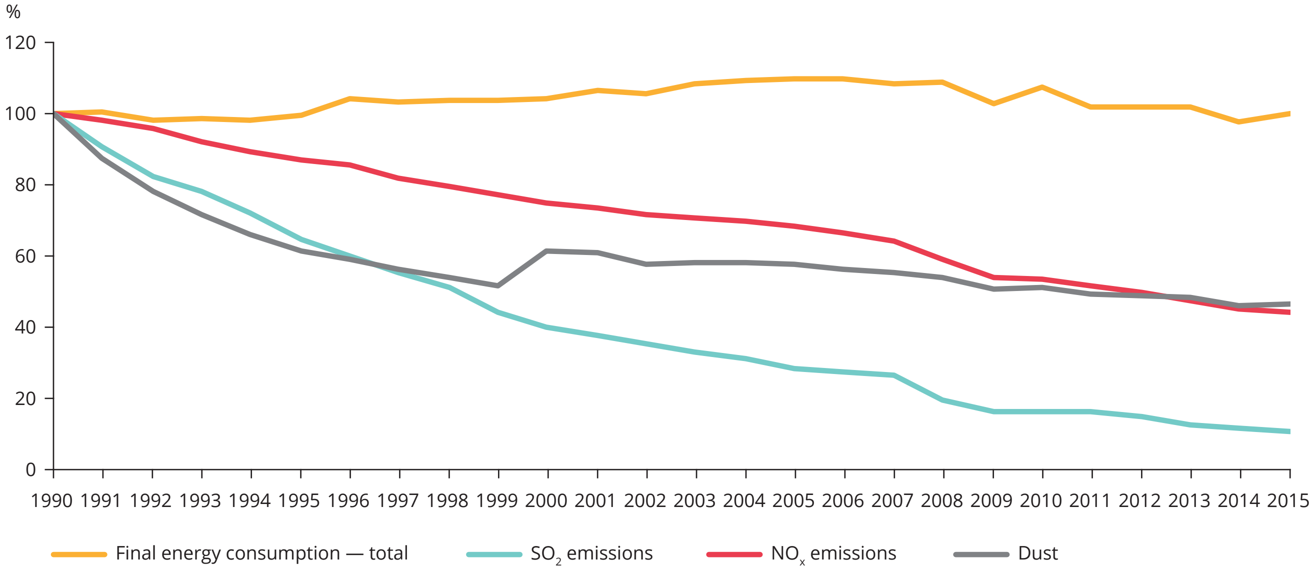
Analysis of decoupling in the LCP sector

Related to the LCPD objective of reducing IEFs is the decoupling of emissions and production levels. Furthermore, energy efficiency improvements in the LCP sector would contribute to meeting EU energy efficiency targets.

Figure 4.9 shows the total final energy consumption in the EU-28 in the period 1990-2015. The total final energy consumption in 2015 was comparable to the final energy consumption in 1990. In the same period, the emissions of NO_x, dust and SO_2 decreased substantially. This indicates a clear decoupling of energy consumption from the emissions of these substances. The reduction was most substantial for SO_2.

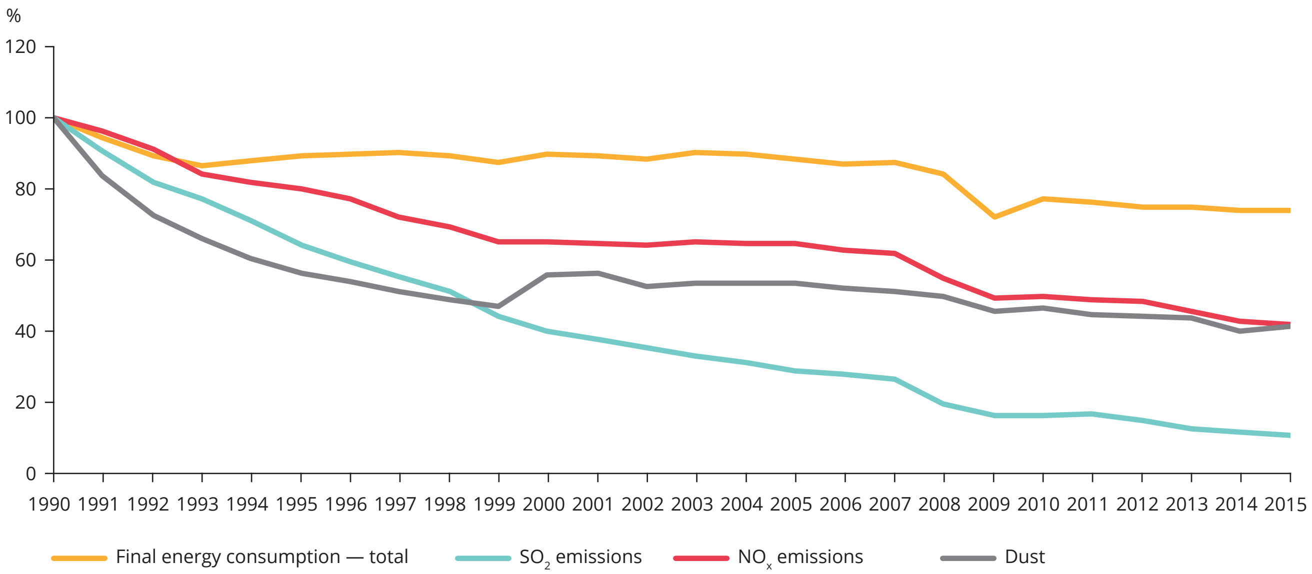
In the period 1990-2015, the final energy consumption in industry in the EU-28 was reduced by more than 25 %. The reductions in emissions of NO_x, SO_2 and particulate matter were 58 %, 89 % and 59 %, respectively. Although these effects can be ascribed to various factors, including to other regulatory drivers and economic factors, the assessment presented in Chapter 3 demonstrates the leading role that the LCPD had in reducing total and LCP-related air pollutant emissions.

Figure 4.9 Decoupling of final energy consumption from the emissions of SO_2, NO_x and dust in the EU-28 (1990-2015)



Sources: EEA, 2018a; Eurostat, 2017.

Figure 4.10 Decoupling of final energy consumption in industry from the emissions of SO_2, NO_x and dust in the EU-28 (1990-2015)



Source: EEA, 2018a; Eurostat, 2017.

The assessment of gross value added, final energy consumption and emissions of NO_x, SO_2 and dust in the EU-28 in the period 2005-2015 points towards a decoupling of gross value added, on the one hand, and final energy consumption and emissions, on the other hand. With the exception of a decrease in 2009 (due to the eurozone crisis) and a dip in 2012, the gross value added has grown steadily over the period, while final energy consumption and total emissions of NO_x, SO_2 and dust decreased. The emissions of NO_x, SO_2 and particulate matter have reduced more significantly than final energy consumption. A similar decoupling over the period also took place in industry across the EU-28, as illustrated in Figure 4.11.

4.3 Relevance

4.3.1 To what extent were the objectives of the LCPD relevant to the need to reduce air pollution in the EU?

Relevance is understood in this report as the relationship between the main problem identified (i.e. emissions or harmful substances from the combustion sector, which drive environmental impacts) and the objectives of the intervention (i.e. to reduce these emissions to more acceptable levels).

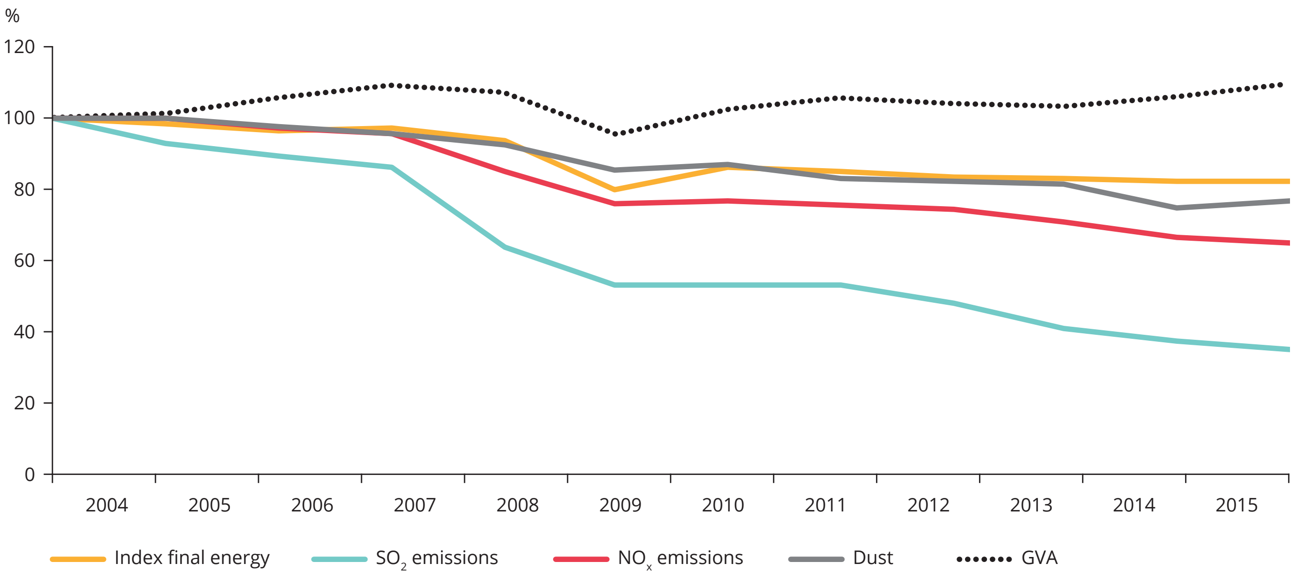
The relevance of the problem originating from the combustion sector is explained in detail in Chapter 1.

The evolution of emissions from LCPs is thoroughly described in Chapter 3. In the run up to the adoption of the LCPD, the combustion sector was the main source of acidifying substances and a key contributor to the deterioration of air quality in large areas in Europe.

Among the three pollutants emitted by LCPs, SO_2, NO_x and dust, the environmental impacts associated to SO_2 emissions were most relevant because of the more significant detrimental impacts associated with high SO_2 emission levels. The LCPD was designed to achieve significant reductions in emissions of all three pollutants by LCPs, although more emphasis was placed on efforts to reduce SO_2 emissions (through the implementation of limit values for SO_2). This is also illustrated by the evolution of the IEFs in Figure 3.6, where the reduction of the IEF for SO_2 is far more relevant than for NO_x. The reduction of dust emissions was also very significant, in relative terms, but the IEF was lower at the start of the period and the abatement measures were easier to implement.

In light of the trends and the causality confirmed by the decomposition analysis performed, the objectives set in the LCPD were deemed to be appropriate for addressing the relevance of the issue in question, namely the need to reduce air pollution. The combustion sector is now significantly more performant and proportionally less relevant in the context of all anthropogenic emissions for these key pollutants, and the resulting impacts are largely shifting for the better.

Figure 4.11 Decoupling of final energy consumption, gross value added and the emissions of SO_2, NO_x and dust in industry in the EU-28 (1990-2015)



Sources: EEA, 2018a; Eurostat, 2017.

4.4 Coherence

4.4.1 To what extent was the LCPD internally coherent?

The legal text of the LCPD shows a generally high level of internal consistency and coherence. The majority of terms and definitions in the directive did not pose problems for stakeholders or competent authorities tasked with the implementation of the LCPD in the Member States.

Nevertheless, the assessment also identified a number of inconsistencies, especially related to the LCPD's objective to improve information and knowledge regarding the emissions of key air pollutants. A key example is the 'common stack' definition introduced by the LCPD. Whereas most countries seem to have followed the 'stack approach' when developing their national LCP inventories, reporting in some Member States and for some years took place at the boiler, installation or even site level, in particular during the 2004-2006 reporting period (AMEC, 2012). This has resulted in interpretation issues and a lack of data comparability, issues that had to be resolved among data providers and at the EU level. In addition, certain parameter definitions and calculation rules pertaining to the national reporting of the LCP inventories could have been better defined in the legal basis, as outlined in Subsection 3.3.3. This may concern the definitions of reported fuel types, which could have been aligned to fuel categories used to derive the actual ELVs, and the provision of information regarding the economic sector to which an LCP belongs, which would have enabled more in-depth assessments of LCP performance in relation to sectoral economic activity.

4.4.2 To what extent was the LCPD complementary to and coherent with other EU initiatives in the field? Did it have synergies with them?

Policy overlaps often lead to intended and unintended policy interactions. The resulting effects vary in terms of magnitude and nature, and can be mutually reinforcing, supporting, enabling, blurring or counteracting ([39]), even cancelling each other out and preventing the achievement of specific policy goals.

Interactions increase in significance when the degree of overlap between instruments that address the same types of emissions from the same sources is high (OECD, 2019), such as in the case of the LCPD and the EU ETS. Nevertheless, indirect interactions, for instance between energy and industrial emissions policies, can also have significant effects.

The LCPD mainly covered the energy production sector, in which such installations were dominant at the time. However, the coverage of the LCPD also extended to other sectors, such as the refining sector, and the waste, pulp and paper, and manufacturing industries. Therefore, the LCPD was a cross-sectoral policy instrument that needs to be considered in the wider context of EU policies on the environment, climate and energy.

As illustrated in Figure 1.1 and Figure 4.7, the LCPD interacted most notably with the following three policy landscapes:

- EU air quality/air pollutant emission reduction policies;
- EU climate mitigation policies;
- EU energy and electricity market policies.

Interactions with EU air quality/air pollutant emission reduction policies

The LCPD played a key role in the implementation of thematic EU policies to improve air quality and to reduce air pollutant emissions from industrial combustion sources. As such, together with the IPPCD, the LCPD was one of the most important pillars supporting the delivery of targeted reductions in air pollutant emissions in the context of the National Emission Ceilings Directive (NECD). With over half of the total anthropogenic SO_2, 15 % of the NO_x and 4 % of the dust being released by combustion plants, the objectives of the LCPD were inextricably linked to the accomplishment, by 2010, of EU and national commitments under the Gothenburg Protocol (EU, 2001b; UNECE, 2012).

In addition, the LCPD complemented and reinforced other sector-specific instruments to reduce air pollutant emissions, especially the Air Quality Framework Directive (Directive 96/62/EC) and its first daughter directive (Directive 1999/30/EC), and the Sulphur Content of Certain Liquid Fuels Directive (Directive 93/12/EEC) ([40]). The emission controls implemented by operators to reduce emissions from solid-fuel-firing LCPs led to co-benefits in terms of reduced mercury emissions from these

([39]) Shifting of impacts across sectors or environmental media, such as when pollution is shifted from air to water or soil and/or across countries because of uneven playing fields, can result from counteracting effects.

([40]) Directive 93/12/EEC subsequently replaced by the Sulphur Content Reduction of Certain Liquid Fuels Directive (Directive 1999/32/EC) in 2003.

plants, in line with the objectives of the Community Strategy Concerning Mercury (EC, 2005).

Yet, the strongest synergies, designed from the outset, were between the LCPD and the IPPCD: through its command-and-control approach, wielded through mandatory ELVs, the LCPD set minimum standards for the environmental performance of combustion plants, and the IPPCD reinforced and strengthened these standards, encouraging the uptake of more ambitious best available technologies to enhance the achievement of the thematic air quality goals. In theory, this indivisible set of interactions should have improved the effectiveness and efficiency of air pollutant abatement across industry. However, this theoretical model was not fully functional in practice because of market and behavioural failures: there is evidence that the minimum requirements in the LCPD were often used as default emission limits in IPPC permits (EC, 2007c), limiting the implementation of the more ambitious operational requirements indicated as BAT by the BREF document (EC, 2006a). In other words, while effective in upping the environmental performance of the most-polluting fossil fuel plants, in interaction with the IPPCD the LCPD was blurring the other policy's signals. This situation was redressed in 2010, with the adoption of the IED (EU, 2010c).

Interactions with EU climate mitigation and energy policies

Interactions with climate mitigation policies, predominantly the EU ETS, and with energy policies, especially the RED and the EED, were already described in Subsection 4.1.4. Key interactions are briefly summarised below:

- **Interactions with the EU ETS:** to the extent that fuel switches and plant decommissioning driven by the LCPD were not factored into the emission ceilings set by the EU ETS, the direct overlap between the LCPD and the ETS may have weakened the effectiveness of the latter. Over the whole period, however, the magnitude of the effects is likely to have been minor: the literature reviewed overwhelmingly suggests that drivers other than the emission standards for industrial pollutants under the LCPD affected the effectiveness of the EU ETS.

- **Interactions with the RED:** although there was no direct overlap between the LCPD and the RED, the LCPD is likely to have played an enabling role in terms of the implementation of the RED, enhancing the conditions for a switch from fossil to renewable fuels across all sectors.

- **Interactions with the EED:** as with the RED, there was no direct overlap between the LCPD and the EED. The LCPD is likely to have enhanced energy efficiency/energy savings efforts, since its emission standards triggered a switch to more efficient combustion techniques (as demonstrated by the improvements in the IEFs), to cleaner fuels and to the decommissioning of the oldest, least-efficient (often back-up) plants. Where the adoption of abatement measures slightly reduced the efficiency of LCPs, this may have weakened the effectiveness of the EED.

- **Interactions with the EPBD (EU, 2002), the Ecodesign Directive (ECD (EU, 2005)) and the Energy Labelling Directive (ELD (EU, 2010a)):** interactions were indirect and probably limited in magnitude; together with the EED, it is likely that these frameworks have offset or cushioned the effects on end users of potential energy price increases due to the LCPD.

- **Interactions with the internal energy market:** since 1996, a suite of measures has been adopted to harmonise and liberalise the EU's internal energy market and to ensure a more transparent, flexible, competitive and non-discriminatory EU electricity market (European Parliament, 2018). By harmonising limits for air pollutant emissions from large plants, the transposition of the LCPD into national legislation resulted in a set of coordinated national policies and measures. The effects of the LCPD were therefore in synergy with the goals of the EU's internal energy market and the European single market and helped promote a level playing field across the EU.

4.5 Added value

Being closely related, the evaluation questions regarding the EU added value of the LCPD are addressed jointly in this section. The report clearly highlights how different the EU countries were in terms of their emission factors when the LCPD started to operate. At the same time, a series of international commitments set ambitious objectives in terms of air pollution reductions.

As is reasoned below, the different point of departure implied that EU-level action could help channel a mechanism to bring countries together in terms of environmental protection, ease the transition with coherent derogatory regimes and guarantee that a key sector of the economy would be dealt with in a consistent way from regulatory and level playing field perspectives.

The main EU added value of the LCPD consisted in improving the levels of health and environmental protection for all EU citizens in a fair and harmonised manner, while creating a level playing field among private operators and Member States.

Large differences between the environmental performance of LCPs with the same fuel type were observed across EU Member States when the LCPD came into force ([41]). In the early years of the directive, the IEFs of LCPs differed markedly among the three groups of Member States shown in this report, but also among individual Member States. With time, these differences decreased, thanks to faster improvements in those Member States that had the least-performant LCP sector in 2004 (see also Figure 3.1, for example).

Harmonised standards for LCPs across the EU were important from a liberalised market perspective and, with many LCPs belonging to the energy generation sector, especially for the proper functioning of the EU's integrated energy and electricity markets. By preventing market fragmentation and potential trade barriers that could have emerged in response to uncoordinated national environmental policies, the LCPD facilitated the achievement of the EU's objectives under the single market and the internal energy market.

The harmonisation of mandatory minimum ELVs for all LCPs across the EU also increased transparency and reduced transaction costs for investors and for operators, who could now factor into their decisions costs related to complying with the same set of minimum standards across the Union.

Harmonisation under the LCPD took place in two stages: first, through the requirement for immediate compliance with respective ELVs set under the LCPD, in the case of 'new-new' and 'old-new' plants; second, by also introducing a compliance obligation with maximum permissible ELVs for 'existing' LCPs, starting from 1 January 2008 ([42]). In other words, while supporting the achievement of an EU level playing field, the LCPD distributed the burden of harmonisation with flexibility across countries, taking into consideration differences that existed at the level of the national energy mixes.

Had the LCPD not been in place, different national frameworks could have competed against each other and private actors could have lobbied, in response, for protection against competitors in EU countries with less stringent measures. This could have jeopardised or limited the effectiveness of measures under the internal energy market, to ensure fair access to (energy) markets, cross-border interconnections, energy supply security, and increased competitiveness and flexibility across the EU.

At the time of adoption of the LCPD, all Member States had signed the Gothenburg Protocol (in the context of the CLRTAP) on combating acidification, eutrophication and the formation of ground-level ozone. Meeting the reduction commitments for SO_2 and NO_x was challenging for the EU, particularly for those countries that relied heavily on solid fuels in their energy mix.

With air emissions dispersing over large areas in response to climatic and geographical conditions not affected by national borders, differing national frameworks may have contributed to the unfair shifting of the impacts of pollution across EU countries. In putting forward a coherent, Union-wide approach to addressing the challenge of industrial air pollutant emissions, the LCPD provided EU added value beyond what could have been achieved by individual national policies and measures. The fifth Considerata in the legal text of the LCPD attests the same interpretation:

> *In accordance with the principle of subsidiarity as set out in Article 5 of the Treaty, the objective of reducing acidifying emissions from large combustion plants cannot be sufficiently achieved by the Member States acting individually and unconcerted action offers no guarantee of achieving the desired objective; in view of the need to reduce acidifying emissions across the Community, it is more effective to take action at Community level.*

Finally, another example of EU added value was the best practice sharing that occurred among Member States, provided for regularly by the LCPD (together with the IPPCD with which it interacted). This enabled the transfer of knowledge and experience between countries with differing LCP sector energy mixes and environmental performances, and contributed to the harmonised implementation of legal provisions across the EU.

([41]) In Chapters 3 and 4, IEFs were used as proxies against which to express the environmental performance of LCPs across countries and at the EU level.

([42]) Unless a commitment to close the plant within 20 000 operating hours, considered from 1 January 2008 to 31 December 2015, is communicated to the competent authority before 30 June 2004.

Glossary and abbreviations

Acidification	Process by which primary pollutants sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3) react in the atmosphere and, together with their reaction products, lead after their deposition to changes in the chemical composition of the soil and surface water
Acidifying air pollutants	A class of air pollutants such as SO_2, NO_x and NH_3 that can lead to acidification
BAT	Best available techniques
BAT-AEL	Emission level associated with best available techniques
BREF	Reference document on best available techniques
CHP	Combined heat and power, also referred to as 'cogeneration'
CLRTAP	Convention on Long-Range Transboundary Air Pollution
Dust	Airborne particulate matter, also referred to as 'total suspended particles', which includes particles up to 100 μm
EEA	European Environment Agency
EED	Energy Efficiency Directive
ELV	Emission limit value — the permissible quantity of a substance contained in the waste gases from a combustion plant, which may be discharged into the air during a given period
EMEP	European Monitoring and Evaluation Programme
EPBD	Energy Performance of Buildings Directive
EPER	European Pollutant Emission Register
E-PRTR	European Pollutant Release and Transfer Register
ETC/ACM	European Topic Centre on Air Pollution and Climate Change Mitigation, a consortium of European institutes contracted by the EEA to carry out specific tasks in the field of air pollution and climate change
ETS	Emissions Trading System
EU	European Union
EU-28	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovenia, Slovakia, Spain, Sweden and United Kingdom

EU-15	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and United Kingdom
EUA	European Emission Allowance
GDP	Gross domestic product
GHG	Greenhouse gas
GW	Gigawatt
IEA	International Energy Agency
IED	Industrial Emissions Directive
IEF	Implied emission factor — the ratio between pollutant emissions and the energy input (i.e. fuel) used in the operation of a combustion plant when generating such emissions
IIASA	International Institute for Applied Systems Analysis
IPPC	Integrated pollution prevention and control
IPPCD	Integrated Pollution Prevention and Control Directive
LCP	Large combustion plant — the rated thermal input of which is equal to or greater than 50 MW, irrespective of the type of fuel used (solid, liquid or gaseous)
LCPD	Large Combustion Plants Directive
MW	Megawatt
NECD	National Emission Ceilings Directive
NERP	National emission reduction plan
NO_x	Nitrogen oxides (nitric oxide (NO) and nitrogen dioxide (NO_2)) — these contribute to acidification, eutrophication, tropospheric ozone formation (ground-level smog) and hazardous/toxic air pollution and secondary particulate matter formation, and come from combustion processes, such as typically in the energy sector
PM	Particulate matter — a complex mixture of suspended particles with small diameters, usually less than 10 µg
Ozone precursors	Chemical compounds, such as carbon monoxide (CO), methane (CH_4), non-methane volatile organic compounds (VOCs) and NO_x, which in the presence of solar radiation react with other chemicals present in the atmosphere to form ozone (O_3), mainly in the troposphere. Tropospheric ozone, also known as ground-level ozone, leads to a range of impacts on health and the environment
RED	Renewable Energy Directive
SO_2	Sulphur dioxide — atmospheric emissions of SO_2 are a main contributor to acidification and air pollution. SO_2 is released from the combustion of fossil fuels such as coal and oil
TSP	Total suspended particulates
UNECE	United Nations Economic Commission for Europe

WEPP	World Electric Power Plants
WID	Waste Incineration Directive

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European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark

Tel.: +45 33 36 71 00
Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

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