Decomposition analysis for air pollutants and CO_2 emissions from large combustion plants in Europe

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Main findings report

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Decomposition analysis for air pollutants and CO2 emissions from large combustion plants across Europe - under Framework Contract EEA/ACC/13/003/LOT-2

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1 Overview

1.1 Aims of this work

The observed reduction in emissions of key pollutants from electricity-generating[1] large combustion plants (LCPs) between 2004 and 2015 were likely to have been driven by a combination of multiple factors. Many of these factors can be influenced by or directly linked to one another. The most likely factors driving improved environmental performance include:

- Change in electricity demand from LCPs, which itself results from many factors such as:
  - economic activity;
  - the energy intensity of activity;
  - the degree of electrification of energy use; and,
  - generation of electricity from other (non-LCP) sources.
- Change in the fuel mix used in LCPs;
- Changes in LCP efficiency; and,
- Responses to industrial emissions legislation, including installation of abatement technologies and closure of inefficient plants.

The decomposition analysis carried out in this study aimed to decompose the contribution of each factor to changes in LCP emissions; such an attribution has not been possible in previous LCP studies. This study has therefore isolated the impact of factors which could have been influenced by legislation versus other causes.

This report describes the results of the analysis, firstly the EU-level macro analysis which considers all LCPs, the sub-set of electricity generating LCPs and considers patterns by pollutant and between countries. Secondly key outcomes of the micro-level analysis are presented, which considers patterns for individual LCPs. A separate methodology report has also been provided previously to the EEA so methodology details are not included in this document.

1.2 Summary of the findings of the macro-level analysis

At the EU-level, the most important factor in reducing emissions of SO_2, NO_x and dust (particulate matter) from electricity-generating LCPs between 2004 and 2015 was **improvements in the emission factor** - i.e. the quantity of pollutant emitted per unit of fuel consumed for a given pollutant and fuel type. This was most marked for SO_2 and dust, where changes in emissions factors would have resulted in 71% and 75% decreases in emission respectively, had all else remained constant. For SO_2, and dust, the most rapid period of decline in emissions due to the emission factor effect was between 2007 and 2008, which coincides with the introduction of the LCP directive in 2008.

The emission factor effect for NO_x was smaller, contributing a 38% decrease in emissions, but was still the most important single factor. For all three of these pollutants (SO_2, NO_x and dust), it is improvements in the national- or EU-level emission factor at electricity-generating LCPs burning various types of coal (termed “other solid fuels” in the LCP emissions reporting database) which have

[1] This study focused mainly on electricity-generating LCPs, as the linkage between the economy, energy consumption, efficiency and emissions can be made, which is not possible for other types of LCP such as refineries or blast furnaces. Full explanation is provided in the separate methodology report.

dominated the overall effect. At the Member State level, the importance of the emission factor effect varied from country to country for SO_2, NO_x and dust. For example, Bulgaria saw large reductions in emissions of SO_2, NO_x and dust from electricity-generating LCPs due to improvements in the emission factors from among the highest values in Europe in 2004. In contrast, countries having low emission factors at the start of the time period (such as Germany) saw relatively small improvements or even slight worsening of emission factors between 2004 and 2015, as there was little scope for improvement. In other cases (such as Sweden, Luxembourg and Latvia), a worsening of emission factors was observed for some pollutants, but this applied to very low quantities of emissions generally across the period so does not equate to an important change in emissions. In Slovakia, a worsening of the SO_2 emission factor was observed, which did have an important impact on SO_2 emissions. This situation may be due to high SO_2 emissions at SK0035 (SLOVENSKÉ ELEKTRÁRNE, a.s. ENO granulacné kotly) and which are particularly high for 2015. This plant dominates SO_2 emissions in Slovakia, masking declines in SO_2 emissions from smaller electricity-generating LCPs.

The decreases in EU-28-level or national-level emission factors can be driven by improvements in individual LCPs due to installation of cleaner technologies, or by fleet turnover where cleaner plants replace dirtier ones over time. The results of the macro-level analysis cannot disentangle these drivers; this requires analysis of plant-level data, discussed in section ¤.

Other important factors affecting emissions at the EU-level and for 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 a decrease in emissions of between 6% and 11% for all four pollutants. This was mainly driven by a reduction in the energy intensity of the industrial sector.
- Acting in the opposite direction to increase emissions, there was an overall **rise in economic activity** at the EU-level, contributing a small increase of between 4% and 7% in emissions of all four pollutants. Additionally, there was an increase in the degree of electrification of all sectors, therefore increasing demand for electricity from LCPs. This contributed a rise of between 6% and 9% depending on the pollutant.
- Finally, shifts in the energy mix of electricity generation helped to reduce emissions at the EU level, by 13%, 15%, 12% and 17% for SO_2, NOx, dust and CO_2 respectively. 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 to 25% in 2015), but a reduction in liquid fuel burning was also important, being the main driver in some 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.

1.3 Summary of the findings of the micro-level analysis

An analysis at the individual LCP level allows more detailed investigation of the drivers identified than the national (macro-) level in situations where these signals are most clear. This analysis has allowed us to verify that **some observed changes in emissions were clearly a response to industrial emissions legislation** (e.g. installation of abatement technologies to comply with the Emission Limit Values (ELVs) from the LCP Directive or fuel switching to biomass). However, there are many complex situations at the individual plant level that mask signals that are easier to discern at the national level.

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

At the macro-level the largest driver of reduced emissions is changes in the emission factor. The review of selected micro-level data (i.e. individual LCPs) has shown this change to be driven by improved environmental performance at LCPs burning various types of coal (termed "other solid fuels" in the LCP reporting database), predominantly around the 2007-2008 timeframe which strongly points to a response to the LCP Directive (hereafter LCPD). The second biggest driver of reduced emissions is fuel switching as electricity generation shifts away from "other solid fuel" burning in LCPs partly to more biomass burning in LCPs, but primarily to non-biomass renewables at the European level.
In general, the micro-level analysis has identified three groups of electricity-generating LCPs where different patterns were found in the data: where abatement technology has been installed, where there has been a switch between fuel types, and where closures of plants and changes in groups of electricity-generating LCPs owned by large companies appears to play a role. Case study examples are presented for each group.

1.4 Effect of industrial emissions policies

The largest driver of reduction in emissions from electricity-generating LCPs is a change in the environmental performance of LCPs burning other solid fuels (i.e. coal). The LCPD has impacted this change in two key ways: firstly, through installation of abatement technologies so that plants could comply with the LCPD ELVs by 2008; and secondly, through the closure of LCPs that were unable to meet the LCPD ELVs. Electricity-generating LCPs that "opted-out" using Article 4(4) of the LCPD closed at various times across the interval 2008-2015, leading to the steady increase in environmental performance from coal-burning electricity-generating LCPs. Installation of abatement technologies to comply with the LCPD ELVs was not economically viable for many of these particular plants, which were often near the end of their operational lifespan. Thus while the decision to close a particular plant was an economic one made by the operator, this decision was precipitated by the LCPD.

Of lesser importance than electricity-generating LCPs meeting compliance with the LCPD is the increase in the burning of biomass in such plants. Where this fuel has replaced other solid fuel the environmental performance of electricity-generating LCPs has improved. This change will have been incentivized, at least partially, by the EU-ETS which has a zero-rating for carbon emissions from biomass burning. Other policy tools within Member States to meet renewable energy targets in the Renewable Energy Directive will have further incentivized the uptake of biomass, such as Renewable Obligation Certificates in the UK.

A goal of the EU-ETS is to reduce emissions of CO_2 but reductions of emissions of this pollutant are likely to result in co-reductions of SO_2, NOx and Dust. However, the specific effects on reducing emissions from electricity-generating LCPs that can be definitively ascribed only to the EU-ETS (i.e. beyond the impact of the LCPD) are difficult to discern, given that this program follows a market-based approach.

While the IED only came into effect for LCPs in 2016, i.e. later than the time period covered by this study, it is possible operators may have made decisions not to invest in, reduce operations at, or close earlier than planned certain electricity-generating LCPs in response to the prospect of stricter ELVs and new BAT conclusions from 2016 and later. Such actions could have partially contributed to the patterns observed in the data through 2015.

1.5 Recommendations for future data collection and analysis

There are limited comprehensive data sets in the public domain detailing LCP abatement technologies and the date of their installation. Consequently, it has been necessary to identify trends and changes within the LCP inventory and then to investigate selected examples to see if these changes are 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 at specific LCPs.

It is therefore recommended that a future study compile such information from competent authority permits and related determinations and correspondence. Given the likely range of accessibility to such information it is recommended such work initially focuses on selected countries. Consultations with inspectors at Competent Authorities, perhaps as part of a formal Eionet consultation, should yield useful insights.

A compilation of data on electricity generated by each individual LCP would allow a more robust comparison of the macro- and micro-level analyses. This data compilation could be done through review of company reports and electricity regulator reports amongst other sources. It would then be possible to relate the electricity generated at specific LCPs with electricity generated by all LCPs and from all sources within a country.

The analysis at the micro level identifies several groups which exhibit responses in reported data that could be attributed to the LCPD. However, such analysis also identifies several limitations of LCP reporting. Firstly, single power stations tend to be split into several units, each reported 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, tends to apply to the entire station. In addition, the reporting for each individual unit may show interrelated responses to one another, relative to the status of each unit, the connectivity between units, and the overall required power demand of the power station. This complicates the identification of specific trends.

Secondly, 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 only run during periods of peak electricity demand (see section 3). Plant closures and changes in role, therefore, may not be solely due to the impact of the LCPD or the motivations of the country, but due 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 impacts on the analysis at the country and individual LCP level. Consultations with operators and competent authorities may yield insights on the broader context for operational changes in multiple electricity-generating LCPs across one or more countries.

Identification of the effect of abatement technologies is limited due to a lack of data regarding which LCPs are subject to controls, and the impact of variable fuel input. Clear identification of LCPs subject to abatement is therefore only possible when fuel input remains relatively consistent, in turn identifying large proportional shift in the implied emission factor (IEF). With more detailed data on the control technologies in may be possible to isolate the effect of variable fuel input, or to understand the relative impact this has on emissions.

A final limitation of reported LCP data is the lack of monitoring of CO_2 emissions, which necessitated the use of default CO_2 emission factors from the 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 (CCS) may play a significant role in the near future, increasing the need for monitoring of CO_2 emissions.

2 Macro-level decomposition

2.1 Introduction

2.1.1 Outline

The macro-level decomposition considered trends in emissions of SO_2, NO_x, dust (particulate matter) and CO_2 from large combustion plant (LCP) emissions between 2004 and 2015. The decomposition comprised two separate identities:

- A detailed 8-factor identity, focusing on changes in emissions from **electricity-generating LCPs only**;
- A simpler 5-factor identity, encompassing changes in emissions from **all LCPs**.

This report focuses on the results of the detailed 8-factor identity, which can provide insights into the drivers of emissions trends among electricity-generating LCPs. The results of the simpler identity - in particular the influence of changes in emission factors - are used to assess the representativeness of the detailed results, and provide a more complete picture for countries where the share of electricity-generating LCPs in all LCPs is relatively low.

The decomposition analyses were performed for the EU-28 as a whole, as well as for individual Member States. The remainder of this report considers 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 that show different behaviour over the study period.

Full details of the methodology used in the decomposition are in a separate methodology report that was provided earlier to EEA.

2.1.2 How to interpret the decomposition results

The decomposition calculations break down overall changes in emissions from electricity-generating LCPs into the additive sum or multiplicative product of the effects several factors. In this report, we focus on the results of the additive decomposition calculations. The factors included in the detailed decomposition are:

- **Overall economic activity ("Activity (economic)")** - the effect of changes in the whole-economy gross value-added (GVA);
- **Economic structure ("Structure")** - the effect of shifts in the balance of the economy towards sectors with higher or lower energy intensity, 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")** – within a particular economic sector, the effect of increases or decreases in final energy consumption per unit of value added. For example, a decrease in energy intensity of the manufacturing sector would act to lower emissions;
- **Energy consumption not attributable to economic sectors ("Activity (non-economic)")** - the effect of changes in final energy consumption in the residential and transport sectors, or through exports of electricity;
- **Sectoral degree of electrification ("Electrification")** - the effect of shifts towards using electricity for a greater or smaller fraction of final energy needs in a given sector;

- **Energy mix in electricity generation ("Generation type")** - the effect of shifts in the generation method of electricity produced, both between non-combustion sources and combustible fuels, and between different types of combustible fuel;
- **Generation efficiency ("Efficiency")** - the effect of increases or decreases in the transformation efficiency between the primary fuel type and electricity produced, for a given fuel type;
- **LCP share of fuel used in electricity production ("LCP share")** - the effect of increases or decreases in the amount of fuel burning for electricity production which takes place in LCPs, compared to outside of LCPs (e.g. in small-scale generators), for a given fuel type;
- **Emission factor** - 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 indications of the impact of improvements in abatement technology or fuel quality.

Effect of each factor on emissions changes, and relationship with overall changes in emissions

In the charts and tables presented below, the contribution of each factor refers specifically to the change in emissions which would have occurred due to changes in that factor alone, if all other factors had remained constant over the period studied. As short-hand, this is referred to throughout the report as "the contribution of factor X to changes in emissions".

The contributions of each factor sum (or multiply when considering the multiplicative decomposition) together to give a net overall change in emissions. However, as the summation may involve both positive and negative contributions from factors, it is hardly ever possible to report what “fraction” of the net change is attributable to factor X, as the contribution of factor X may be in the opposite direction to, or larger than, the overall net change in emissions.

Note that the net overall change in emissions resulting from summing together the individual changes contributed by each factor (i.e. referred to hereafter as the “decomposition calculation emissions”) does not exactly equal the observed change in emissions obtained from the LCP database. This is due to methodological limitations of the decomposition analysis, described in section 2.1.3.

Chaining analysis

The decomposition calculations were carried out using the “chaining” method, where a separate calculation was performed for each of the 11 year-on-year changes in emissions between 2004 and 2015. In this report, where aggregate results are presented for the effect of a given factor across the entire period (as in Figure 1), this is the **sum of the 11 separate calculations**. Note that aggregate results calculated in this way will differ from those calculated for the entire period in a single step, because in the chaining method, the timing of changes in a given factor relative to changes in emissions due to other factors affects the contribution of that factor.

Percentage changes in emissions

The additive decomposition calculations produce results expressed in units of tonnes of pollutant. To facilitate comparison of results among countries with very different emission levels, results in this report have been converted to percentage change values, relative to the emission levels recorded in 2004. For some countries, missing or unreliable data early in the period means that their results are scaled to emissions in later years: Sweden from 2007, Cyprus from 2009, and Denmark and Croatia from 2010.

Whenever the effect of a factor in the decomposition is reported as a percentage change, this *always* refers to the change in emissions which would have occurred due to changes in that factor alone, if all other factors had remained constant over the period studied. It *never* refers to the “fraction” of the net overall change in emissions attributable to that factor, as in most cases this would not make sense.

2.1.3 Limitations and caveats of the analysis

There are caveats and limitations concerning the input data and decomposition calculation methodology which affect the interpretation of results from the macro-level analysis. This section describes the most important of these caveats.

Limitations in calculation of implied emission factors and effect on decomposition calculation emissions.

A key factor in the macro-level decomposition is the “emission factor” effect – i.e. change in the mass of pollutant released per terajoule of fuel combusted in electricity-generating LCPs. In the decomposition calculations, an aggregate implied emission factor (IEF) is calculated for each country, fuel type and pollutant combination using information in the LCP database. In order to link emissions of a particular pollutant to combustion of a particular fuel, only data from “single-fuel” LCPs (defined as burning >= 95% of a single fuel type) was used to calculate the IEF. In the decomposition calculations, this IEF is then used to multiply fuel use in all electricity-generating LCPs (including mixed-fuel plants) to estimate overall emissions. No correction factor was applied. As the IEF calculated from single-fuel plants will rarely be exactly representative of the emission factors for mixed-fuel plants, the emissions calculated in the decomposition identity for any given country and year will differ slightly from the result obtained from simply adding up emissions in the LCP database for that country and year. The pool of single-fuel LCPs from which the IEF is calculated may be further limited through the discarding of data from plants where anomalous fuel usage or emissions was observed.

In this report, where changes in emissions of a pollutant are quoted, this specifically refers to the *emissions calculated in the decomposition identity*, which will slightly differ from the true changes. However, it is unlikely that the relative sizes of the effect of different identity factors for a country are qualitatively affected by this.

Fuel usage data in Eurostat tables and the LCP database

Eurostat energy data contains a detailed categorisation of fuel types, whereas the LCP data contains only 5 broad categories; “biomass”, “other solid fuels”, “liquid fuels”, “natural gas” and “other gases”. In order to carry out the macro-level decomposition of emission from electricity-generating LCPs, a mapping was made between the more detailed Eurostat and less detailed LCP database classifications. There is likely wide variation in the proportions of the more detailed fuel types making up any given category between different countries and over time. Changes in the apparent conversion efficiency or emission factor for a given LCP fuel category may be partly due to the changing constituents of this fuel type. For example, a shift from use of lignite to other forms of coal may significantly affect emissions, but these would both be classed as “Other Solid Fuels”.

A related issue is the potential for variation in how fuels are grouped by different member states, or in different years, and how well these correspond to the groupings used in this decomposition analysis. This may particularly affect slightly ambiguous fuel categories such as wastes and liquid and gaseous biofuels, which could plausibly belong to more than one category. Unfortunately, there is no way to know the extent to which this has affected our analysis. Nonetheless, this issue has certainly impacted the "LCP share" factor in the decomposition analysis, because for roughly 9% of Member State / Year / Fuel type combinations the quantity of fuel used in electricity-generating LCPs is greater than the total amount of that fuel used in the same Member state and year (which should not be possible).

In addition to ambiguity and variation in how specific fuel types are mapped to broad categories, there may also be numerical errors in the data reported either to Eurostat or the LCP database. A series of data checks[2] were implemented on the LCP database to identify and exclude LCPs with implausible fuel input or emissions data, but these highlighted only the most extreme cases, which may have allowed some erroneous reported fuel input or emissions data to be used in the analysis.

In this report, the limitations mentioned above will impact on the generation efficiency, LCP share and implied emission factor terms of the decomposition results. Where reported fuel use in electricity generation in Eurostat has been too low, for example, this can be seen in a simultaneous apparent improvement in generation efficiency, and apparent increase in LCP share which mirror one another.

Identification of electricity-generating LCPs in the LCP database

In order to carry out the 8-factor decomposition of emissions from electricity-generating LCPs, a critical step was to identify electricity-generating LCPs in the LCP database. A consistent approach was taken for all countries, using a combination of the self-declared main activity (NACE rev.2 codes) of plants from E-PRTR data and the "other sector" classification of plants in the LCP database.

However, the labelling of LCP with activity codes from the E-PRTR database is incomplete, and in general the labelling is more complete for later years than for earlier years. This could lead to a) erroneous exclusion of electricity-generating LCPs from the analysis lacking an activity label, and b) an apparent increase in the energy use by electricity-generating LCPs over time, as the labelling improves. Note that this is only a problem if an LCPs having a particular unique ID does not have any activity information for any year; if activity data is present for any one year, this was applied across the whole time-series.

The impact of this issue on the decomposition results would be to affect the "LCP share" term, as the primary energy use by electricity-generating LCPs would increase or decrease relative to the primary energy consumption data from Eurostat. Unfortunately, without inspecting each plant individually to ascertain whether it is electricity-generating or not it is difficult to make an estimate the extent of the problem that incomplete labelling has caused.

CHP plants

Finally, a key caveat affecting interpretation of some of the factors in the analysis is the inclusion of combined heat and power (CHP) LCPs. These facilities both generate electricity and export derived heat in a usable form such as steam or hot water. However, in the macro-level decomposition of emissions from electricity-generating LCPs reported below, it is only the *electricity* generated by these LCPs which is taken into account. Therefore, the energy efficiency of these plants and changes in this over time only pertains to the fuel input required to produce a given unit of electricity, not counting

[2] These checks are described in the 2016 ETC/ACM technical paper "Methodology of LCP Data Flow Management", lead author Lorenz Moosmann

the heat output. For countries where CHP plants make up a large proportion of electricity-generating LCPs, this could have a considerable influence on the importance of the efficiency factor.

2.2 EU-level summary for all pollutants

The contribution of different factors to changes in emissions between 2004 and 2015 of all four pollutants from electricity-generating LCPs at the EU-28 level is summarised in the waterfall plots shown in Figure 1.

Between 2004 and 2015, decreases in emissions from electricity-generating LCPs in the EU-28 were seen for all three air pollutants: SO_2, NO_x and dust.

Several factors tended to act 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 emission to reduce (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.

Changes in the first five factors of each decomposition (reading from left to right in Figure 1) affect the total electricity demand, so had a similar (but not identical) effect for all pollutants. The small differences in the magnitude of the effects of these factors across the different pollutants are due to the differing overall emission reductions, and different timing of reductions in the emissions of each pollutant.

For each of SO_2, NO_x and dust, the most important factor in reducing emissions was improvements in the emission factors - i.e. the quantity of pollutant emitted per unit of fuel consumed. This was most marked for SO_2 and dust, where changes in emissions factors would have resulted in 71% and 75% decreases in emission respectively, had all else remained constant. The emission factor effect for NO_x was smaller, contributing a 38% decrease in emissions, but was still the most important single factor.

For CO2 emissions, the emission factor effect was not calculated, due to the use of constant default emission factors from the IPCC throughout the time period. Instead, the most important factor driving the decrease in CO_2 emissions was a change in the energy mix in electricity generation, which contributed to a 17% decrease in emissions.

Changes in the energy mix of electricity generation was the second largest contributor to emissions reductions in SO_2, NO_x and dust, by 13%, 15% and 12% respectively.

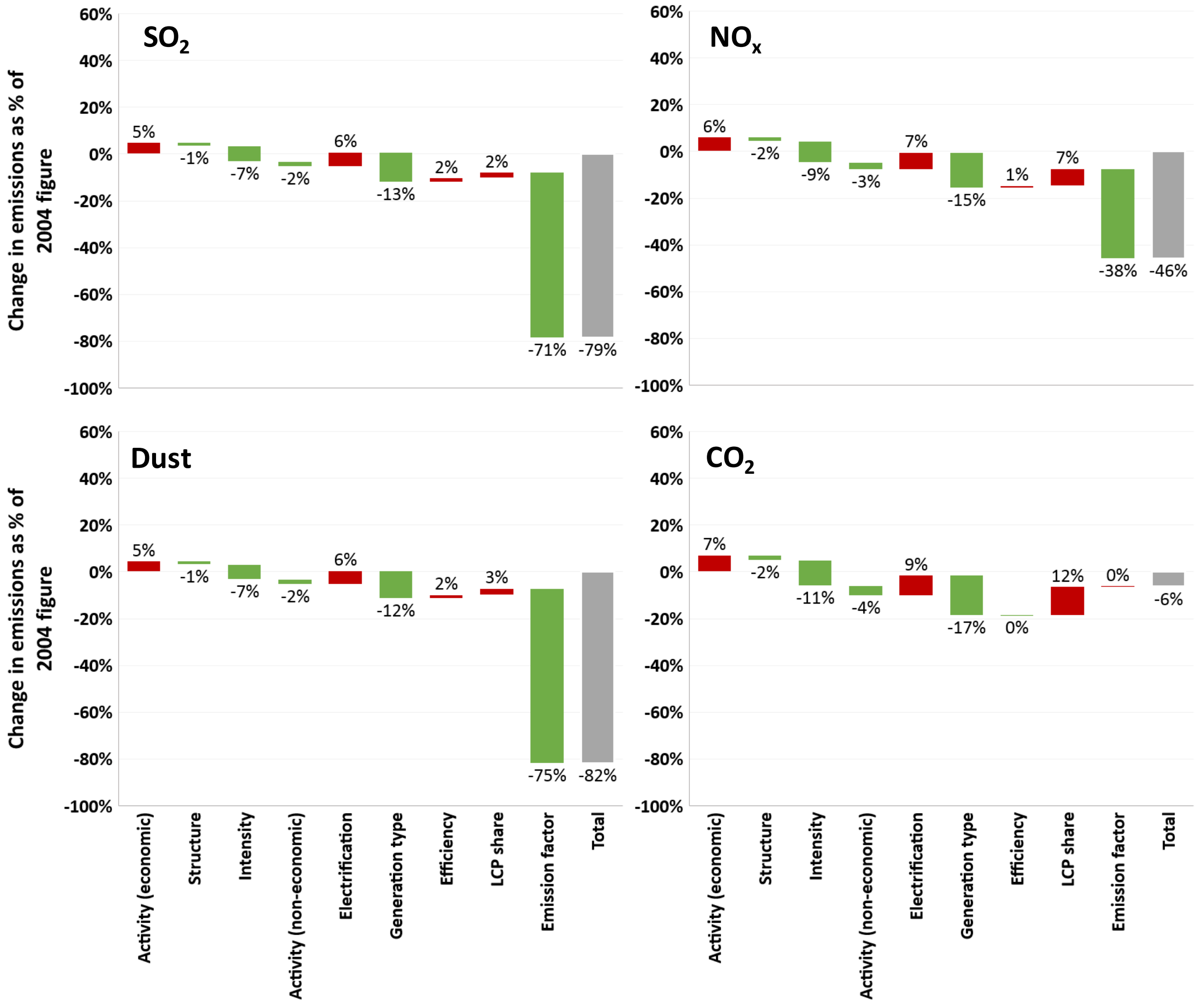


FIGURE 1. WATERFALL PLOTS SHOWING THE CONTRIBUTION OF EACH FACTOR IN THE DETAILED DECOMPOSITION TO CHANGES IN EMISSIONS OF SO_2, NO_x, DUST AND CO_2 BETWEEN 2004-2015, AS A PERCENTAGE OF 2004 EMISSIONS, FOR ELECTRICITY-GENERATING LCPS.

2.2.1 Exploration of EU-level changes in factors affecting all pollutant emissions

This section delves deeper into the factors affecting emissions of all pollutants, due to their influence on demand for energy from LCPs. Changes in emission factors are specific to each pollutant, so are discussed in the individual pollutant chapters.

Economic activity and sectoral structure

Across the EU-28, between 2004 and 2015 economic activity (gross value added (GVA) at 2010 prices) rose by 13% from EUR 10.7 trillion to EUR 12.2 trillion (Figure 2, left), which contributed increases in emissions of all four pollutants from electricity-generating LCPs by between 5% and 7%. The contribution is slightly higher for NO_x and CO_2 than for the other pollutants, because they saw smaller overall decreases in emission levels due to other factors.

At the same time, there was a slight shift in the structure of the EU-28 economy, with the share of the service sector increasing from 72% to 74% of total GVA, and the share of industry decreasing correspondingly from 26% to 24% of total GVA. This shift contributed a net decrease in emissions from electricity-generating LCPs (Figure 2, right), as the increase from the services sector was outweighed by reduction from the industrial sector, as the latter is much more energy intensive. In Figure 2 (right), CO_2 emissions are used as an example, but the qualitative pattern is similar for all pollutants.

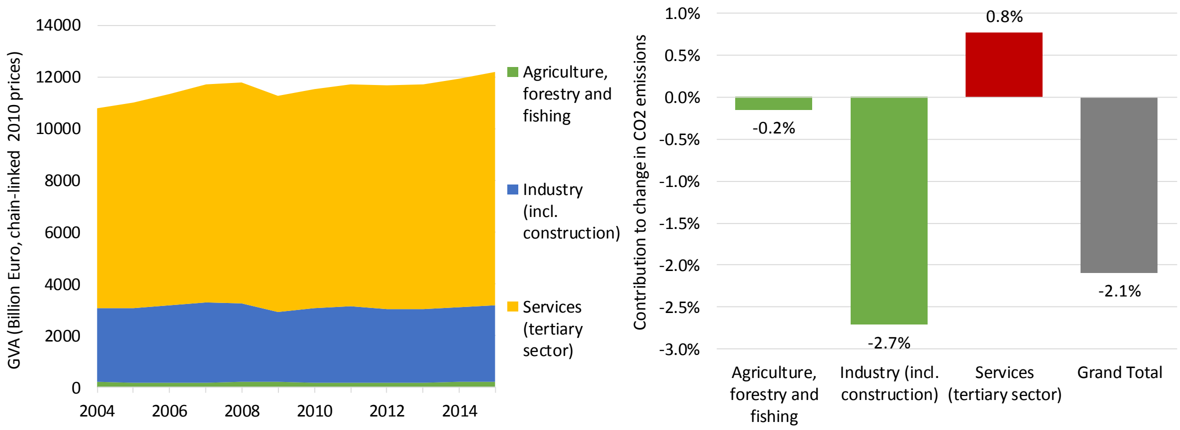


FIGURE 2. GROSS VALUE ADDED (GVA) BY ECONOMIC SECTOR BETWEEN 2004 AND 2015 IN THE EU-28 (LEFT), AND THE EFFECT CHANGES IN THE SECTORAL SHARE OF TOTAL GVA ON CO2 EMISSIONS FROM ELECTRICITY-GENERATING LCPS (AS AN EXAMPLE).

Sectoral energy intensity, and energy consumption in households and transport

Sectoral energy intensity (final energy consumption per unit of sectoral gross value added (GVA)) reduced in all economic sectors between 2004 and 2015. The largest changes were in agriculture, forestry and fishing and industry, seeing 15% and 21% decreases in energy intensity over the period (Figure 3, left).

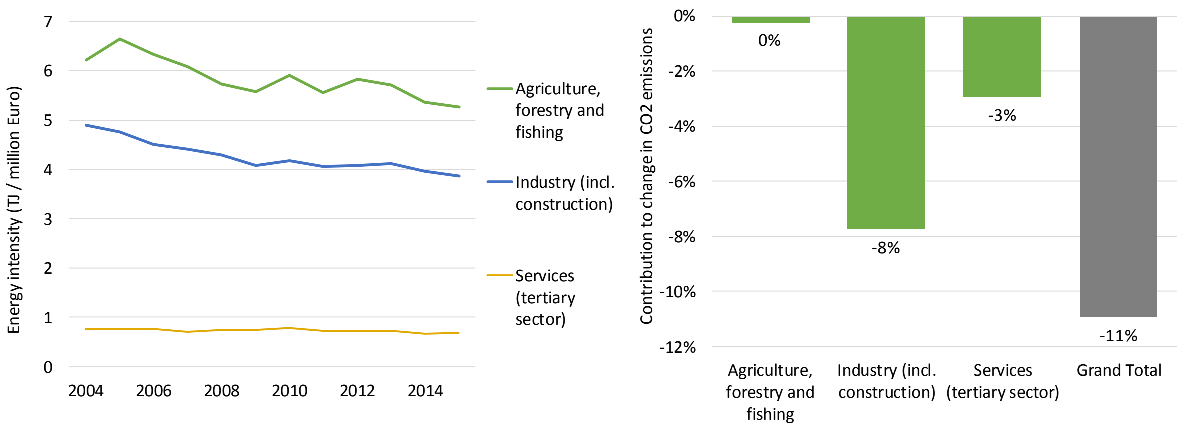
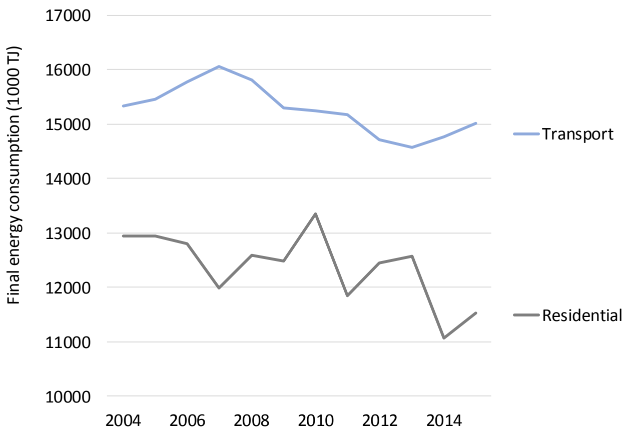


FIGURE 3. CHANGES IN SECTORAL ENERGY INTENSITY (FINAL ENERGY CONSUMPTION PER UNIT OF SECTORAL GVA) AT THE EU LEVEL 2004-2015 (LEFT), AND THE OVERALL CONTRIBUTION OF THE CHANGES IN ENERGY INTENSITY IN EACH SECTOR TO CHANGES IN EMISSIONS OF CO_2 FROM ELECTRICITY-GENERATING LCPS ACROSS THE TIME-SERIES (RIGHT).

When translated into the effect on emissions from electricity-generating LCPs, the reduction in industrial energy intensity has a larger effect than improvements in the other sectors (Figure 3, right), because it makes up a much larger share of GDP than the agriculture, forestry and fishing sector. CO_2 emissions are used in Figure 3 as an example, though effects for all pollutants are similar.

In the household and transport sectors (to which GVA figures are not assigned), final consumption of energy in all forms fell by 11% and 2% respectively between 2004 and 2015 (Figure 4, left).



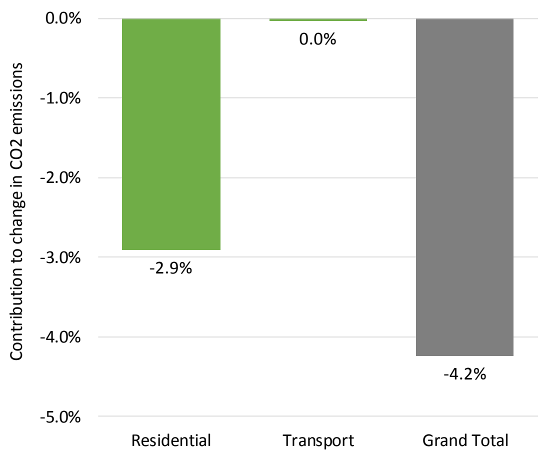
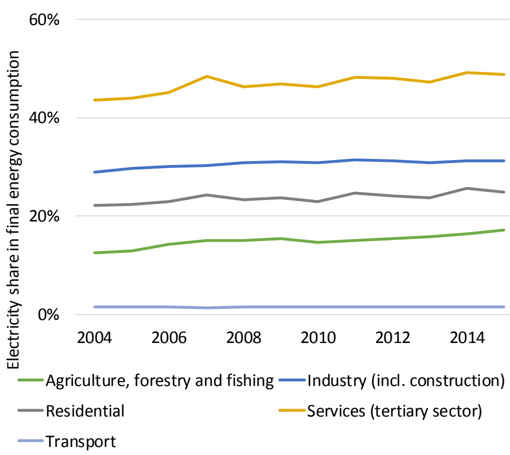


FIGURE 4. CHANGES IN TOTAL FINAL ENERGY CONSUMPTION IN HOUSEHOLDS AND IN THE TRANSPORT SECTOR IN THE EU-28, 2004-2015 (LEFT), AND THE OVERALL CONTRIBUTION OF THESE CHANGES TO CHANGES IN EMISSIONS OF CO_2 ACROSS THE TIME-SERIES (RIGHT).

The household and transport sectors are responsible for a significant proportion of all final energy consumption, at 25% and 29% of the total respectively. However, only the decrease in final energy consumption across all households had an effect on emissions from electricity-generating LCPs between 2004 and 2015 (a 2.9% reduction, Figure 4 right), because so little electricity is currently used in the transport sector. Figure 4 (right) shows results for CO_2 emissions, but the results for other pollutants are also similar.

Sectoral degree of electrification

Another factor affecting demand for electricity from LCPs is the share of electricity in final energy consumption ("degree of electrification"). Overall, there has been an increase in the degree of electrification of all sectors of the economy, as well as a rise in the share of electricity in energy consumed by households and transport (Figure 5, left).



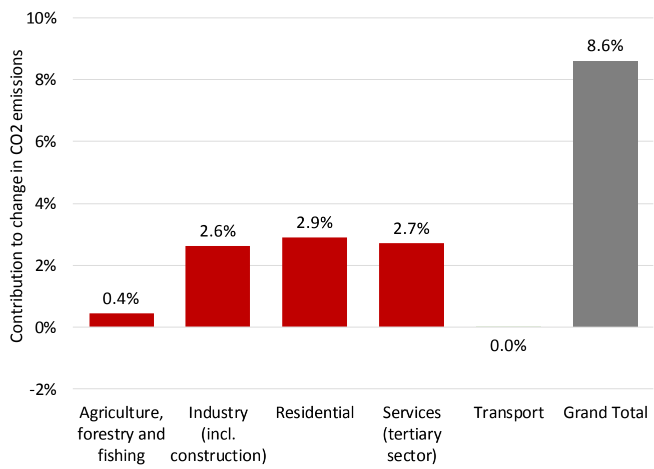


FIGURE 5. CHANGES IN THE SECTORAL DEGREE OF ELECTRIFICATION (SHARE OF ELECTRICITY IN FINAL ENERGY CONSUMPTION) AT THE EU LEVEL 2004-2015 (LEFT), AND THE OVERALL CONTRIBUTION OF CHANGES IN DEGREE OF ELECTRIFICATION IN THE DIFFERENT SECTORS ACROSS THE TIME-SERIES ON CO_2 EMISSIONS (RIGHT).

When translated into effects on emissions from electricity-generating LCPs, the increases in the degree of electrification in industry, the services sector, and the residential sector all contributed to small increases in emissions (Figure 5, right). CO_2 is used in Figure 5 as an example, though effects for all pollutants are similar.

Generation type

The generation type used to provide electricity in the EU has been a factor affecting emissions of all pollutants from electricity-generating LCPs to a similar magnitude (Figure 1). Between 2004 and 2015, there have been several temporal shifts in this mix at the EU level (Figure 6).

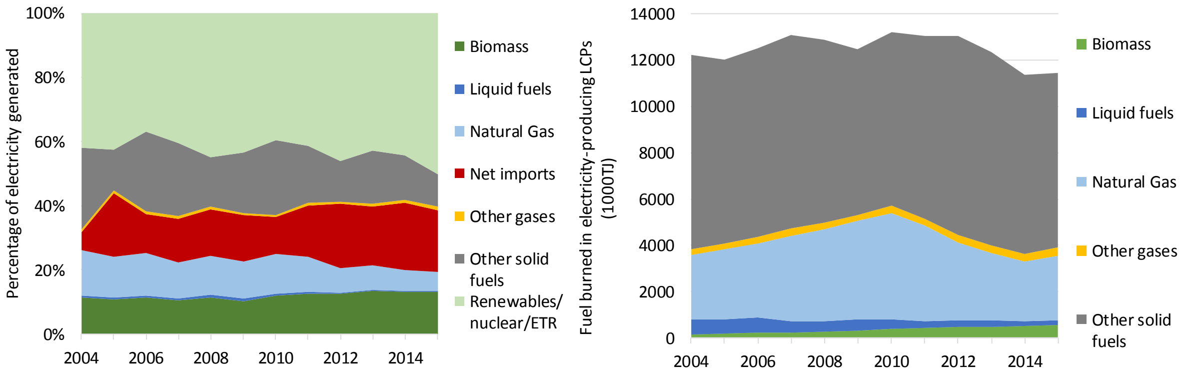


FIGURE 6. ENERGY TYPES IN ALL ELECTRICITY GENERATION (LEFT), AND FUEL MIX IN ELECTRICITY-GENERATING LCPS (RIGHT) AT THE EU-28 LEVEL, 2004 – 2015. ETR = EXCHANGES, TRANSFERS AND RETURNS.

For overall electricity production (including outside of LCPs), there was an overall increase in the fraction of electricity produced from nuclear or non-biomass renewables, from 43% in 2004 to 51% in 2015. There has been a corresponding decrease in electricity production from combustible fuels, from 57% to 49% (Figure 6, left). This decrease is reflected in a 6.5% overall decrease in quantity of fuel burned (by energy content) in electricity-generating LCPs (Figure 6, right).

The main variation in fuel burned in electricity-generating LCPs between 2004 and 2015 was a peak in natural gas usage in 2010 (at 35% of fuel by energy content), and a simultaneous dip in “other solid fuels[3]” usage (at 57% of fuel by energy content). By 2015 however, the shares of fuel use had returned to levels more similar to 2004. This pattern may have been driven by relative prices of coal and natural gas. The only noteworthy linear trend was a steady reduction in the use of liquid fuels (5% in 2004, 2% in 2015) and an increase in solid biomass usage (1% in 2004, 5% in 2015).
These trends have impacts on the emissions of all pollutants, and will be referred to later in this report.

Generation efficiency (“Efficiency”)

Generation efficiency is defined in this analysis as the amount of electricity produced per unit of primary energy consumed, both within LCPs and in other, smaller generators.
Between 2004 and 2015 at the EU-28 level, the amount of fuel burned to produce one terrajoule (TJ) of electricity decreased (efficiency improved) for all fuel types except for “other solid fuels”, where 2% more fuel was required per TJ of electricity generated in 2015 than in 2004 (Figure 7, left). For NO_x

[3] “Other solid fuels” is one of the fuel type categories reported in the LCP emissions database owned by the EEA. It includes various types of coal, coke, peat and non-renewable wastes. A full mapping of the aggregate LCP fuel types to the more detailed fuel types used in Eurostat statistics is provided in the methodology report.

emissions (as an example), this worsening of generation efficiency from “other solid fuels” counteracts the improvements for other fuel types, contributing a net 1% increase in NO_x emissions from electricity-generating LCPs (Figure 7, right). This increase is higher for SO_2 and dust (at about 2%) where the emissions intensity from “other solid fuels” has been much higher than for other fuel types. However, for CO_2 the efficiency effect contributes a decrease (-0.2%) because emissions intensities are more similar for the different fuel types, so the efficiency improvements of other fuels cancel out the increase from “other solid fuels”.

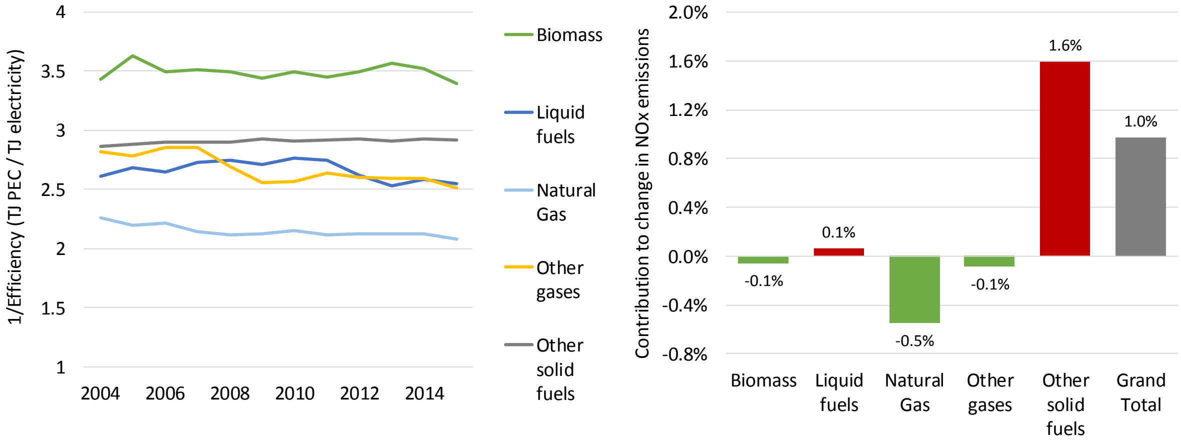


FIGURE 7. INVERSE EFFICIENCY (PRIMARY ENERGY USED PER UNIT OF ELECTRICITY GENERATED) OF ALL ELECTRICITY GENERATION IN THE EU-28 BETWEEN 2004 AND 2015 BY FUEL TYPE (LEFT), AND THE CONTRIBUTION OF CHANGES IN THIS TO CHANGES IN NO_x EMISSIONS FROM ELECTRICITY-GENERATING LCPS OVER THE SAME PERIOD (RIGHT).

The most important driver of the apparent worsening of generation efficiency from “other solid fuel” burning appears to be an increase in the proportion of electricity from “other solid fuels” which is generated in combined heat and power (CHP) plants, from 25% in 2004 to 29% in 2015, with a peak of 31% in 2010 (Figure 8, right). CHP plants burning “other solid fuels” consume more primary energy (PEC) per TJ of electricity generated than electricity-only plants, at 3.4 TJ PEC / TJ electricity versus 2.7 TJ PEC / TJ electricity respectively (Figure 8, right), because they export waste heat in useful forms rather than being optimised to reclaim it. An increase in the CHP share of total electricity production from “other solid fuels” therefore results in an overall decrease in electricity-generation efficiency.

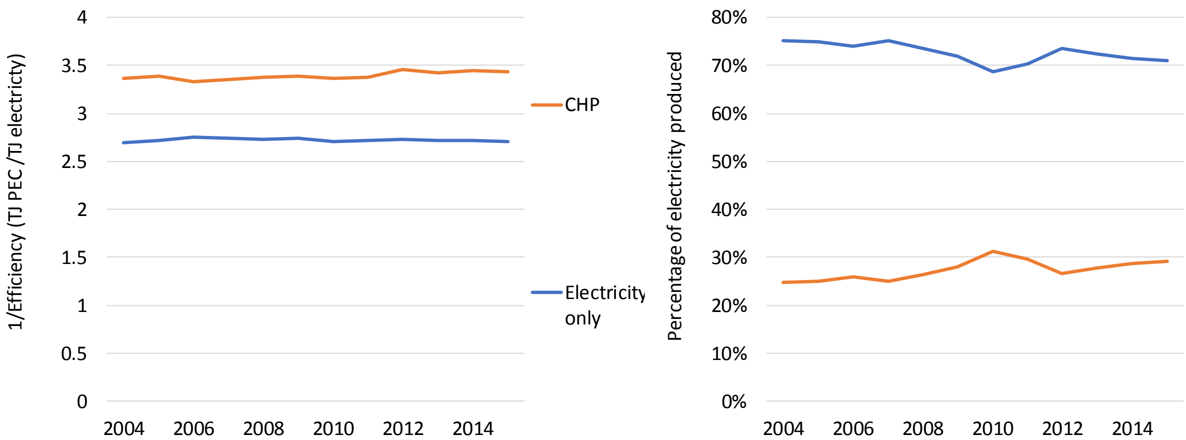


FIGURE 8. INVERSE EFFICIENCY OF ELECTRICITY-ONLY AND CHP PLANTS BURNING “OTHER SOLID FUELS” (LEFT), AND PROPORTION OF ELECTRICITY PRODUCED IN ELECTRICITY-ONLY AND CHP PLANTS FROM “OTHER SOLID FUELS” (RIGHT) IN THE EU-28, 2004- 2015.

In tandem, the electricity-generation efficiency of CHP plants burning “other solid fuels” considered on their own also worsened slightly between 2004 and 2015 (Figure 8, left), with the “other solid fuel” input required to generate 1 TJ of electricity rising by 2%. In contrast, the efficiency of electricity-only plants has changed very little over the period.

However, it must be noted that because CHP plants also produce useful derived heat (not included in this analysis), changes in electricity generation efficiency do not necessarily correspond to changes in efficiency of generation of electricity and heat combined.

LCP share of total fuel use in electricity production (LCP share)

The LCP share is a measure of what fraction of all fuel burned for electricity generation is burned within LCPs. At the EU-28 level, the LCP share increased for biomass, natural gas and “other solid fuels” between 2004 and 2015 (Figure 9, left). This has contributed a net increase to emissions of all pollutants of between 2% for SO_2 to 12% for CO_2 (NO_x used in Figure 9 here as an example). For CO_2, increases in the three fuel types showing increases in LCP share have all been important in the net positive contribution to emissions (with natural gas having the highest impact at 6.2%), whereas for SO_2, NO_x and dust the effect of “other solid fuels” contributes most to the net effect.

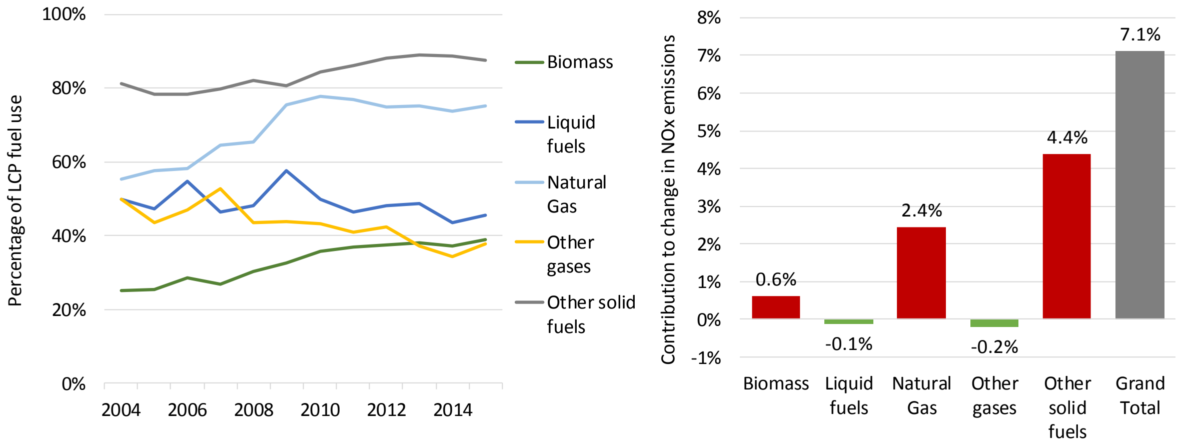


FIGURE 9. THE PERCENTAGE OF FUEL USED IN ELECTRICITY PRODUCTION WHICH IS BURNED IN LCPS, BY FUEL TYPE AT THE EU LEVEL BETWEEN 2004 AND 2015 (LEFT), AND THE EFFECT CHANGES IN THIS HAD ON CO_2 EMISSIONS OVER THE SAME PERIOD FROM ELECTRICITY-GENERATING LCPS (RIGHT).

An important caveat to bear in mind when interpreting the LCP share factor is that it is especially dependent on data quality in comparison to the other factors. This is because it is calculated by dividing the quantity of fuel used in LCPs as reported in the LCP database, by the quantity of fuel used in all electricity production as reported in Eurostat table nrg_110a. There are two potential sources of error in this:

i) The reporting of fuel used to Eurostat and the LCP database may operate through different processes, and therefore report figures in an incompatible manner;

ii) The fuel type categories used in the LCP database are much less specific than the detailed fuel categories published by Eurostat, so aggregation of the detailed Eurostat to the broader LCP database categories was necessary to perform the decomposition calculations. However, there is no way of knowing exactly how well the mappings used here correspond to those used by LCP operators to categorise their fuel input.

One or both of these issues have certainly impacted the LCP share factor in the decomposition analysis, because for roughly 9% of Member State X Year X Fuel type combinations the quantity of fuel used in electricity-generating LCPs is greater than the total amount of that fuel used in the same Member state and year (which should not be possible).
Where reported fuel use in electricity generation in Eurostat has been too low, this can be seen in a simultaneous apparent improvement in generation efficiency, and apparent increase in LCP share which mirror one another.

2.3 SO_2

This section and those that follow for NO_x, dust and CO_2 explore patterns for each pollutant separately at the EU-28 level and for selected Member States. The main focus of these sections is on the contribution of the emission factor effect to changes in emissions, but where relevant other factors will also be analysed in detail.

2.3.1 *EU-28 level decomposition* of SO_2 emissions

The results of the decomposition analysis show a large (79%) net decrease in SO_2 emissions from electricity-generating LCPs between 2004 and 2015 (note that the reported changes in emissions in the LCP database may differ from this - see section 2.1.3). The emission factor effect was the most important single factor, followed by changes in generation type (Figure 10).

Small positive effects on emissions were contributed by changes in economic activity, electrification of final energy use, efficiency of electricity production, and the LCP share of fuel used in electricity production. However, these were more than counteracted by the negative effects of the other factors.

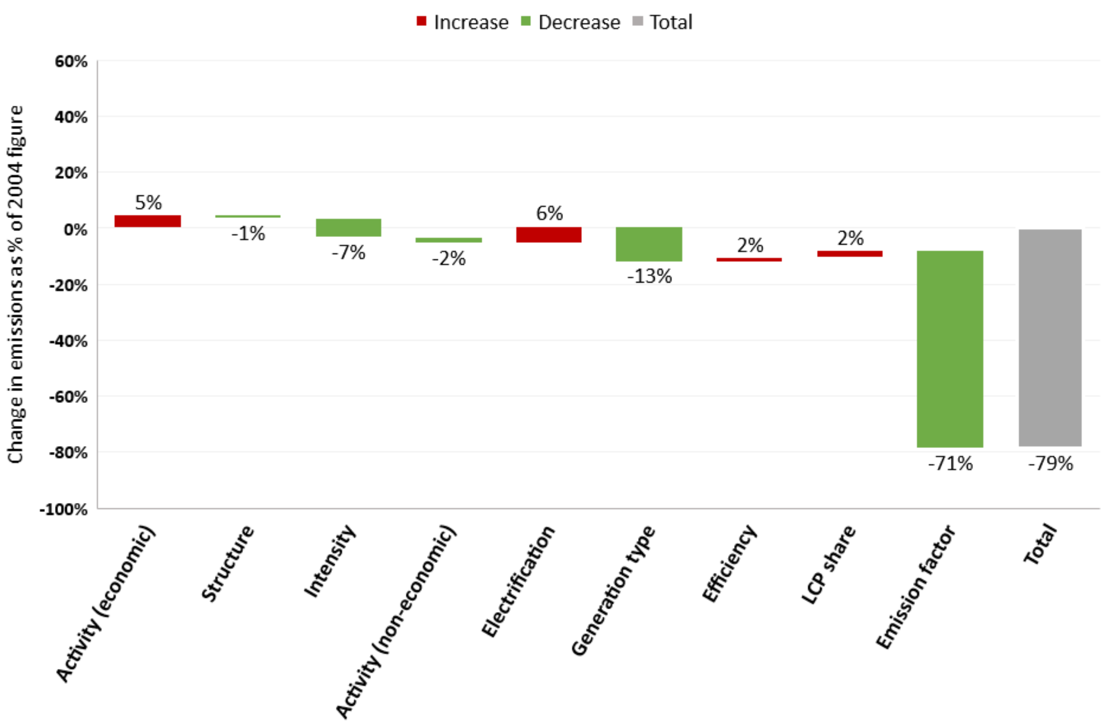


FIGURE 10. CONTRIBUTION OF EACH FACTOR IN THE DETAILED DECOMPOSITION TO CHANGES IN EMISSIONS OF SO_2 BETWEEN 2004-2015, AS A PERCENTAGE OF 2004 EMISSIONS, FOR ELECTRICITY-GENERATING LCPS.

Figure 11 illustrates the cumulative impact of each factor over time, showing that changes in SO_2 emission factors have had steadily increasing impact over time, with the most rapid changes occurring between 2007 and 2008.

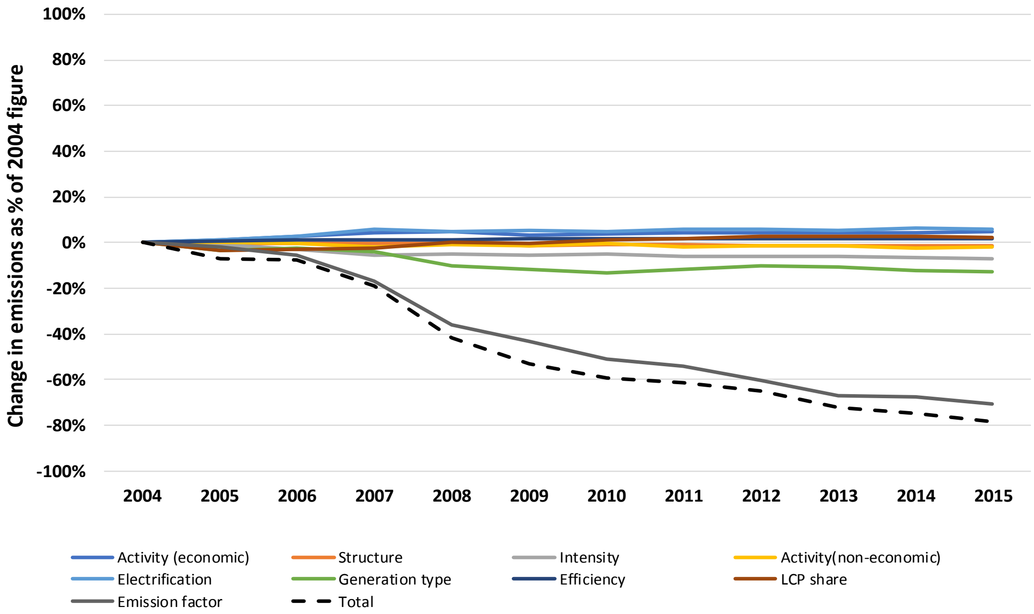


FIGURE 11. CUMULATIVE CONTRIBUTION OF THE EFFECTS OF EACH FACTOR TO CHANGES IN SO_2 EMISSIONS AT THE EU-28 LEVEL BETWEEN 2004 AND 2015, AS A PERCENTAGE OF 2004 EMISSIONS.

Examining the changes in implied emission factors for SO_2 by fuel type in electricity-generating LCPs (Figure 12, **left**), the largest absolute decreases have occurred for "other solid fuels" (largely various types of coal), and liquid fuels, decreasing by 76% and 59% respectively.

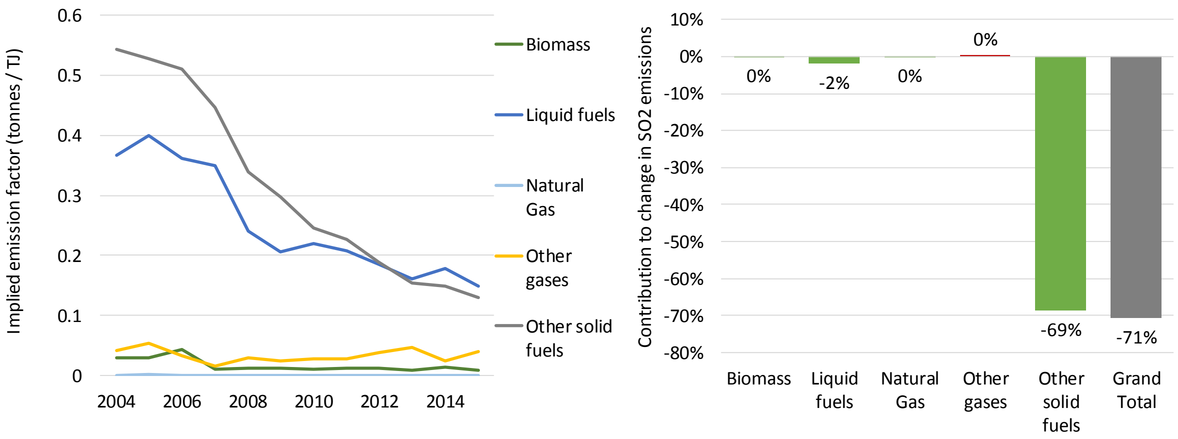


FIGURE 12. CHANGE IN THE AVERAGE SO_2 IMPLIED EMISSION FACTOR BY FUEL TYPE IN ELECTRICITY-GENERATING LCPS ACROSS THE EU-28, 2004-2015 (LEFT), AND THE EMISSION FACTOR EFFECT ON SO_2 EMISSIONS DISAGGREGATED BY FUEL TYPE (RIGHT). NOTE THAT ONLY SINGLE-FUEL LCPS WERE USED IN THE CALCULATION OF IMPLIED EMISSION FACTORS.

When these changes in emission factor by fuel type are translated into their effect on emission reductions from electricity-generating LCPs (i.e. the decomposition results), it is apparent that it is the reduction in the SO_2 emission factor for "other solid fuels" which was most influential in the overall emission factor effect (Figure 12, **right**).

The much larger impact of the change in the “other solid fuels” SO_2 emission factor compared to the change in the liquid fuel emissions factor is due to the much greater quantity of "other solid fuels" consumed in electricity-generating LCPs relative to liquid fuels (over 30 times as much in 2015).
Reductions in the national-level or EU-level implied emission factor for a particular fuel type over time can be driven by a combination of:

a) Improvement in plant-level emission factors due either improving fuel quality (e.g. a switch to cleaner forms of coal), or implementation of pre- during- or post-combustion abatement technology to reduce emissions in individual plants; or
b) Fleet turnover of LCPs, where LCPs having higher emission factors are closed or have their operation reduced, and are replaced by LCPs with lower emission factors. This would result in an overall lower national or EU-level emission factor.

Assessing the importance of each of these factors in reducing national or EU-level emission factors requires the analysis of individual plant-level data, so they cannot be easily disentangled in the results of the macro-level analysis. See sections ¤ and 3 for further discussion.

2.3.2 Member State level decomposition of SO_2 emissions

There was considerable variation among Member States in the importance of different factors in driving changes in SO_2 emissions from electricity-generating LCPs between 2004 and 2015 (Table 1).
For most Member States, changes in emission factors drove a decrease in emissions from electricity-generating LCPs, but the degree of this effect varied between countries. In Bulgaria, Hungary and Slovenia, changes in emission factors alone would have caused decreases of 90% or more in SO_2 emissions; a much larger effect than for any other factor.

In other countries such as Austria, Belgium, Germany, Czech Republic and Finland, more modest reductions in emissions of 10-25% were driven by emission factor changes alone.

In a few cases, emissions factor changes actually drove increases in emissions from electricity-generating LCPs (in Cyprus, Croatia, Luxembourg, Sweden and Slovakia). In the case of Sweden, the very high SO_2 emission percentage changes seen in Table 1 are due to small changes in emissions, which nonetheless have a large percentage impact due to the normally extremely low emission levels. The results for Latvia are greyed-out for the same reason. In Luxembourg, the electricity-generating LCP fleet runs entirely on natural gas and has extremely low SO_2 emissions, so there is little need to take measures to decrease these.

In Slovakia however, a considerable quantity of SO_2 is emitted by electricity-generating LCPs from “other solid fuel” burning, and the national-level emission factor worsened from 0.7 to 2.2 t/TJ SO_2 between 2004 and 2015, contributing a 119% increase in emissions. Nevertheless, this has been partly offset by a reduction in the share of “other solid fuels” in electricity generation, from 19% in 2004 to 10% in 2015.

A shift in generation type was the second most common factor responsible for large reductions in SO_2 emissions from LCPs for individual countries, including Austria, Belgium, Finland and Luxembourg (see also section 2.6.3).

Where opposite impacts of the efficiency and LCP share effects are seen (for example in Belgium and Lithuania), this may be due to inaccuracy in the submitted data on fuel consumption to Eurostat, as this affects both of these terms. However, the LCP share factor is also affected by the quality of fuel usage reporting in the LCP database, and the accuracy of identification of electricity-generating LCPs (see section 2.1.3 for more detailed explanation of caveats).

TABLE 1. RESULTS OF THE DETAILED MACRO-LEVEL DECOMPOSITION OF SO_2 EMISSIONS FOR INDIVIDUAL MEMBER STATES. EFFECTS OF EACH FACTOR ON EMISSIONS CHANGES ARE EXPRESSED AS A PERCENTAGE OF 2004 EMISSIONS, EXCEPT FOR SWEDEN (2007), CYPRUS (2009) AND DENMARK AND CROATIA (2010).

	Activity effect (economic sectors)	Structure effect	Intensity effect	Activity effect (non-economic sectors)	Electricity share effect	Generation type	Efficiency effect	LCP share effect	Emission factor	Total
EU28	5%	-1%	-7%	-2%	6%	-13%	2%	2%	-71%	-79%
AT	8%	-1%	-5%	0%	8%	-48%	35%	-20%	-21%	-45%
BE	7%	1%	-3%	-8%	11%	-68%	53%	-70%	-19%	-98%
BG	10%	1%	-13%	4%	7%	7%	-2%	-7%	-98%	-90%
CZ	10%	2%	-21%	-3%	12%	-15%	2%	-5%	-23%	-42%
DE	8%	1%	-7%	2%	1%	-10%	1%	20%	-24%	-7%
EE	7%	1%	-8%	3%	8%	-11%	5%	-9%	-29%	-34%
EL	-2%	-4%	4%	-5%	12%	-17%	0%	2%	-74%	-86%
ES	7%	-2%	-7%	5%	6%	-31%	4%	-6%	-63%	-88%
FI	5%	-1%	-8%	-1%	2%	-55%	11%	2%	-13%	-59%
FR	4%	-2%	-6%	-6%	8%	-34%	15%	-12%	-52%	-84%
HU	1%	0%	-2%	1%	2%	-9%	-3%	2%	-91%	-99%
IE	12%	-1%	-12%	0%	8%	-38%	-5%	-6%	-47%	-88%
IT	0%	-1%	-3%	0%	4%	-25%	4%	-7%	-61%	-89%
LT	8%	0%	-4%	-54%	2%	84%	-102%	71%	-98%	-92%
LU	17%	-15%	-9%	3%	6%	-80%	10%	-20%	10%	-76%
LV										
MT	23%	-4%	-1%	-7%	-7%	-18%	-14%	3%	-57%	-83%
NL	8%	-2%	-14%	-2%	11%	32%	-3%	29%	-79%	-19%
PL	15%	2%	-16%	-5%	9%	-9%	-2%	1%	-56%	-62%
PT	2%	-2%	0%	-1%	6%	-15%	1%	-25%	-58%	-92%
RO	9%	2%	-21%	4%	13%	-12%	-3%	4%	-84%	-88%
SI	4%	0%	-6%	-4%	4%	-1%	-2%	-1%	-91%	-96%
SK	27%	3%	-37%	-10%	13%	-64%	8%	-4%	119%	56%
UK	5%	-2%	-6%	-4%	4%	-8%	2%	-3%	-66%	-80%
SE	13%	-6%	-9%	28%	-3%	-83%	2%	-81%	224%	86%
CY	-3%	-1%	-2%	-5%	-2%	-8%	-3%	-13%	4%	-33%
DK	2%	0%	-8%	-10%	7%	-43%	10%	3%	-21%	-60%
HR	-2%	0%	-5%	-6%	8%	-25%	-4%	-42%	34%	-43%

Some of the differences between Member States in the importance of the emission factor effect in changes in SO_2 emissions from electricity-generating LCPs between 2004 and 2015 can be explained by differing national-level implied emission factors in 2004 (as calculated from LCPs burning >=95% of a single fuel type). Many countries showing relatively modest emission factor effects (e.g. BE, DE, CZ, FI) already had low emission factors for “other solid fuels” in 2004, so only limited further improvements were possible (Figure 13). By contrast, countries showing very large emission factor effects (BG, HU, RO, SI) began with much higher emission factors, leaving much more scope for improvement.

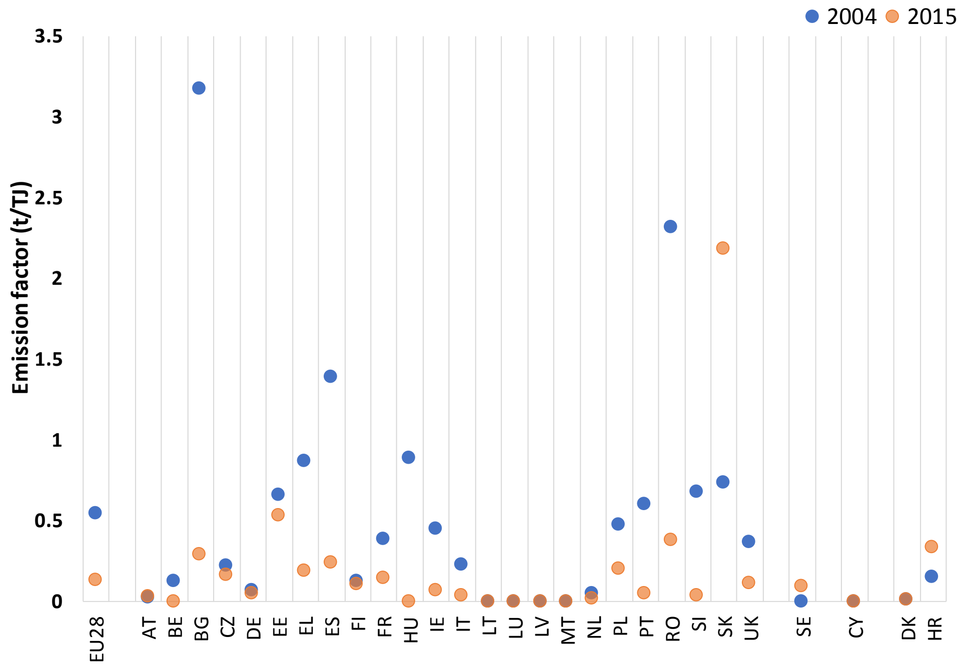


FIGURE 13. SO_2 IMPLIED EMISSION FACTORS IN 2004 (2007, 2009 AND 2010 FOR SE, CY AND DK AND HR RESPECTIVELY) AND IN 2015 BY COUNTRY, FROM BURNING "OTHER SOLID FUELS" IN ELECTRICITY-GENERATING LCPS. NOTE THAT ONLY SINGLE-FUEL LCPS WERE USED IN THE CALCULATION OF IMPLIED EMISSION FACTORS.

2.3.3 *How representative are electricity generating LCPs of all LCPs concerning changes in SO_2 emissions?*

Member States vary in the proportion of LCPs which are electricity-generating, as well as in the quality of the labelling of LCPs by activity type. As such, a useful check on the representativeness of the electricity-only decomposition results is to compare the emission factor effect from the two decompositions (

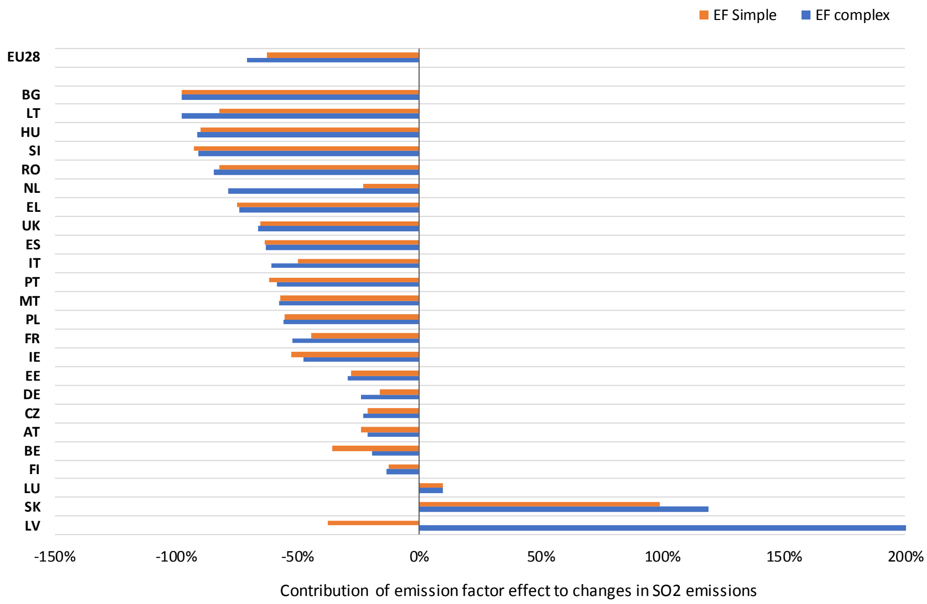


Figure 14). This is the only directly comparable factor in the two identities.

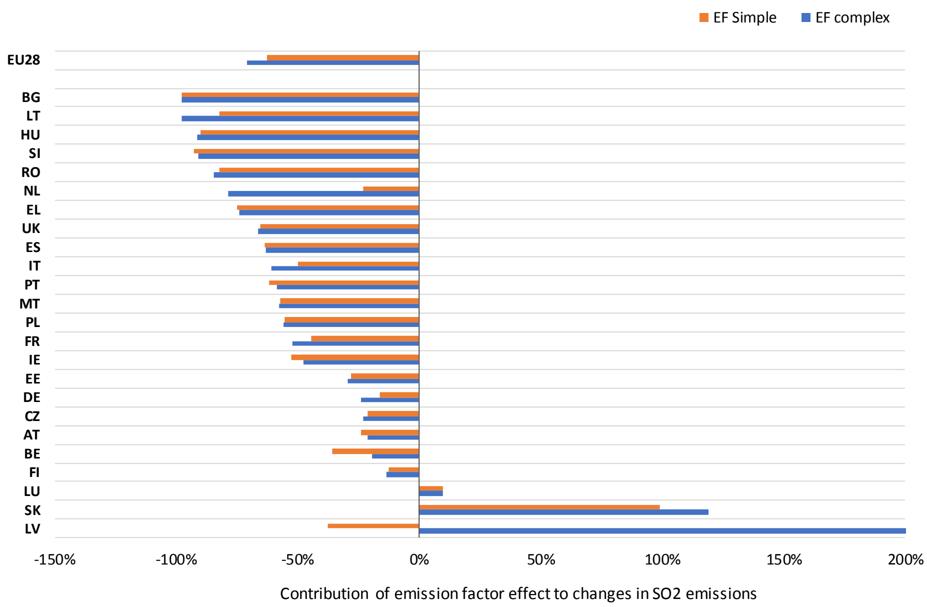


FIGURE 14. EMISSION FACTOR EFFECTS ON SO_2 EMISSIONS BETWEEN 2004 AND 2015, FROM THE DETAILED DECOMPOSITION OF ELECTRICITY-GENERATING LCPS (BLUE), AND SIMPLE DECOMPOSITION OF ALL LCPS (ORANGE), AS A PERCENTAGE OF 2004 EMISSIONS.

In general, the results for SO_2 emission factor effects are similar, indicating that trends seen for electricity-generating LCPs are fairly representative of the whole range of LCPs.
Where they differ, this indicates that

iii) A sizeable share of SO_2 emissions are released from other (non-electricity-generating) LCPs;
iv) The trend in SO_2 emissions from LCPs producing electricity and other LCPs has differed between 2004 and 2015.

For example, in the Netherlands in 2015 only 44% of fuel burned in all LCPs was used to generate electricity, so other (non-electricity-generating) LCPs may have been more important in affecting the changes in emission factor from all LCPs for SO_2.

2.3.4 Results from selected countries

Slovenia

Slovenia saw a 96% reduction in SO_2 emissions from electricity-generating LCPs between 2004 and 2015, largely driven by the 91% contribution of improvements in the SO_2 emission factor. As can be seen in

Figure 15, a large proportion of this change occurred between 2004 and 2006.

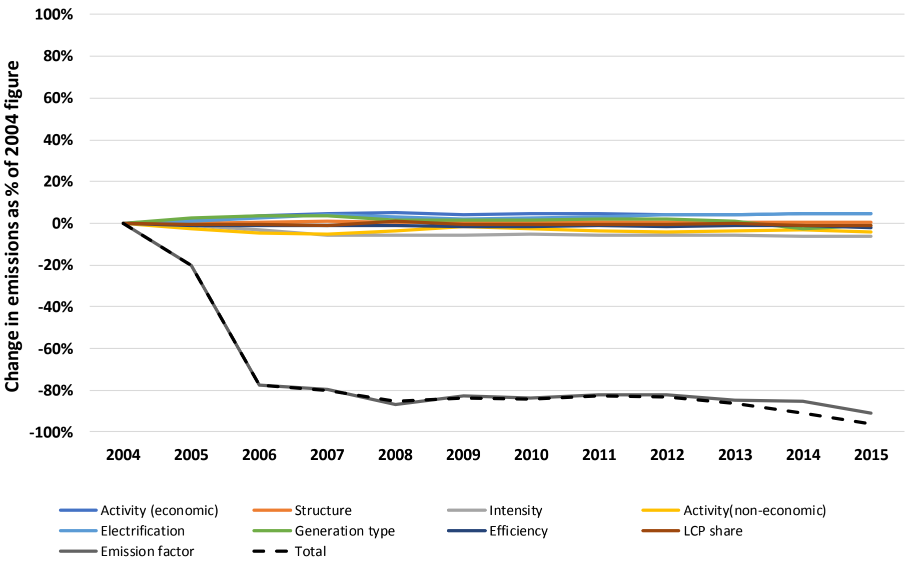


FIGURE 15. CUMULATIVE CONTRIBUTION OF THE EFFECTS OF EACH FACTOR TO CHANGES IN SO_2 EMISSIONS IN SLOVENIA BETWEEN 2004 AND 2015, AS A PERCENTAGE OF 2004 EMISSIONS.

The change was virtually entirely driven by a change in the national-level implied emission factor for "other solid fuels" in electricity-generating LCPs, reducing from 0.68 t/TJ in 2004 to 0.04 t/TJ in 2015 (Figure 16).

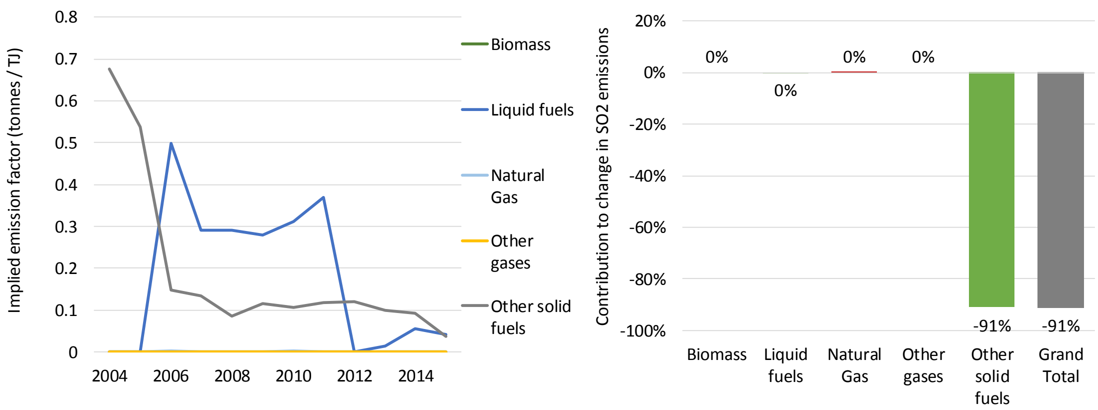


FIGURE 16. CHANGE IN THE AVERAGE SO_2 IMPLIED EMISSION FACTOR BY FUEL TYPE FOR ELECTRICITY-GENERATING LCPS IN SLOVENIA, 2004-2015 (LEFT). EFFECT ON SO_2 EMISSIONS BY FUEL TYPE FROM ELECTRICITY-GENERATING LCPS OVER THE SAME PERIOD (RIGHT). NOTE THAT ONLY SINGLE-FUEL LCPS WERE USED IN THE CALCULATION OF IMPLIED EMISSION FACTORS.

Finland

In Finland, shifts in the energy mix of electricity consumption had a larger effect on SO_2 emissions reduction from electricity-generating LCPs than did changes in emission factors (Figure 17).

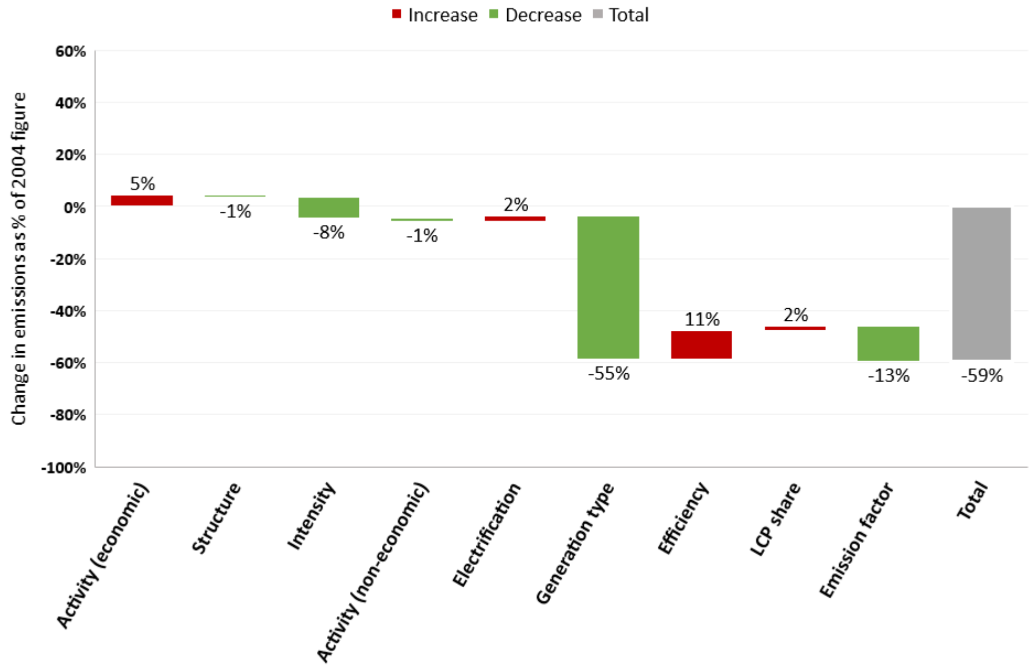


FIGURE 17. CONTRIBUTION OF EACH FACTOR IN THE DETAILED DECOMPOSITION TO CHANGES IN EMISSIONS OF SO_2 BETWEEN 2004-2015 IN FINLAND, AS A PERCENTAGE OF 2004 EMISSIONS, FOR ELECTRICITY-GENERATING LCPS.

The main driver of this effect is the reduction in "other solid fuels" use in electricity production (Figure 18, right), contributing a 52% reduction in Finnish SO_2 emissions. Between 2004 and 2015, "other solid fuels" burning reduced from 25% to 10% of fuel burning in electricity production. However, this was not offset by increases in other combustible fuels, whose share overall fell from 53% to 31% of electricity production. Rather, the share of non-biomass renewables, nuclear power stations and imports from other countries increased, from 47% to 69% over the same period (Figure 18, left).

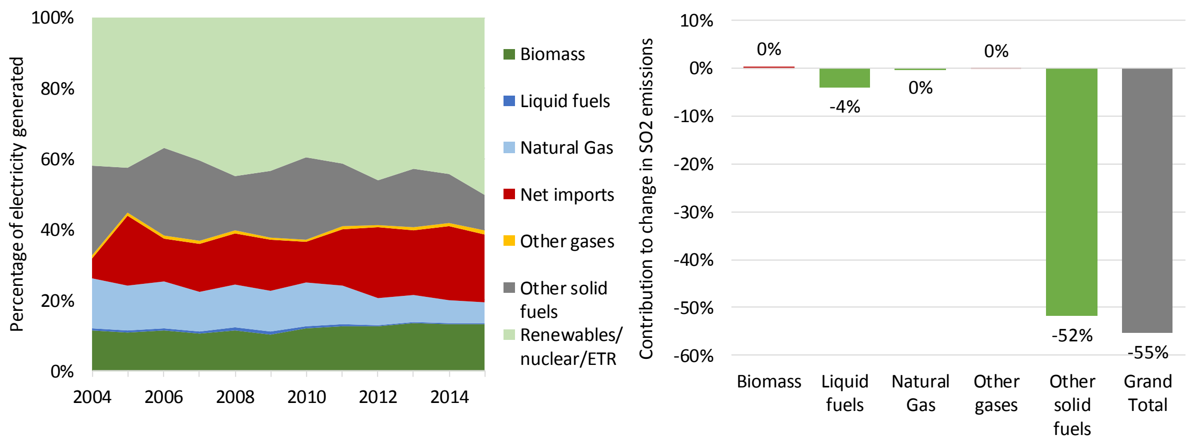


FIGURE 18. PROPORTION OF ELECTRICITY GENERATED BY SOURCE (LEFT) AND EFFECT OF CHANGES IN THIS BETWEEN 2004 AND 2015 ON SO_2 EMISSIONS IN FINLAND.

2.4 NO_x

2.4.1 *EU-28 level decomposition* of NO_x emissions

As in the decomposition of SO_2 emissions, change in the emission factor was the most important influence on changes in NO_x emissions from electricity-generating LCPs at the EU-28 level between 2004 and 2015 (Figure 19), contributing a 38% decrease in emissions relative to 2004. Changes in the mix of electricity generation types contributed the second largest reduction (15%) in emissions.
However, the emission factor effect was in general much smaller for NO_x than for SO_2, and so other effects had a relatively larger contribution to the net reduction in emissions calculated in the decomposition analysis.

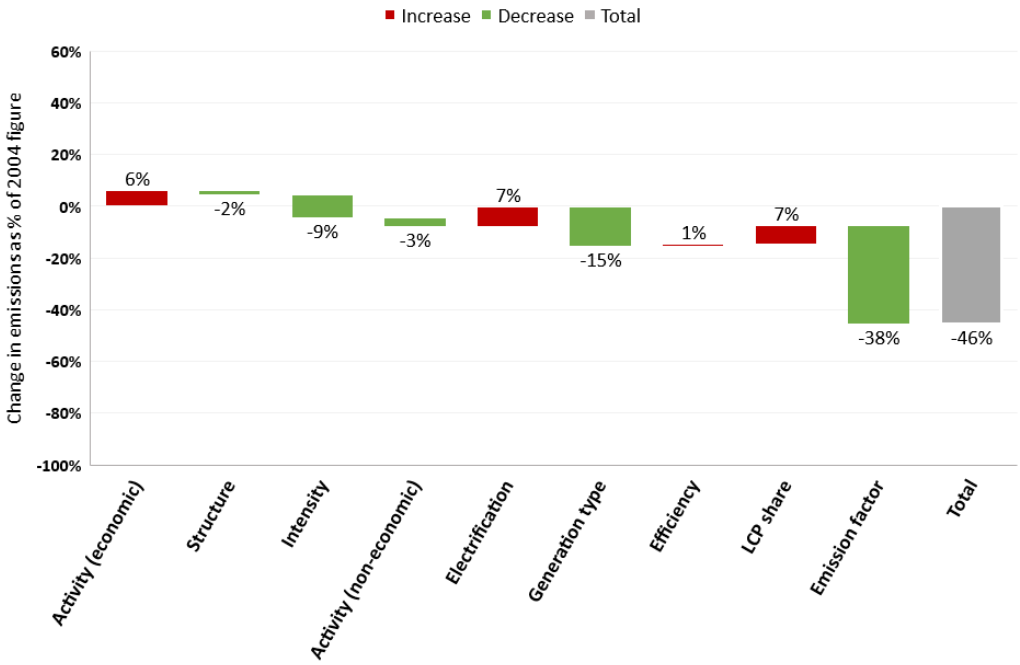


Figure 19. Contribution of each factor in the detailed decomposition to changes in emissions of NO_x between 2004-2015, as a percentage of 2004 emissions, for electricity-generating LCPs.

The effect of improvements in emissions factors evolved steadily over the period studied at the EU-28 level (Figure 20), with no sudden jumps from one year to the next (as seen, for example for Slovenia's SO_2 emission factor in

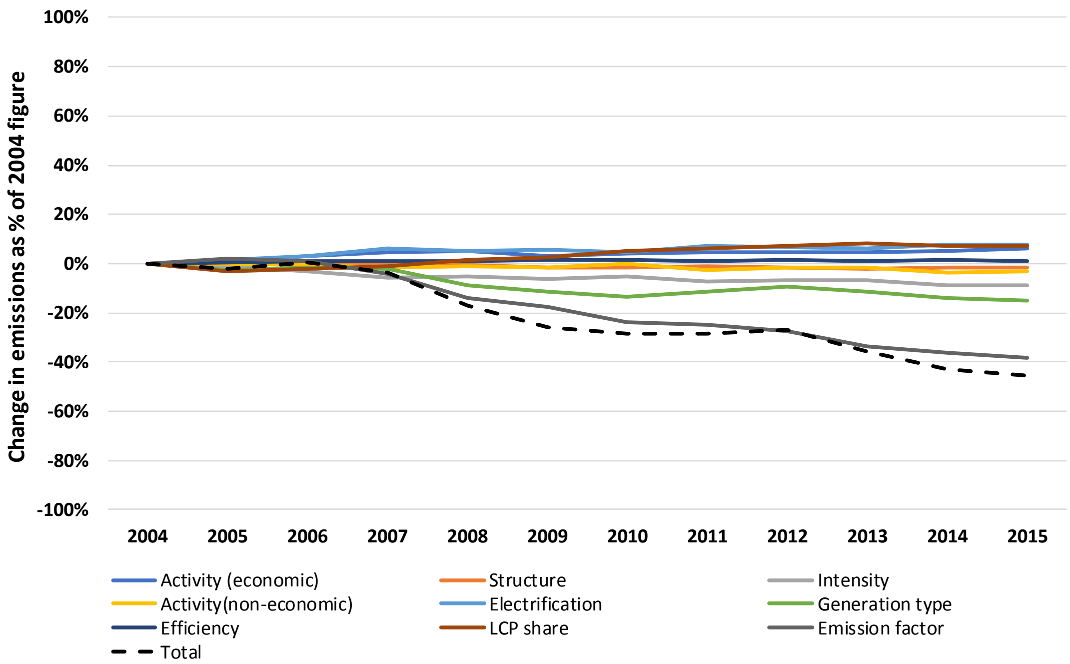


Figure 15).

FIGURE 20. CUMULATIVE CHANGE IN NO_x EMISSIONS FOR THE EU-28 FROM 2004 - 2015 ATTRIBUTABLE TO EACH COMPONENT.

As for SO_2, once again the reduction in the NO_x emission factor for "other solid fuels" was the key driver of the overall emission factor contribution (35.1% of a total 38.2% reduction), although changes in the natural gas emission factor were also important. The "other solid fuels" implied emission factor for NO_x fell by 42% from 0.18 t/TJ in 2004 to 0.1 t/TJ in 2015 (Figure 21).

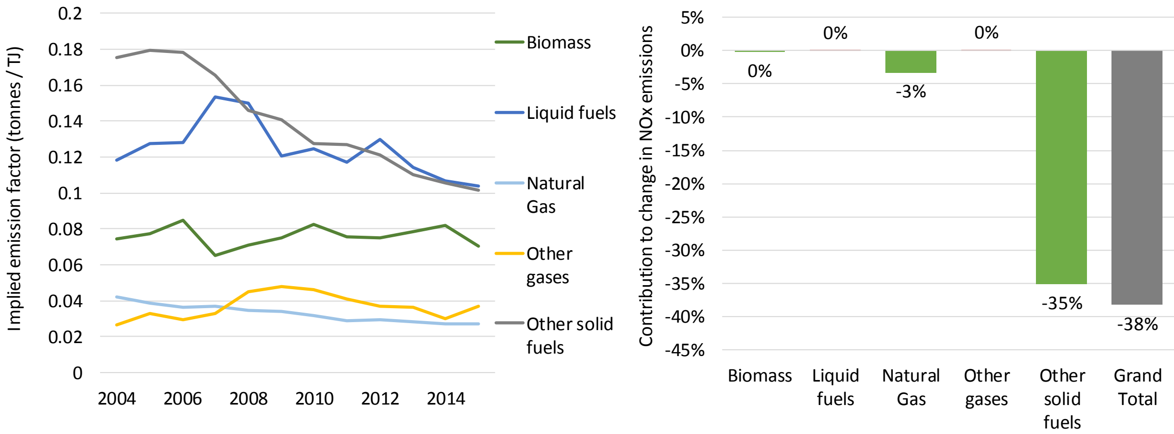


FIGURE 21. CHANGE IN THE AVERAGE NO_X IMPLIED EMISSION FACTOR BY FUEL TYPE ACROSS THE EU-28, 2004-2015 (LEFT), AND EFFECT OF CHANGES ON OVERALL NO_X EMISSIONS OVER THE SAME PERIOD (RIGHT). NOTE THAT ONLY SINGLE-FUEL LCPS WERE USED IN THE CALCULATION OF IMPLIED EMISSION FACTORS.

This reduction in the NO_x emission factor from “other solid fuels” is substantially less than the 76% improvement in SO_2 emission factor for “other solid fuels” seen over the same period (Figure 12). As discussed for SO_2 emissions, several underlying factors may have contributed to the reduction in the EU-level implied NO_x emission factor from electricity-generating LCPs, which cannot be resolved using the macro-level analysis results alone. Analysis of data from individual LCPs is required to bring greater insight, which is discussed in sections ¤ and 3.

2.4.2 Member State level decomposition of NO_x emissions

Table 2 shows the variation seen in the results of the decomposition of NO_x emissions from electricity-generating LCPs among member states. In general, there was less variation between Member States in the size of the emission factor effect among member states than was the case for SO_2 emissions (in Table 2). This may reflect the fact that NO_x emission factors are more equal among fuel types than are SO_2 emission factors (contrast Table 1 and Table 2), so are less dramatically affected by differences in the fuel mix used in LCPs between countries.

In several countries the emission factor effect contributed more than a 50% decrease in NO_x emissions between 2004 and 2015 (IE, NL, BG, LV), whereas in Cyprus, Denmark and Finland only small emission factor effects were seen (-5%, -4% and -5% respectively).

In Germany, changes in the national-level NO_x emission factor contributed a 3% increase to emissions from electricity-generating LCPs, and in Croatia and Sweden a 42% and 64% increase in emissions respectively. In the case of Sweden, this large percentage change results from generally very low NO_x emissions throughout the period, associated with the small but fluctuating quantity of liquid fuels burned in electricity-producing LCPs. Therefore, the large positive percentage change for Sweden does not represent a major issue.

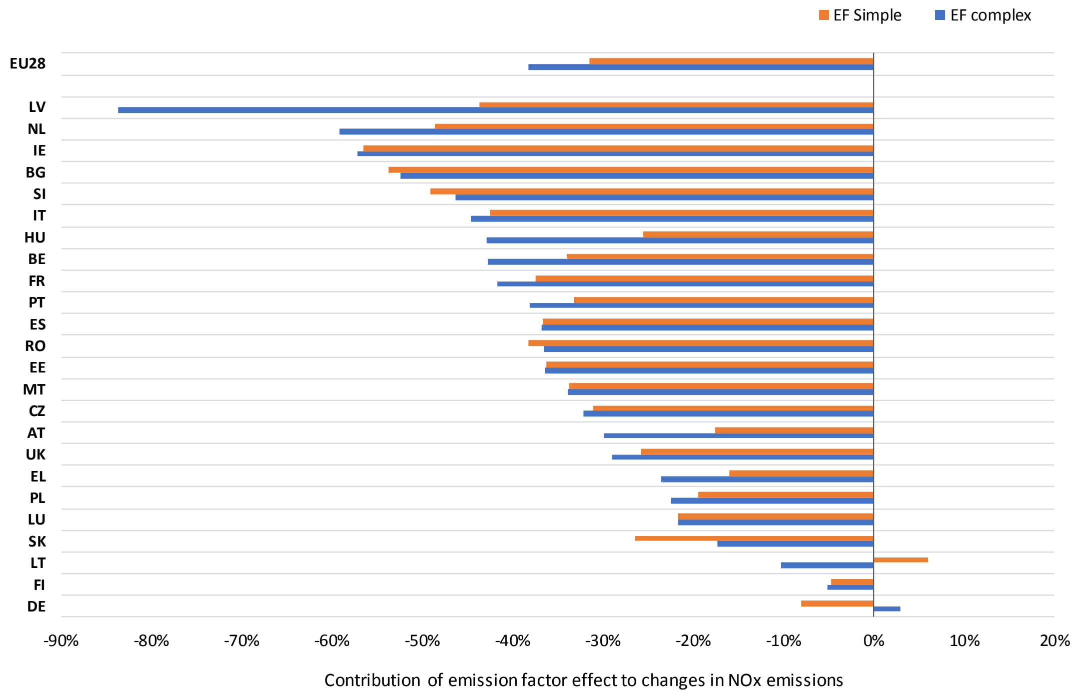
TABLE 2. RESULTS OF THE DETAILED MACRO-LEVEL DECOMPOSITION OF NO_X EMISSIONS FOR INDIVIDUAL MEMBER STATES. EFFECTS OF EACH FACTOR ON NO_X EMISSIONS CHANGES ARE EXPRESSED AS A PERCENTAGE OF 2004 EMISSIONS, EXCEPT FOR SWEDEN (2007), CYPRUS (2009) AND DENMARK AND CROATIA (2010).

	Activity effect (economic sectors)	Structure effect	Intensity effect	Activity effect (non-economic sectors)	Electricity share effect	Generation type	Efficiency effect	LCP share effect	Emission factor	Total
EU28	6%	-2%	-9%	-3%	7%	-15%	1%	7%	-38%	-46%
AT	9%	-2%	-6%	3%	6%	-66%	28%	48%	-30%	-9%
BE	7%	0%	-6%	-6%	6%	-8%	7%	-12%	-43%	-55%
BG	12%	1%	-19%	7%	11%	7%	-8%	-6%	-52%	-45%
CZ	10%	2%	-20%	-2%	11%	-14%	2%	-5%	-32%	-50%
DE	10%	1%	-8%	3%	1%	-11%	0%	25%	3%	23%
EE	8%	1%	-10%	-1%	9%	-16%	11%	-13%	-36%	-47%
EL	-8%	-6%	4%	-8%	18%	-33%	0%	2%	-24%	-55%
ES	6%	-3%	-7%	3%	7%	-35%	4%	-3%	-37%	-64%
FI	4%	-2%	-8%	-2%	3%	-51%	11%	5%	-5%	-45%
FR	4%	-2%	-7%	-6%	9%	-38%	13%	-7%	-42%	-75%
HU	5%	0%	-9%	-1%	12%	-32%	-9%	6%	-43%	-71%
IE	15%	0%	-17%	0%	10%	-26%	-6%	14%	-57%	-68%
IT	-1%	-2%	-5%	0%	7%	-17%	0%	-2%	-45%	-65%
LT	11%	0%	-10%	-63%	9%	56%	-28%	-3%	-10%	-37%
LU	15%	-13%	-6%	3%	5%	-58%	7%	-13%	-22%	-82%
LV	10%	-2%	-7%	-7%	15%	45%	-34%	10%	-84%	-54%
MT	27%	-5%	1%	-10%	-11%	-27%	-18%	4%	-34%	-71%
NL	6%	-2%	-10%	-1%	8%	6%	-6%	13%	-59%	-45%
PL	20%	2%	-22%	-6%	12%	-13%	-4%	2%	-22%	-31%
PT	1%	-3%	-1%	-2%	10%	-26%	4%	-17%	-38%	-72%
RO	13%	1%	-27%	5%	18%	-26%	-7%	1%	-36%	-57%
SI	9%	0%	-19%	-3%	13%	-15%	-6%	-2%	-46%	-69%
SK	18%	2%	-21%	-6%	3%	-37%	3%	0%	-17%	-54%
UK	7%	-4%	-9%	-6%	5%	-19%	2%	5%	-29%	-50%
SE	11%	-7%	-8%	24%	-3%	-35%	22%	-30%	64%	37%
CY	-3%	-1%	-2%	-4%	-1%	-6%	-5%	-7%	-5%	-34%
DK	3%	0%	-10%	-11%	8%	-46%	11%	0%	-4%	-49%
HR	-1%	0%	-5%	-7%	9%	-10%	1%	-62%	42%	-35%

The generation type effect was the most important driver of emissions changes for a larger number of countries for NOx than for SO_2, including Austria, Finland, Greece, Luxembourg and Slovakia. This is because the emission factor effect was in general much smaller for NO_x than for SO_2, and so other effects had a relatively larger contribution to the overall reduction in emissions.

2.4.3 How representative are electricity generating LCPs of all LCPs concerning changes in NO_x emissions?

The comparison of NO_x emission factor effects from the detailed and simple decompositions (see section 0 for more information) shows that for the majority of countries, the pattern seen for electricity generating LCPs is quite representative of LCPs as a whole (Figure 22). However, the degree of correspondence between the results of the two decompositions does not seem to be as high for NO_x as was the case for SO_2 (contrast



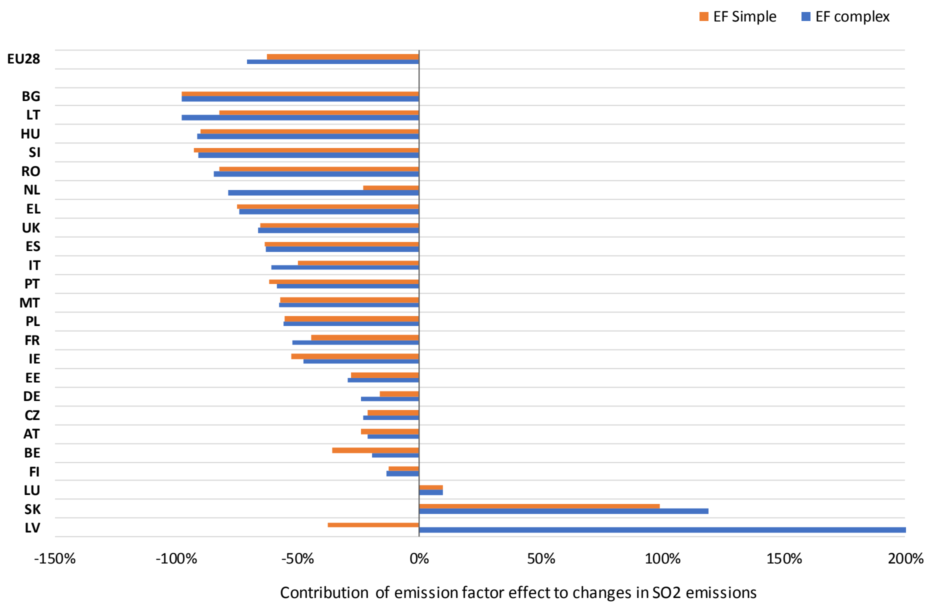


Figure 14 and Figure 22).

FIGURE 22. EMISSION FACTOR EFFECTS ON NO_x EMISSIONS BETWEEN 2004 AND 2015, FROM THE DETAILED DECOMPOSITION OF ELECTRICITY-GENERATING LCPS (BLUE), AND SIMPLE DECOMPOSITION OF ALL LCPS (ORANGE), AS A PERCENTAGE OF 2004 EMISSIONS.

Austria, Latvia, Germany, Hungary and Lithuania are the countries with the greatest discrepancy; all are countries with a relatively low proportion of LCPs producing electricity. In these Member States, other (non electricity-generating) LCPs, with differing trends in emission factors, may have been important in affecting the changes in NO_x emission factor from all LCPs.

2.4.4 Results from selected countries

Ireland

Between 2004 and 2015, Ireland was one of the countries having the largest decrease in NO_x emissions attributable to changes in emissions factors (in Table 2), of 57%, in addition to a substantial (26%) decrease due to changes in the generation type. This resulted in a 68% overall decrease in NO_x emissions, in spite of a sizeable increase in emissions (15%) contributed by economic growth in Ireland over the period.

Examining these effects over time (Figure 23), the majority of the change in emissions due to the emission factor effect occurred between 2007 and 2011, with the most rapid impact occurring between 2007 and 2009. Emission reductions due to shifts in generation type occurred slightly earlier, with the most rapid changes lying between 2005 and 2007.

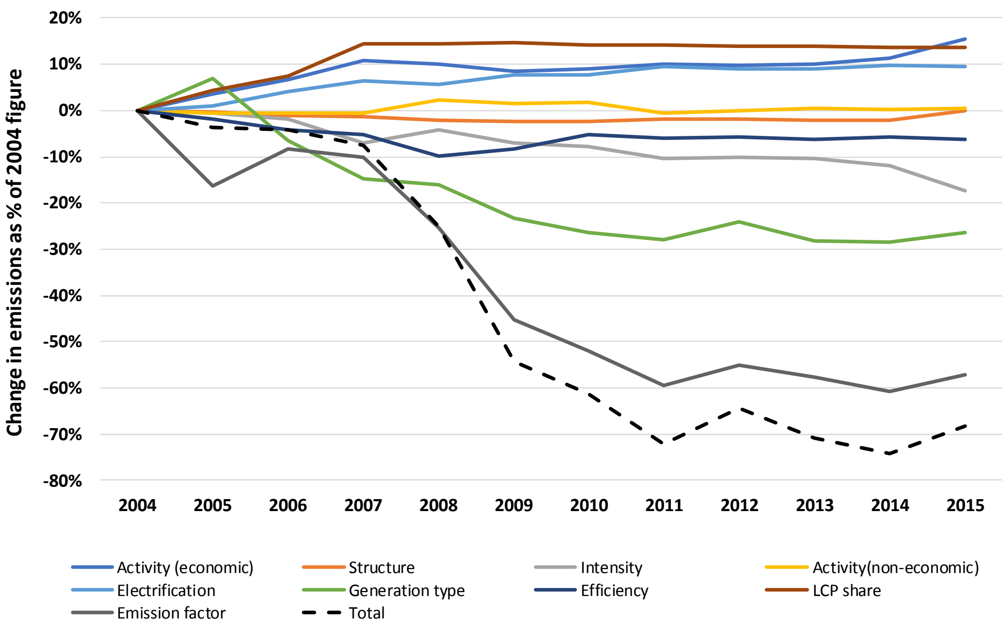


FIGURE 23. CUMULATIVE CHANGE IN NO_x EMISSIONS FROM ELECTRICITY-GENERATING LCPS IN IRELAND FROM 2004 - 2015 ATTRIBUTABLE TO EACH COMPONENT.

Figure 24 shows how changes in the emission factors for individual fuel types have contributed to the overall NO_x emission factor effect. The improvement in the "other solid fuels" emission factor from 0.33 to 0.10 t/TJ contributed the most significant reduction in NO_x emissions between 2004 and 2015, of 48%, followed by natural gas which contributed an 11% decrease.

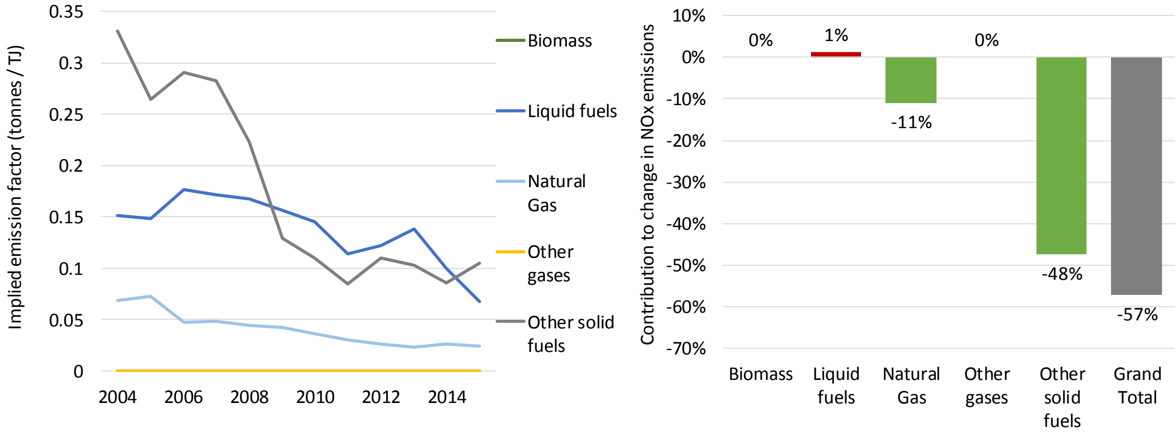


FIGURE 24. CHANGE IN THE AVERAGE NO_x IMPLIED EMISSION FACTOR BY FUEL TYPE IN IRELAND, 2004-2015 (LEFT), AND EFFECT OF CHANGES ON OVERALL NO_x EMISSIONS OVER THE SAME PERIOD (RIGHT). NOTE THAT ONLY SINGLE-FUEL LCPS WERE USED IN THE CALCULATION OF IMPLIED EMISSION FACTORS.

Figure 25 delves deeper into the drivers of the relatively large reduction in NO_x emissions from electricity-generating LCPs contributed by a shift in electricity generation type between 2004 and 2015. In contrast to the emission factor effect, the generation type effect is mainly driven by the large reduction in the share of liquid fuels burnt in electricity generation, from 12% in 2004 to around 1% from 2011 onwards.

This reduction in liquid fuel use contributed an 18% reduction in NO_x emissions from electricity-generating LCPs between 2004 and 2015. The reduction in the share of "other solid fuels" was also important, contributing a 9% decrease.

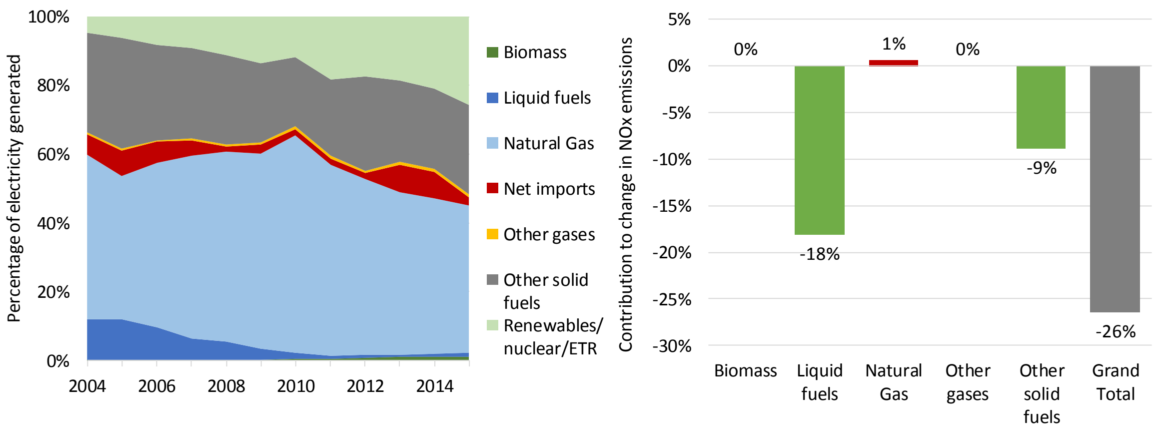


FIGURE 25. PROPORTION OF ELECTRICITY GENERATED BY SOURCE (LEFT) AND EFFECT OF CHANGES IN THIS BETWEEN 2004 AND 2015 ON NO_x EMISSIONS FROM ELECTRICITY-GENERATING LCPS IN IRELAND.

Germany

Germany is an unusual Member State, in that it was the only one to see an increase in NO_x emissions attributable to changes in the emission factor effect. Until 2011, the emission factor effect had a slightly negative effect on emissions (Figure 26; dark grey line), but between 2011 and 2013 caused an increase in emissions. Additionally, the LCP share of fuel burned in electricity production increased sharply between 2009 and 2012, causing an overall increase in NO_x emissions from electricity-generating LCPs (dashed line).

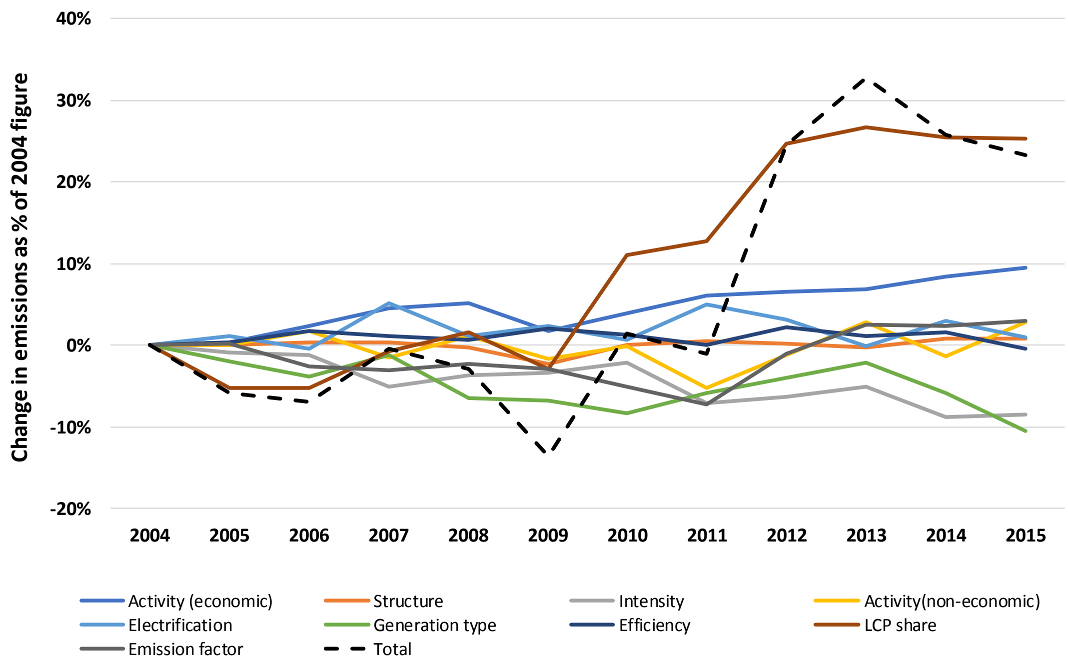


FIGURE 26. CUMULATIVE CHANGE IN NO_x EMISSIONS FROM ELECTRICITY-GENERATING LCPS IN GERMANY FROM 2004 - 2015 ATTRIBUTABLE TO EACH COMPONENT.

The lack of improvement in NO_x emissions from electricity-generating LCPs attributable to the emission factor effect is largely due to the emission factors for all fuel types being already low in 2004, allowing little scope for improvement (Figure 27). For example, the emission factor for “other solid fuels” remained below 0.1 t/TJ across the whole period; a value only obtained in Ireland in 2011 (Figure 24).

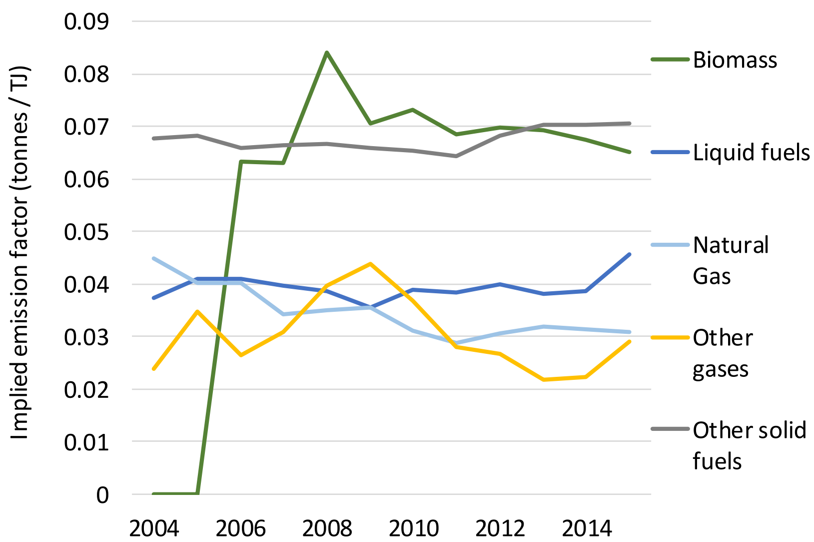


FIGURE 27. NO$_x$ EMISSION FACTORS FOR ELECTRICITY-GENERATING LCPS BY FUEL TYPE IN GERMANY, BETWEEN 2004 AND 2015. NOTE THAT ONLY SINGLE-FUEL LCPS WERE USED IN THE CALCULATION OF IMPLIED EMISSION FACTORS.

Figure 28 breaks down the LCP share effect on NO$_x$ emissions in Germany by fuel type. Although the proportion of both liquid fuels and "other solid fuels" burned in LCPs have increased over time, it is the change for "other solid fuels" which had the largest effect (25% increase) on NO$_x$ emissions from electricity-generating LCPs (Figure 28, right).

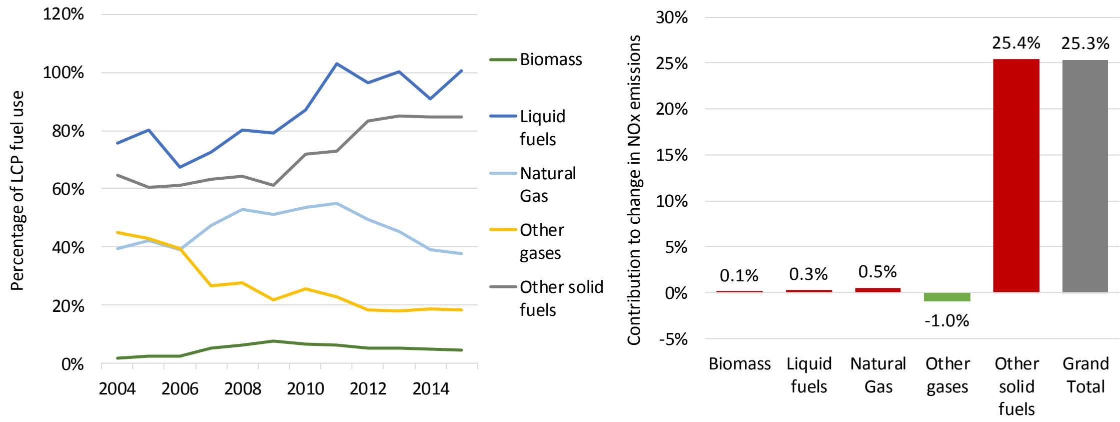


FIGURE 28. CHANGE IN THE PERCENTAGE OF FUEL BURNED FOR ELECTRICITY PRODUCTION WITHIN LCPS BY FUEL TYPE IN GERMANY, 2004-2015 (LEFT), AND EFFECT OF CHANGES ON OVERALL NO$_x$ EMISSIONS OVER THE SAME PERIOD (RIGHT).

2.5 Dust (particulate matter)

2.5.1 *EU-28 level decomposition* of dust emissions

Of the pollutants considered in this study, dust emissions from electricity-generating LCPs at the EU-28 level saw the largest decreases between 2004 and 2015. As was the case for SO_2, improvements in the EU-28 level emission factors were the main driver of falls in dust emissions, contributing a 75% reduction (Figure 29). Shifts in the energy mix of electricity generation also contributed a 12% decrease in emissions from electricity-generating LCPs.

Small positive effects on dust emissions were contributed by changes in economic activity, electrification of final energy use, efficiency of electricity production, and the LCP share of fuel used in electricity production. However, these were more than offset by the combined negative effects of the other factors.

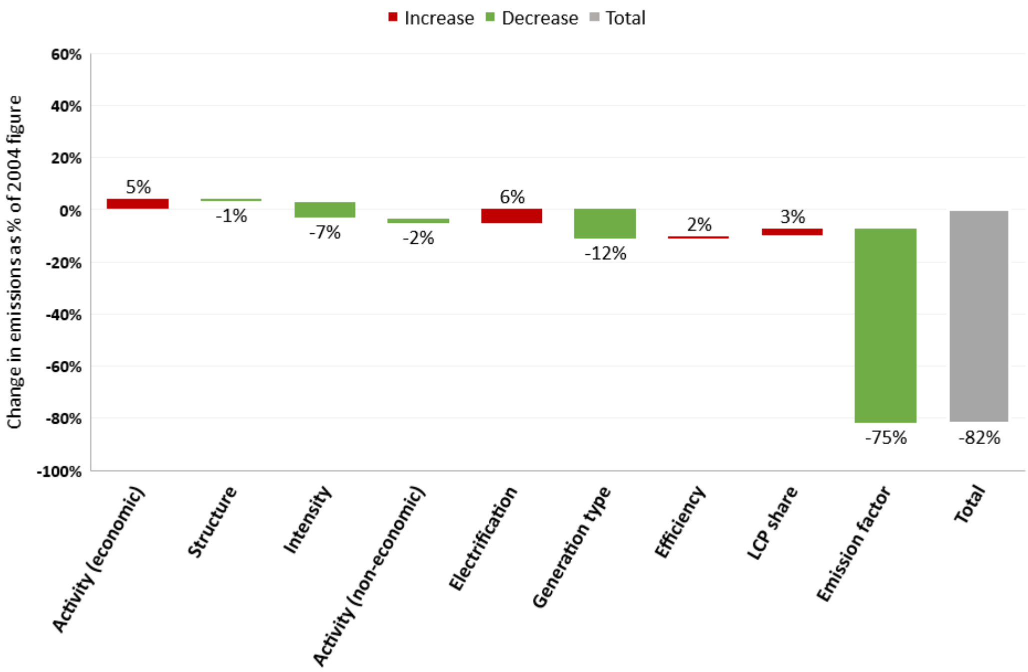


FIGURE 29. CONTRIBUTION OF EACH FACTOR IN THE DETAILED DECOMPOSITION TO CHANGES IN EMISSIONS OF DUST BETWEEN 2004-2015, AS A PERCENTAGE OF 2004 EMISSIONS, FOR ELECTRICITY-GENERATING LCPS.

Figure 30 displays the cumulative change in the contribution of each factor year on year across the period 2004-2015. At the EU level, the contribution of the emission factor effect on dust emissions has increased quite steadily over time, with a slightly larger decrease between 2007 and 2008 than across other time periods.

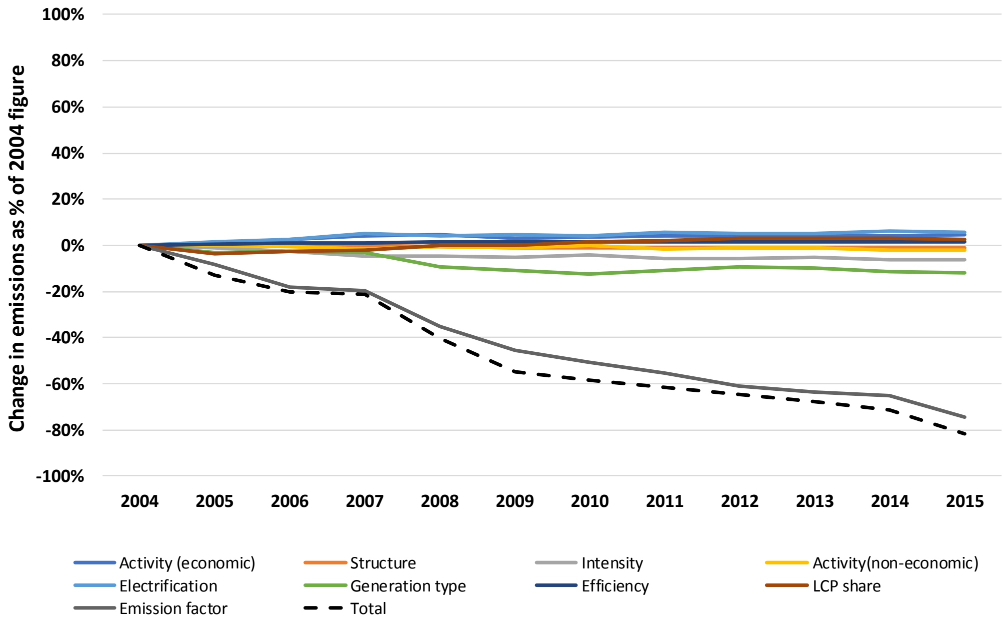


FIGURE 30. CUMULATIVE CHANGE IN DUST EMISSIONS FOR THE EU-28 FROM 2004 - 2015 ATTRIBUTABLE TO EACH COMPONENT.

Breaking down the changes in implied emission factors for dust from electricity-generating LCPs by different fuel types (Figure 31, left), there were substantial decreases in emission factors for "other solid fuels" (largely various types of coal), liquid fuels and biomass, decreasing by 81%, 67% and 58% respectively.

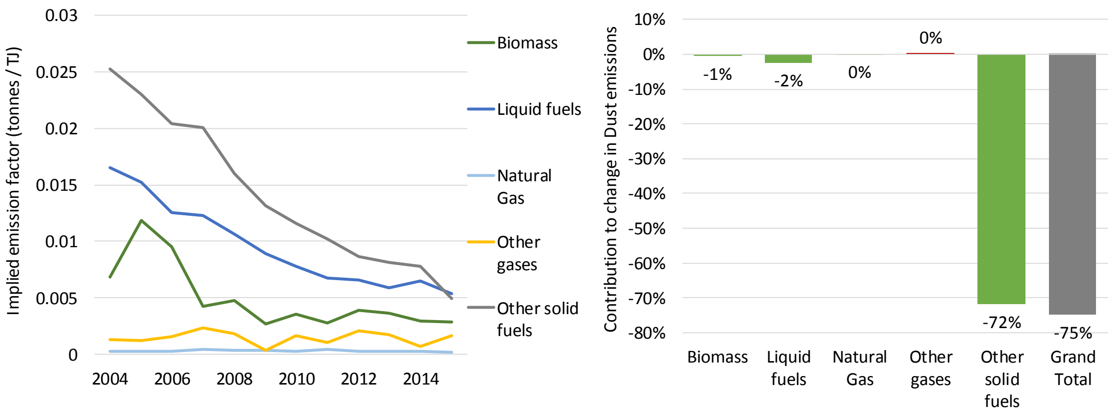


FIGURE 31. CHANGE IN THE AVERAGE DUST IMPLIED EMISSION FACTOR BY FUEL TYPE ACROSS THE EU-28, 2004-2015 (LEFT), AND EFFECT OF CHANGES ON OVERALL DUST EMISSIONS OVER THE SAME PERIOD (RIGHT). NOTE THAT ONLY SINGLE-FUEL LCPS WERE USED IN THE CALCULATION OF IMPLIED EMISSION FACTORS.

Figure 31 (right) shows how these change in dust emission factor translate into their effect on dust emission reductions from electricity-generating LCPs, when the quantities of each fuel type burned are taken into account. It shows that the reduction in the dust emission factor for “other solid fuels” which was by far the most important driver of the overall emission factor effect.

2.5.2 Member State level decomposition of dust emissions

Table 3 shows the results of the decomposition of changes in dust emissions from electricity-generating LCPs for each Member State individually.

Table 3. Results of the detailed macro-level decomposition of dust emissions for individual Member States. Effects of each factor on dust emissions changes are expressed as a percentage of 2004 emissions, except for Sweden (2007), Cyprus (2009) and Denmark and Croatia (2010). Results for Luxembourg and Latvia are removed, due to zero emissions occurring in many years during the period.

	Activity effect (economic sectors)	Structure effect	Intensity effect	Activity effect (non-economic sectors)	Electricity share effect	Generation type	Efficiency effect	LCP share effect	Emission factor	Total
EU28	5%	-1%	-7%	-2%	6%	-12%	2%	3%	-75%	-82%
AT	7%	-1%	-4%	0%	6%	-33%	24%	-12%	-37%	-49%
BE	7%	1%	-3%	-9%	11%	-65%	55%	-73%	-3%	-78%
BG	10%	1%	-14%	6%	8%	8%	-3%	-7%	-103%	-94%
CZ	10%	2%	-20%	-4%	11%	-14%	2%	-2%	-24%	-39%
DE	6%	0%	-5%	2%	1%	-8%	1%	10%	-44%	-37%
EE	12%	1%	-12%	-18%	12%	-20%	17%	-24%	138%	106%
EL	-2%	-3%	3%	-4%	8%	-15%	0%	0%	-80%	-94%
ES	6%	-2%	-6%	4%	6%	-32%	3%	-4%	-59%	-84%
FI	5%	-2%	-11%	-1%	3%	-47%	12%	5%	-27%	-64%
FR	4%	-2%	-7%	-7%	9%	-28%	10%	-9%	-59%	-87%
HU	4%	0%	-4%	1%	4%	-21%	-5%	8%	-68%	-80%
IE	6%	0%	-5%	0%	4%	-18%	-2%	1%	-79%	-94%
IT	-1%	-2%	-4%	0%	6%	-28%	3%	-10%	-43%	-78%
LT	6%	0%	-3%	-60%	2%	113%	-46%	7%	-93%	-76%
LU										
LV										
MT	18%	-3%	-2%	-6%	-2%	-22%	-6%	-2%	-57%	-83%
NL	11%	-4%	-19%	-3%	16%	53%	-5%	20%	-20%	51%
PL	13%	1%	-14%	-4%	7%	-7%	-2%	0%	-66%	-71%
PT	2%	-2%	-1%	-2%	8%	-20%	1%	-36%	-45%	-95%
RO	8%	1%	-16%	4%	10%	-11%	-4%	5%	-90%	-93%
SI	3%	0%	-4%	-2%	3%	-2%	-1%	0%	-91%	-96%
SK	26%	3%	-29%	-9%	5%	-47%	4%	2%	37%	-8%
UK	8%	-4%	-10%	-7%	5%	-23%	3%	2%	-18%	-44%
SE	5%	-6%	-5%	14%	-3%	-29%	-1%	4%	1%	-22%
CY	-2%	-1%	-1%	-3%	-1%	-4%	-4%	-6%	-36%	-58%
DK	3%	0%	-12%	-12%	10%	-45%	9%	4%	-7%	-50%
HR	-1%	0%	-3%	-4%	5%	-16%	-4%	-38%	3%	-59%

For most countries, change in the national-level emission factor is the dominant driver of changes in emissions, having a substantial negative effect between 2004 and 2015. However, this is not the case across the board, with Belgium showing only a small negative emission factor effect, and two countries (Estonia and Slovakia) having positive emission factor effects (Sweden and Croatia are ignored here, as their data is only available from 2007 and 2010 respectively).

For both countries, this may be explained by the relatively small number of single-fuel electricity-generating LCPs from which the implied emission factor is calculated (4 and 1 for SK and EE respectively), causing volatility over time.

As was the case for SO_2, the largest decreases in emission factor were seen in countries where the emission factor in 2004 was relatively high (such as Bulgaria, Greece, Ireland and Romania), leaving scope for significant reduction (

Figure 32).

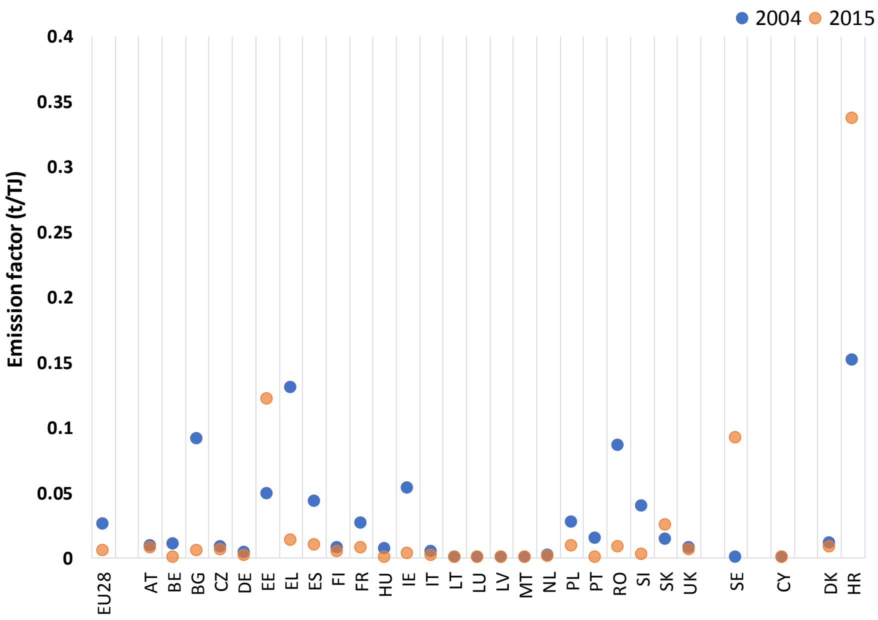


FIGURE 32. DUST IMPLIED EMISSION FACTORS IN 2004 (2007, 2009 AND 2010 FOR SE, CY AND DK AND HR RESPECTIVELY) AND IN 2015 BY COUNTRY, FROM BURNING “OTHER SOLID FUELS” IN ELECTRICITY-GENERATING LCPS. NOTE THAT ONLY SINGLE-FUEL LCPS WERE USED IN THE CALCULATION OF IMPLIED EMISSION FACTORS.

The magnitude and direction of the generation type effect on dust emissions also varied between countries, and had substantial effects in some cases. The largest reduction in emissions contributed by shifts in the generation type occurred in Belgium, at a 65% decrease. At the other end of the scale, in the Netherlands (see case study later in this section) and Lithuania the generation type effect contributed 53% and 113% increases in dust emissions.

Note that the results for Luxembourg and Latvia have been removed, because the dust emissions from these countries were so low that even very small absolute changes resulted in enormous percentage changes, which are not comparable with the results from other countries.

2.5.3 Comparison of results from detailed and simple decompositions

Figure 33 below displays graphically the comparison between the dust emission factor effects from the detailed and simple decompositions (see section 0 for more information). It shows that, as for the other pollutants, for the majority of countries the pattern seen for electricity generating LCPs is quite representative of LCPs as a whole, driving emissions in the same direction and with about the same magnitude.

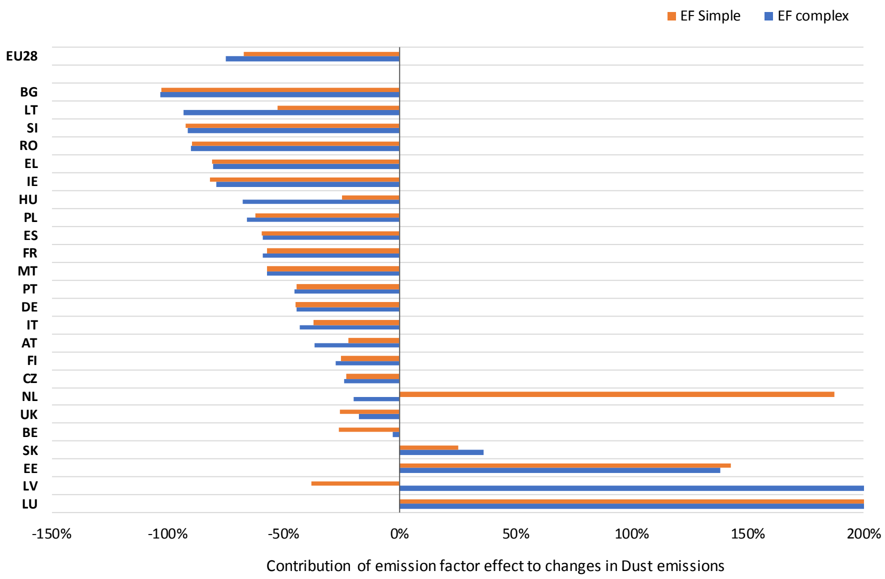


FIGURE 33. EMISSION FACTOR EFFECTS ON DUST EMISSIONS BETWEEN 2004 AND 2015, FROM THE DETAILED DECOMPOSITION OF ELECTRICITY-GENERATING LCPS (BLUE), AND SIMPLE DECOMPOSITION OF ALL LCPS (ORANGE), AS A PERCENTAGE OF 2004 EMISSIONS.

The obvious exceptions to this are the results from the Netherlands and Latvia. As mentioned above, the results from Latvia can be disregarded as dust emission from electricity-generating LCPs were zero or extremely low in most years of the time series. Results for the Netherlands will be discussed in the next section.

2.5.4 *Results from selected countries*

Belgium

Belgium has been chosen as an example due to the very large (65%) reduction in dust emissions from electricity-generating LCPs contributed by shifts in the energy mix of electricity generation (**Table 3**).

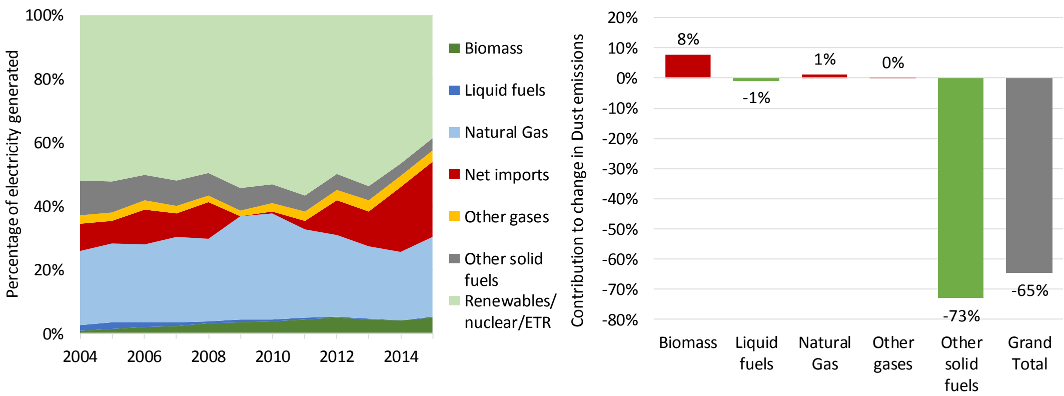


Figure 34 shows how the energy mix in electricity generation in Belgium evolved between 2004 and 2015, and the effect this has had on dust emissions over the same period. The reduction in the share of “other solid fuels” from 11% to 4% of generation had by far the largest impact on emissions reductions (73% reduction). This was slightly offset by an increase in biomass and natural gas burning, together contributing a 9% increase in dust emissions.

The remainder of the decrease in “other solid fuels" use was offset by an increase in the share of electricity imports in the energy mix.

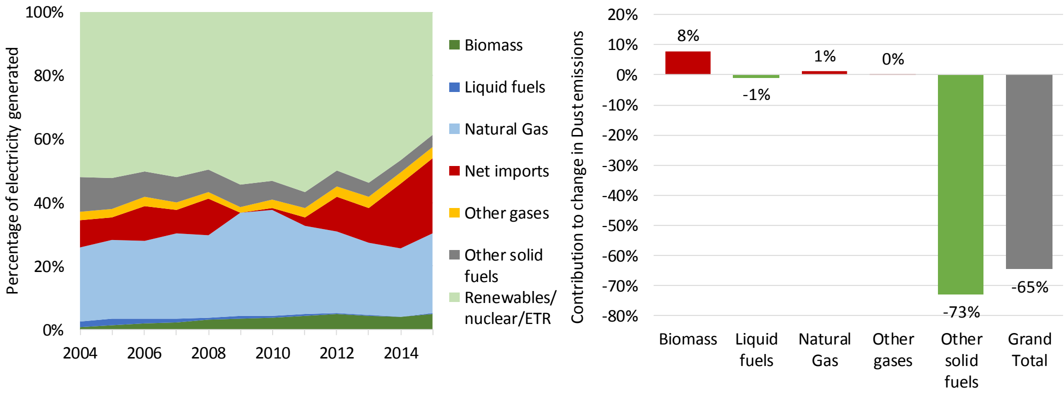


FIGURE 34. PROPORTION OF ELECTRICITY GENERATED BY SOURCE (LEFT) AND EFFECT OF CHANGES IN THIS BETWEEN 2004 AND 2015 ON DUST EMISSIONS FROM ELECTRICITY-GENERATING LCPS IN BELGIUM.

Netherlands

The Netherlands was chosen as an example to study in further detail here due to the large positive effect on dust emissions from electricity-generating LCPs (53%; Table 3) contributed by shifts in the energy mix of electricity production between 2004 and 2015.

Considering the cumulative impact of factors in the decomposition over time, the generation type effect only begins to contribute to an increase in dust emissions from 2013 onwards (Figure 35).

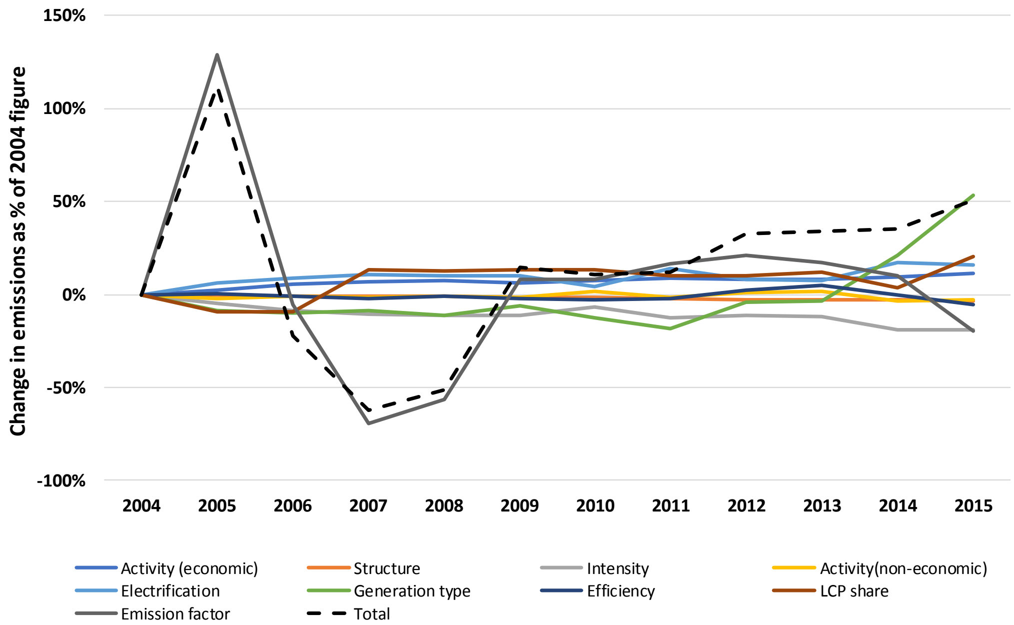


FIGURE 35. CUMULATIVE CHANGE IN DUST EMISSIONS FROM ELECTRICITY-GENERATING LCPS IN THE NETHERLANDS FROM 2004 - 2015 ATTRIBUTABLE TO EACH COMPONENT.

Figure 36 provides more insight into the causes of this trend. The underlying reason for the increase in emissions due to the generation type effect was a rise in the share of “other solid fuels” used in electricity-production, from 19% in 2011 to 34% in 2015. This was responsible for almost all of the combined generation type effect.

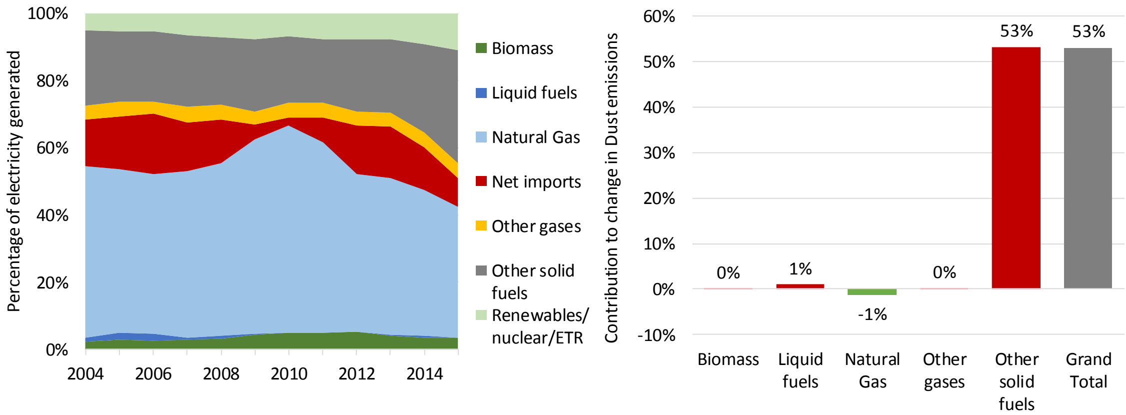


FIGURE 36. PROPORTION OF ELECTRICITY GENERATED BY SOURCE (LEFT) AND EFFECT OF CHANGES IN THIS BETWEEN 2004 AND 2015 ON DUST EMISSIONS FROM ELECTRICITY-GENERATING LCPS IN THE NETHERLANDS.

The increase in “other solid fuels” share of electricity production between 2011 and 2015 was balanced by a similar reduction in the share of natural gas burning over the same period.

2.6 CO_2

2.6.1 EU-28 level decomposition of CO_2 emissions

In contrast to the other pollutants, changes in emission factor were not the most important driver of changes in CO_2 emissions from electricity-generating LCPs over the period 2004-2015 (

Figure 37). This is a necessary limitation of the methodology; due to the lack of reported actual CO_2 emissions from LCPs, a constant set of default IPCC emission factors was used for the entire period.

Consequently, the changes in CO_2 emissions are estimates based on the changes in fuel usage. Under these assumptions, CO_2 emissions from electricity-generating LCPs reduced by 6.4% at the EU-28 level over the period 2004-2015. The most important drivers of the reductions were shifts in the electricity generation type, and sectoral energy intensity, contributing 17% and 11% reductions respectively. Note that CO_2 emissions from burning biomass and other biofuels are included in these estimates (i.e. emissions are those leaving the LCP), because it is not possible to split some of the aggregated fuel types reported in the LCP database into carbon-neutral and non-carbon-neutral components.

These negative effects were partially offset by emissions increases contributed by changes in economic activity, the degree of electrification, and the LCP share of fuel burned for electricity production.

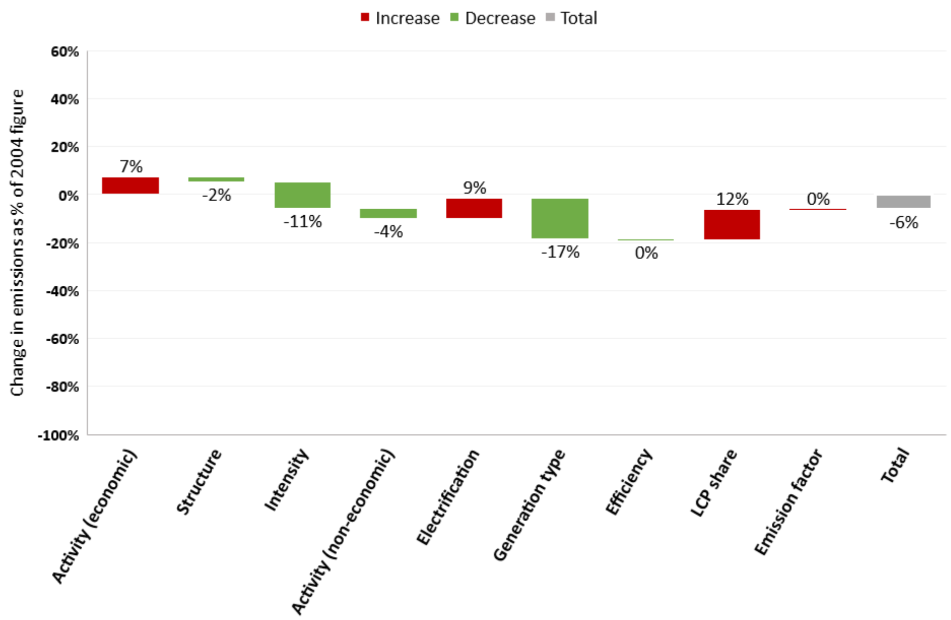


FIGURE 37. CONTRIBUTION OF EACH FACTOR IN THE DETAILED DECOMPOSITION TO CHANGES IN EMISSIONS OF CO_2 BETWEEN 2004-2015, AS A PERCENTAGE OF 2004 EMISSIONS, FOR ELECTRICITY-GENERATING LCPS.

Figure 38 shows the cumulative effect of these factors year-on-year from 2004-2015. It shows that the emissions reductions due to shifts in the generation type occurred in two phases, between 2007 and 2010, then again between 2012 and 2015. The largest positive effect on emissions - increases in the LCP share of fuel burned for electricity production - increased most rapidly between 2005 and 2010, then flattened-off after that point.

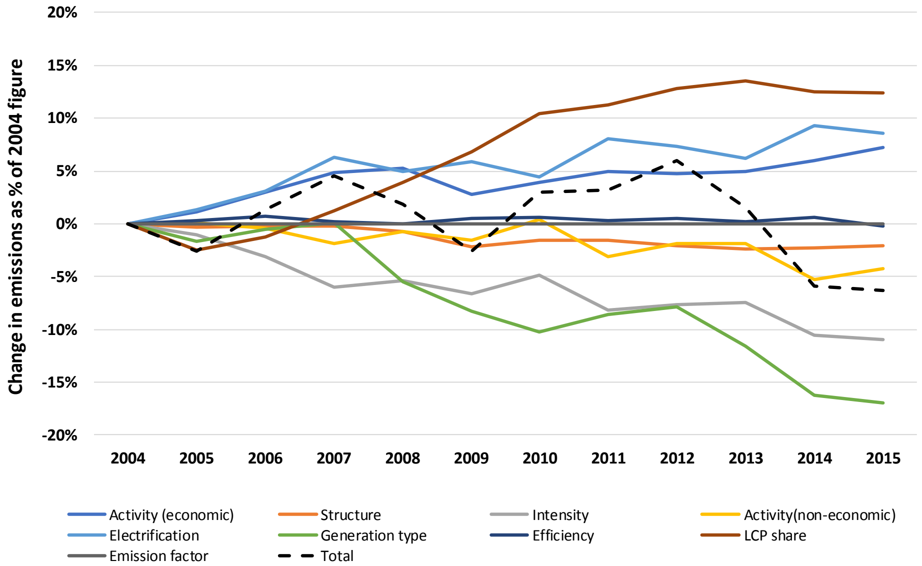


FIGURE 38. CUMULATIVE CHANGE IN CO_2 EMISSIONS FOR THE EU-28 FROM 2004 - 2015 ATTRIBUTABLE TO EACH COMPONENT. NOTE THAT THE Y-AXIS IN THIS FIGURE COVERS A MUCH SMALLER RANGE THAN FOR THE OTHER POLLUTANTS, SO DIFFERENCES OVER TIME ARE VISIBLE.

Breaking down the generation type effect further,

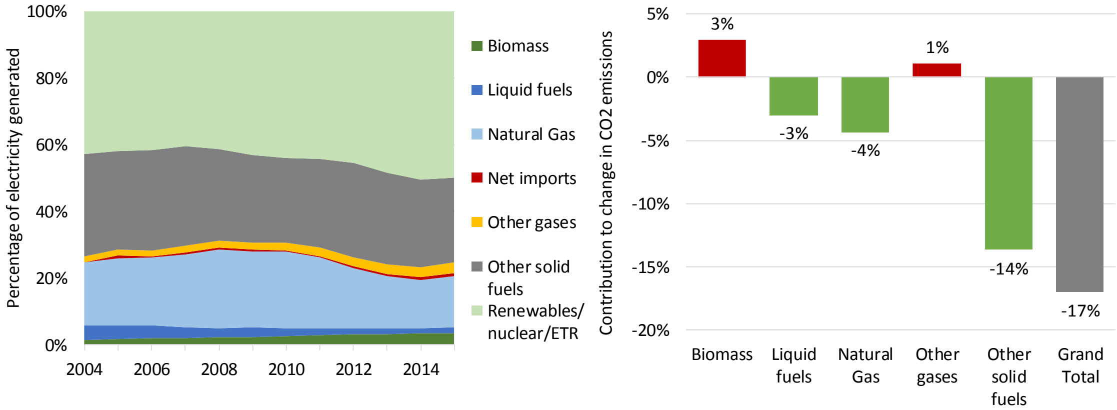


Figure 39 (right) shows that a fall in the share of "other solid fuels" in electricity production is responsible for the largest decrease in CO_2 emissions from electricity-generating LCPs (of 14%) , followed by decreases in natural gas and liquid fuel usage. Increases in the share of biomass and other gases contributed slight increases in CO_2 emissions which partially offset the decreases in other fuel types (although in reality, emissions from biomass burning may be discounted). However, as described in section 2.2.1 there was an overall reduction in the share of combustible fuels in electricity generation from 57% to 49% of the total between 2004 and 2015, and a corresponding increase in the share generated from non-biomass renewable sources and nuclear power.

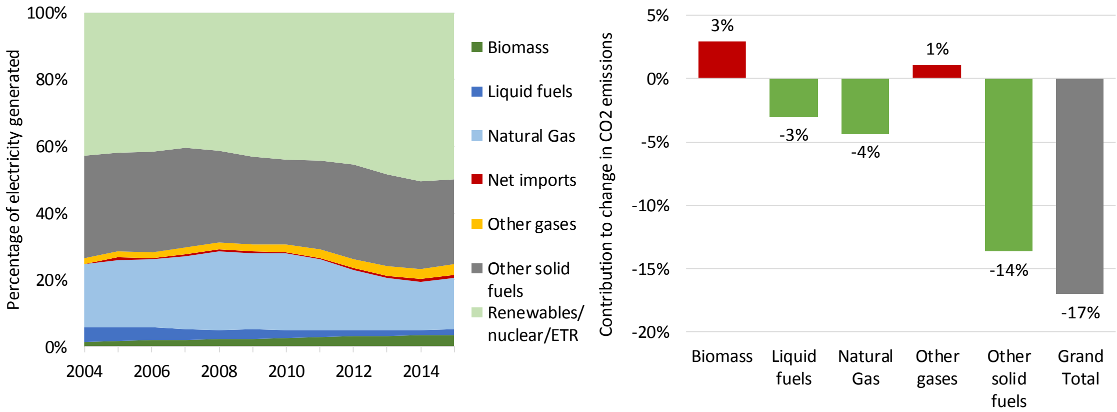


FIGURE 39. SHARE OF DIFFERENT ENERGY SOURCES IN ELECTRICITY GENERATION IN THE EU FROM 2004 TO 2014 (LEFT), AND THE IMPACT OF CHANGES IN EACH FUEL TYPE SHARE ON CO_2 EMISSIONS OVER THE SAME PERIOD (RIGHT), AS A PERCENTAGE OF 2004 EMISSIONS.

The LCP share effect contributed the largest increases in CO_2 emissions at the EU level out of all the factors. Figure 40 breaks down this effect by fuel type, showing that changes in the LCP share of natural gas and "other solid fuels" had the largest impact, increasing emissions from electricity-generating LCPs by 6.2% and 5.3% respectively.

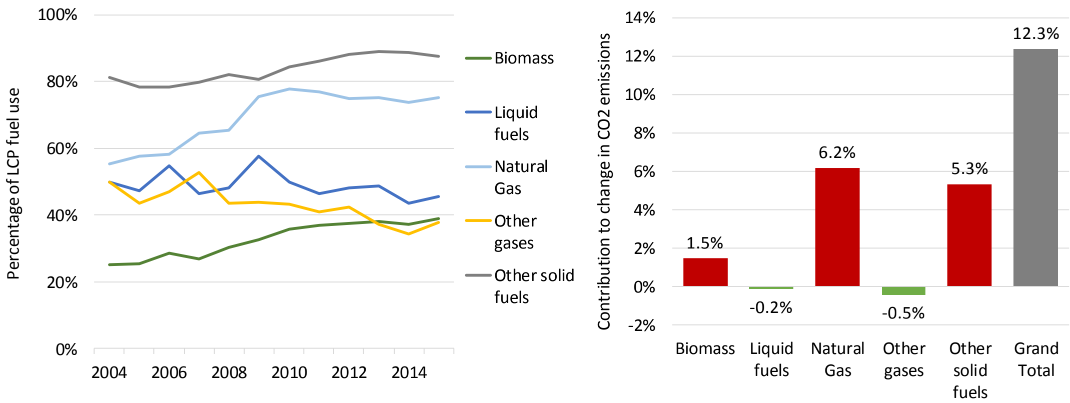


FIGURE 40. THE PERCENTAGE OF FUEL USED IN ELECTRICITY PRODUCTION WHICH IS BURNED IN LCPS, BY FUEL TYPE AT THE EU LEVEL BETWEEN 2004 AND 2015 (LEFT), AND THE EFFECT CHANGES IN THIS HAD ON CO_2 EMISSIONS OVER THE SAME PERIOD (RIGHT).

However, there are data quality caveats which must be borne in mind when interpreting the LCP share effect, which are discussed in more depth above in section 2.2.1.

2.6.2 Member State level decomposition of CO_2 emissions

Table 4 shows the results of the decomposition of CO_2 emissions from electricity-generating LCPs between 2004 and 2015 for individual countries.

TABLE 4. RESULTS OF THE DETAILED MACRO-LEVEL DECOMPOSITION FOR INDIVIDUAL MEMBER STATES. EFFECTS OF EACH FACTOR ON CO_2 EMISSIONS CHANGES ARE EXPRESSED AS A PERCENTAGE OF 2004 EMISSIONS, EXCEPT FOR SWEDEN (2007), CYPRUS (2009) AND DENMARK AND CROATIA (2010).

	Activity effect (economic sectors)	Structure effect	Intensity effect	Activity effect (non-economic sectors)	Electricity share effect	Generation type	Efficiency effect	LCP share effect	Emission factor	Total
EU28	7%	-2%	-11%	-4%	9%	-17%	0%	12%	0%	-6%
AT	10%	-2%	-7%	4%	7%	-67%	26%	44%	0%	15%
BE	9%	0%	-9%	-8%	7%	-7%	3%	-7%	0%	-12%
BG	12%	1%	-18%	9%	11%	1%	-8%	-6%	0%	2%
CZ	11%	2%	-23%	-4%	12%	-14%	1%	-4%	0%	-18%
DE	10%	1%	-9%	3%	1%	-11%	0%	26%	0%	20%
EE	10%	1%	-11%	-8%	10%	-10%	18%	-18%	0%	-8%
EL	-11%	-6%	5%	-9%	20%	-38%	-2%	12%	0%	-28%
ES	6%	-4%	-8%	2%	8%	-35%	6%	12%	0%	-14%
FI	4%	-2%	-8%	-2%	3%	-46%	9%	5%	0%	-37%
FR	5%	-2%	-7%	-7%	9%	-52%	15%	3%	0%	-35%
HU	5%	0%	-8%	-3%	11%	-30%	-10%	6%	0%	-29%
IE	33%	5%	-47%	-2%	18%	-32%	-9%	43%	0%	9%
IT	-2%	-3%	-8%	-1%	11%	-17%	-2%	0%	0%	-22%
LT	15%	0%	-12%	-65%	12%	113%	-41%	-53%	0%	-30%
LU	17%	-14%	-8%	3%	6%	-74%	9%	-18%	0%	-78%
LV	11%	-3%	-8%	-18%	23%	75%	-47%	14%	0%	48%
MT	33%	-5%	2%	-11%	-14%	-41%	-25%	6%	0%	-56%
NL	11%	-4%	-18%	-2%	13%	24%	-9%	26%	0%	42%
PL	22%	2%	-24%	-7%	14%	-9%	-4%	3%	0%	-2%
PT	0%	-4%	-2%	-4%	14%	-7%	8%	14%	0%	19%
RO	14%	1%	-30%	6%	21%	-33%	-8%	-1%	0%	-30%
SI	10%	-1%	-20%	-1%	13%	-16%	-9%	-2%	0%	-26%
SK	22%	2%	-28%	-9%	8%	-39%	3%	1%	0%	-40%
UK	8%	-5%	-12%	-8%	6%	-27%	0%	16%	0%	-22%
SE	7%	-6%	-6%	17%	-2%	-14%	17%	-18%	0%	-5%
CY	-2%	-1%	-1%	-4%	-2%	-7%	-4%	-8%	0%	-29%
DK	3%	0%	-9%	-11%	7%	-44%	11%	1%	0%	-42%
HR	-1%	0%	-5%	-7%	8%	-14%	5%	-31%	0%	-45%

Compared with the other pollutants, the magnitude of (estimated) changes in CO_2 emissions from electricity-generating LCPs was much lower. This reflects the fact that the emission factor effect dominated changes for these other pollutants, but is absent from the decomposition of CO_2 emissions.

For most of the factors in Table 4, the direction of the effect is relatively consistent across Member States. Nonetheless, there is considerable variation in the magnitude of the effects between Member States. For example, in Ireland the increase in emissions contributed by the economic activity effect was larger than in other countries (Malta's results are not comparable, due to the use of a different measure of GDP for that country). Austria and Luxembourg saw a large decrease in emissions due to shifts in the generation type, whereas Lithuania and Latvia saw large increases in emission due to the same factor.

2.6.3 Results from selected countries

The two countries selected for further analysis here show a large impact of a shift in the energy mix of electricity generation; a reduction in Luxembourg and an increase in Latvia.

Luxembourg

In Luxembourg, the generation type effect contributed a 74% reduction in CO_2 emissions from electricity-generating LCPs between 2004 and 2015. This is entirely due to a sharp reduction in the proportion of electricity supplied in Luxembourg being generated within the country from burning natural gas, from 47% in 2004 to 12% in 2015 (Figure 41).

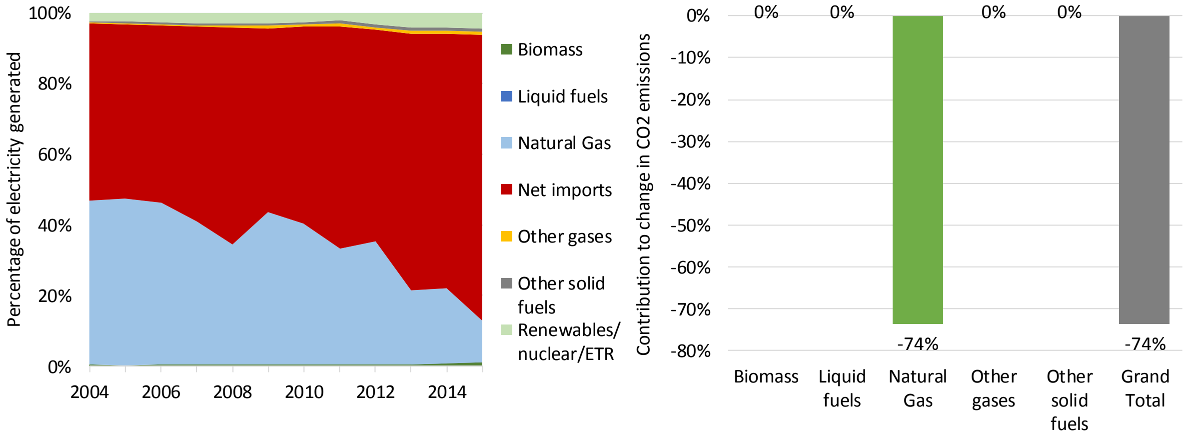


FIGURE 41. SHARE OF DIFFERENT ENERGY SOURCES IN ELECTRICITY GENERATION IN LUXEMBOURG FROM 2004 TO 2014 (LEFT), AND THE IMPACT OF CHANGES IN EACH FUEL TYPE SHARE ON CO_2 EMISSIONS OVER THE SAME PERIOD (RIGHT), AS A PERCENTAGE OF 2004 EMISSIONS.

The fall in natural gas generation was almost exclusively compensated for by a corresponding increase in electricity imports, which rose from 50% of electricity supplied in 2004 to 81% in 2015.

Latvia

In Latvia, the generation type effect contributed a 75% increase in CO_2 emissions from electricity-generating LCPs between 2004 and 2015. Examining this in more detail (Figure 42), the increase in the share of natural gas and biomass burning in electricity production were the key drivers of changes in CO_2 emissions from electricity-generating LCPs, contributing a 65% and 11% increase respectively.

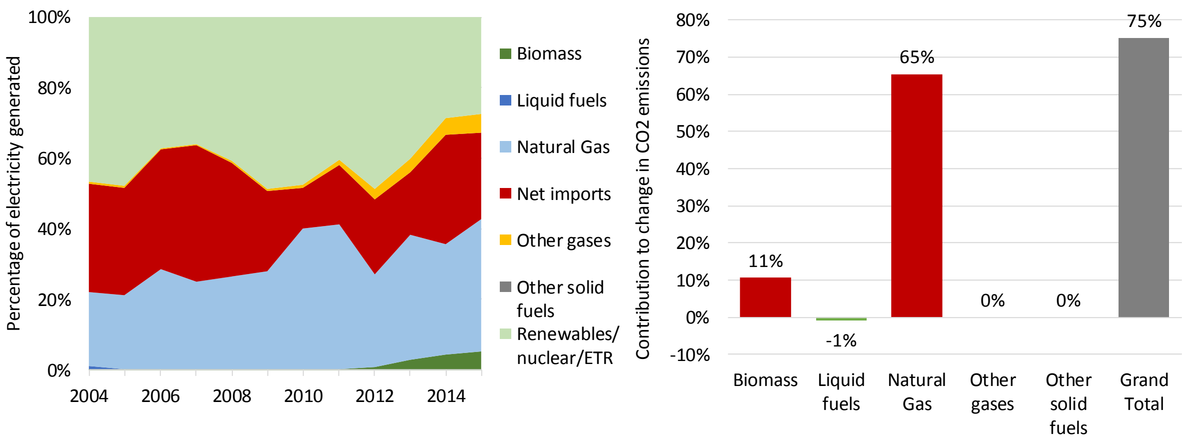


FIGURE 42. SHARE OF DIFFERENT ENERGY SOURCES IN ELECTRICITY GENERATION IN LATVIA FROM 2004 TO 2014 (LEFT), AND THE IMPACT OF CHANGES IN EACH FUEL TYPE SHARE ON CO_2 EMISSIONS OVER THE SAME PERIOD (RIGHT), AS A PERCENTAGE OF 2004 EMISSIONS.

The increase in natural gas and biomass burning in Latvia was mirrored by a corresponding decrease in the share of electricity produced from non-biomass renewables and nuclear power.

3 Micro-level analysis

Analysis at the micro-level attempts to analyse trends in the data for individual plant that have been observed at the macro-level. These trends are observed in the reported data within the LCP database. This analysis has been implemented through review of a series of plots that show changes over the time period 2004-2015 for individual LCPs in the implied emission factor (IEF; the ratio of emissions to fuel input), the fuel input in TJ classified according to type, and the emissions.

Within the emissions plot, the empirical relationship between the net calorific value (NCV) of the fuel and the corresponding volume of the flue gas4 was used to calculate the emissions from an LCP, if the emission limit values (ELVs) within the LCPD were adhered to. This, alongside the analysis of marked proportional changes in the IEF, enabled a series of flags to be devised to identify key trends. These flags allowed for a systematic approach of working through the LCP dataset.

Those LCPs which were considered as 'electricity generating units' (EGUs) were prioritised, according to the criteria set for the macro-level analysis. Those LCPs which had the highest MW thermal capacity within each country, were also prioritised. Where the analysis of the reported data identifies a clear trend, LCPs can generally be attributed into three groups:

Group 1 - Installation of abatement technology or performance tuning to improve emission efficiency: These LCPs tend to display large shifts within the IEF plot, in turn impacting on emissions, often causing reported emissions to intersect with the calculated ELV emissions. The fuel input, in terms of terajoules (TJ), may increase or stay approximately consistent throughout the reporting period in which a shift in the IEF or emissions is observed.

Group 2 – Fuel switching to a fuel with improved emission efficiency: These LCPs tend to be identified by large shifts in the fuel input between fuel types, correlating with reduction in emissions.

Group 3 – Closure, partial closure or change in operating role ("Fleet dynamics") in response to the LCPD or other determining factors. These plants tend to be identified by those which have low fuel input past a specific reporting year, and tend to be characterised by gradual emission reductions prior to this year. A change in the operating role can occur when a single company owns several plants (a "fleet"). Some plants in a fleet may run continuously to provide a "base load" while some may run temporarily to meet peaks in demand, and these roles can be allocated to achieve the best balance between electricity production and emissions.

Examples of LCPs which can be attributed to these different groups are given in the sections below. In addition, a number of issues pertaining to LCP reporting were identified which limited the level of analysis possible. These limitations are discussed in **section 1.5**.

[4] Rosin and Fehling, 1929

3.1 Group 1 - Examples where abatement technology has been installed

BG0015 - 'TPP Maritsa Iztok 3' – Maritsa Iztok 3 is the third largest electricity-generating LCP in Bulgaria, with a total reported thermal capacity of 2420MW. Within the analysis plots it was noted that emissions dramatically declined from 2006 to 2008. This correlated with an 89% decrease in the IEF between these years. The fuel input remained as 'other solid fuel' and increased by 11% in TJ over the same period. These characteristics imply the installation of abatement equipment or other performance measures to significantly improve the emission efficiency of the plant. Both units that make up this LCP are connected to a flue-gas desulphurisation (FGD) system, which was installed before 2009[5]. Each unit was tested separately, and therefore the emissions trend may also show, not only the impact of the FGD system itself, but the impact of the deployment and testing process. The research also identifies that abatement was likely installed due to the strategic importance of the LCP relative to Bulgaria's electricity demand at the time of installation, due to the prior decommissioning of several nuclear plants, removing capacity from the grid network[5].

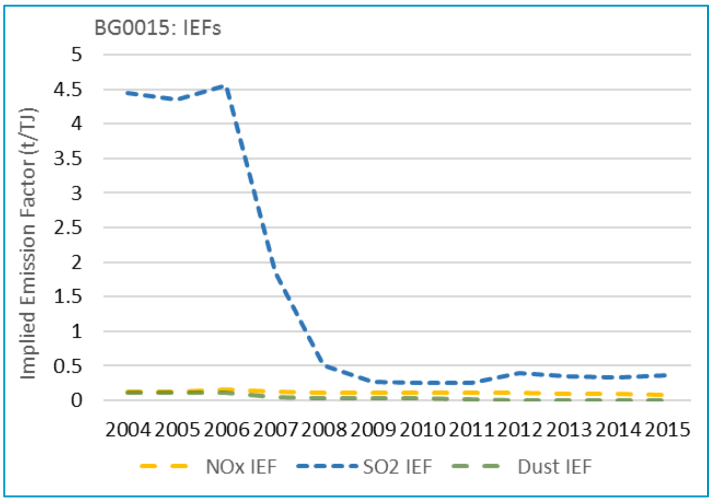


FIGURE 43- IEFS FOR ALL REPORTED POLLUTANTS BETWEEN 2004 AND 2015 AT BG0015 MARITSA IZTOK 3.

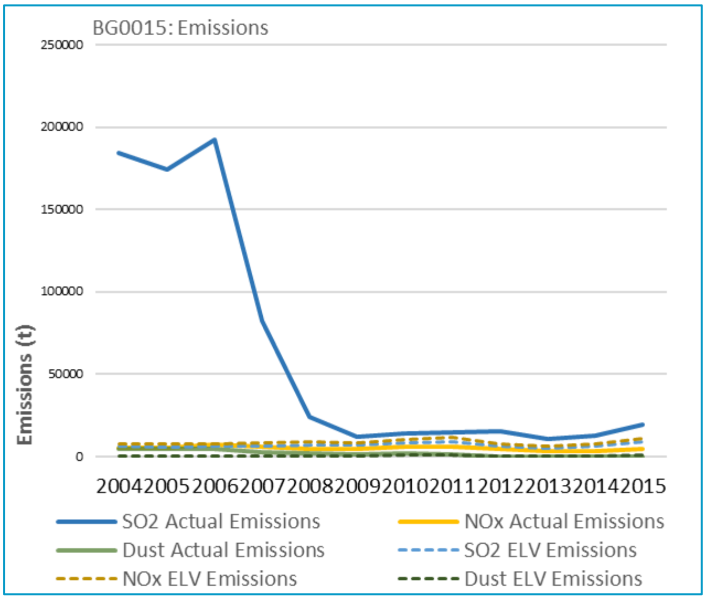


FIGURE 44 - REPORTED EMISSIONS FOR ALL POLLUTANTS BETWEEN 2004 AND 2015 FROM BG0015 MARITSA IZTOK 3.

[5] Bulgaria's Maritsa Iztok 3 Becomes Cleanest T-Plant in Eastern Europe, 2008, Available at: http://www.novinite.com/articles/91302/Bulgaria%27s+Maritza+Iztok+3+Becomes+Cleanest+T-Plant+in+Eastern+Europe

UK0282 – 'RWE npower Aberthaw PS' – Aberthaw is one of the UK's largest coal-fired power stations situated on the Welsh coast. Within the analysis plots, Aberthaw was flagged for large proportional changes within the IEF and for actual emissions intersecting the calculated ELV emissions for SO_2. The fact that the emission reduction occurred over 2006 -2009, increased the likelihood that this is caused by the installation of abatement technologies. This was corroborated by the fact that the emissions continued to reduce between 2007 and 2008, despite the fuel input increasing by 75%. Research confirms that this is the case, and that a form of sea-water based FGD system was installed prior to 2008[6], in response to European legislation.

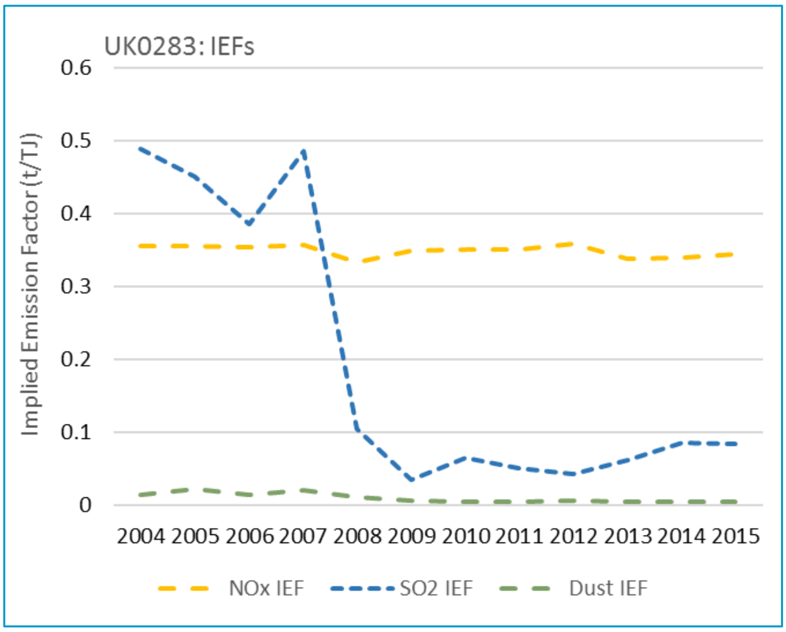


FIGURE 45 - IEFS FOR ALL REPORTED POLLUTANTS BETWEEN 2004 AND 2015 AT UK0283 ABERTHAW.

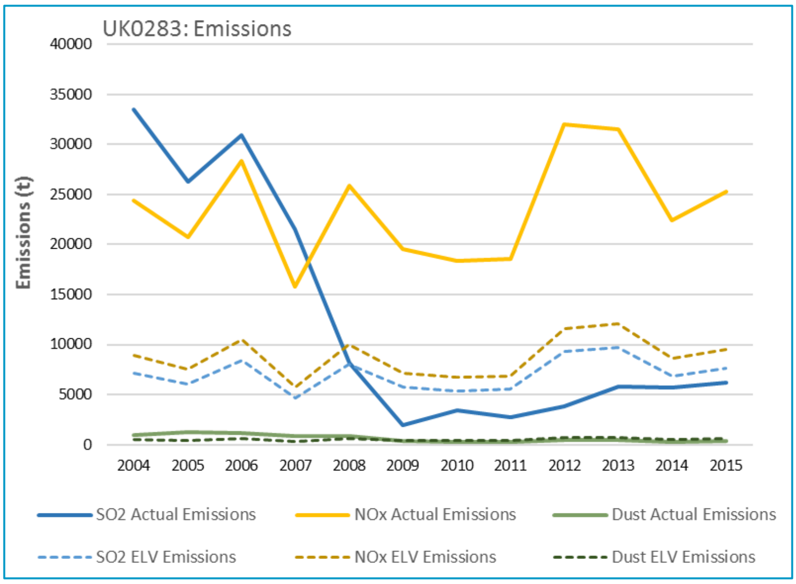


FIGURE 46 - REPORTED EMISSIONS FOR ALL POLLUTANTS BETWEEN 2004 AND 2015 FROM UK0283 ABERTHAW.

[6] Aberthaw Power Station, available at: http://www.engineering-timelines.com/scripts/engineeringItem.asp?id=971

3.2 Group 2 - Examples of Fuel switching

UK0107– 'E.ON Ironbridge PS' – Ironbridge Power Station was designed primarily to combust coal, and is one of several LCPs operated by EON. Ironbridge was flagged both due to large proportional changes in the IEFs but also flagged due to fuel switching. More specifically, a shift from coal, or 'other solid fuels' as termed in LCP reporting, to biomass is visible within the fuel input plot. Ironbridge is one of 16 LCPs within the UK to 'opt out' under Article 4(4) of the LCPD, meaning that after 2008, the LCP can only run a total of 20,000 hours. The LCP must also stop operating by 2015. The emission trend therefore reflects this, generating significantly less emissions once subject to the LCPD. From 2012 the IEF for SO_2 decreases by over 95% due to the conversion of the plant to burn biomass during its last years of operation. Biomass, in conjunction with some liquid fuels, is the only fuel used after 2012. Research corroborates these observations, and Ironbridge underwent full conversion to biomass in 2012. Very similar dynamics are observed in respect to Tilbury Power Station, operated by RWE (UK0281 & UK0282).

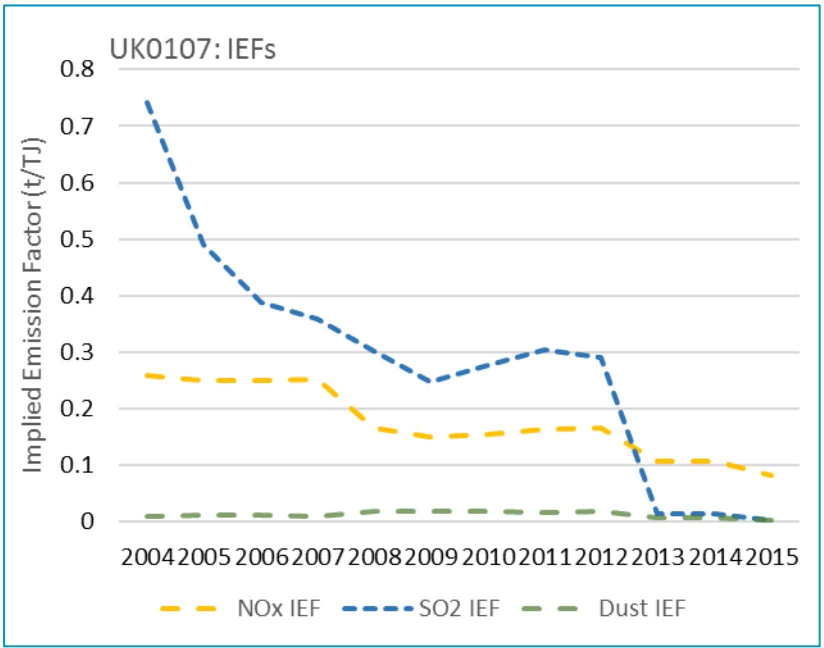


Figure 47 - IEFs for all reported pollutants between 2004 and 2015 at UK0107 Ironbridge.

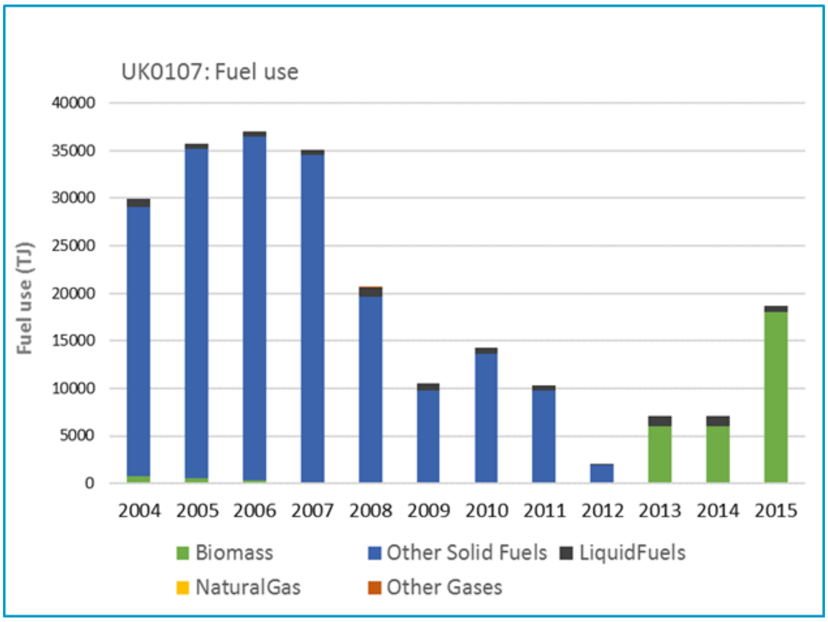


Figure 48 - Reported emissions for all pollutants between 2004 and 2015 from UK0107 Ironbridge.

IE0009 – 'Edenderry Power' - is reported as a single unit, and reporting is available across the time period 2004-2015. The LCP co-fires biomass along with its primary fuel, peat[7]. The plant was flagged due to the intersection of reported SO_2 emissions with calculated SO_2 ELV emissions. Analysis of the implied emission factor for SO_2 also indicates that this decreased over the period 2008-2013. This correlates with the co-firing of biomass, which began in 2008 There are sources to suggest Edenderry operates according to a range of abatement technologies[8], specifically aimed at SO_2 and Dust, however the timing of the installation of these technologies cannot be determined.

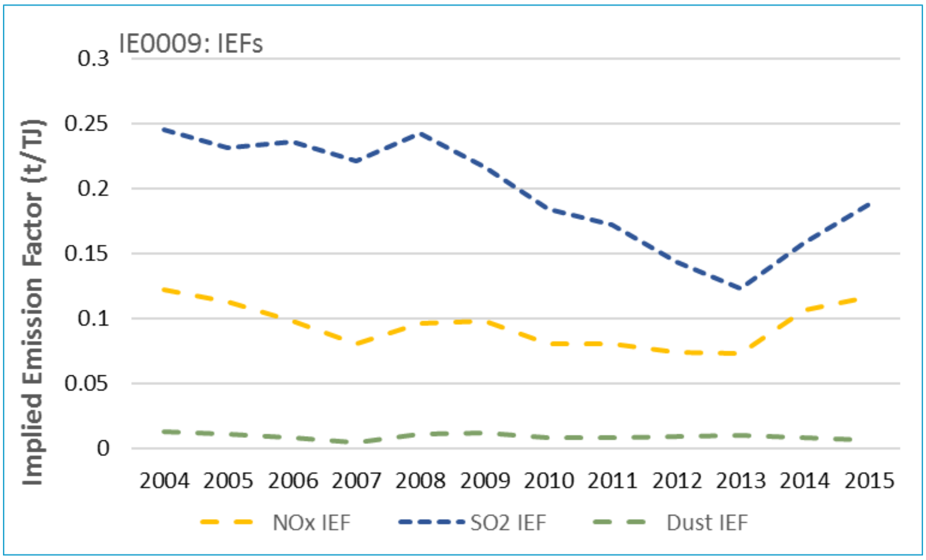


FIGURE 49 - IEFS FOR ALL REPORTED POLLUTANTS BETWEEN 2004 AND 2015 AT IE0009 EDENDERRY.

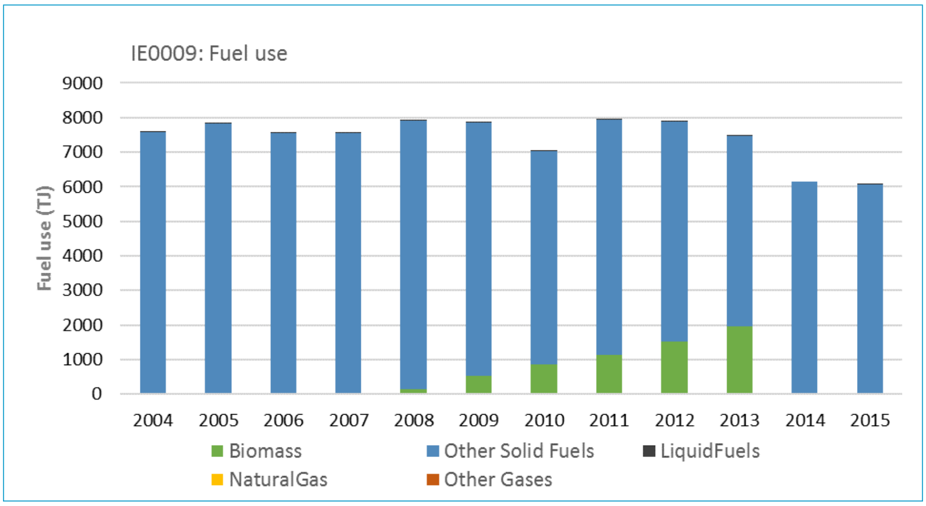


FIGURE 50 - REPORTED EMISSIONS FOR ALL POLLUTANTS BETWEEN 2004 AND 2015 FROM IE0009 EDENDERRY.

[7] Edenderry Power Plant has an installed capacity of up to 128 MW of electricity and supplies about 2.5% of Ireland's national requirement, Bord Na Mona, available at: http://www.bordnamona.ie/company/our-businesses/powergen/edenderry-power-plant/
[8] Edenderry Power Ltd Annual Environmental Report, (2012), available at: http://www.epa.ie/licences/lic_eDMS/090151b280483e93.pdf

3.3 Group 3 - Examples of plant closures and fleet dynamics

UK0275 – 'RWE nPower Plc Didcot A' – Didcot A used Article 4(4) to opt-out of compliance with the LCPD with a limited life derogation. After running for 20,000 hours from the beginning of 2008 it closed completely during 2013. It was run intensively during 2012 in particular when a peak in SO_2 emissions from other solid fuel combustion contributed to the national increase in the emission factor term in the macro-level identity for this year. The complete closure of Didcot A and other similar plants that opted-out under Article 4(4), e.g. UK0114 Kingsnorth, contributes to a decline in the emission factor term for SO_2 through to 2015.

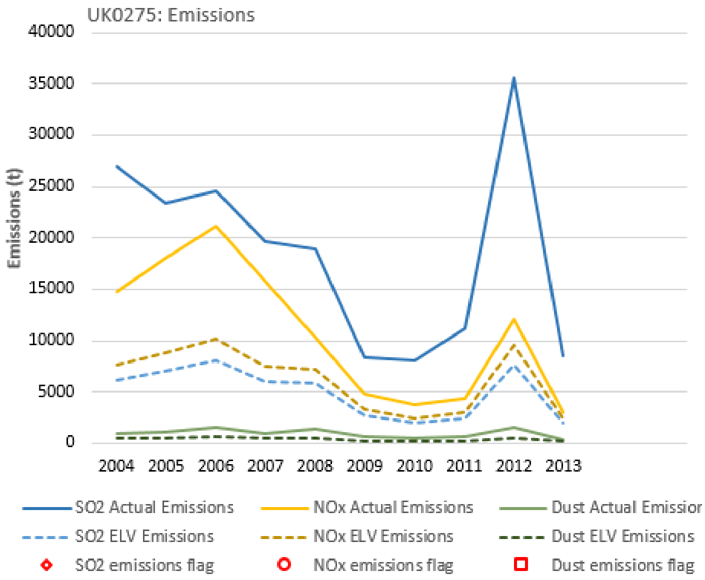


FIGURE 491 - REPORTED EMISSIONS FOR ALL POLLUTANTS BETWEEN 2004 AND 2015 FROM UK0275 DIDCOT A.

ES0142 – 'CT SANTURCE II' – This plant was one of a large group of Spanish LCPs that also used Article 4(4) to opt-out of compliance with the LCPD with a limited life derogation. However, as can be seen in Figure 52, this plant is an example where operations started to be reduced prior to 2008. Many of these plants shut completely in 2008 and 2009. Consequently, and in contrast to the UK, the emission factor term in the macro-level identity for SO_2 for Spain declines quickly between 2006 and 2008 but remains relatively constant through to 2015.

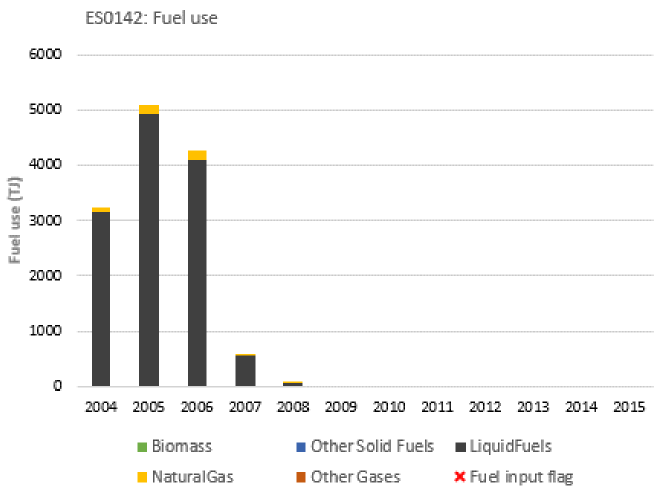


FIGURE 502 - FUEL USE BETWEEN 2004 AND 2015 AT ES0142 SANTURCE II.

IE0010 - 'Great Island 1 & 2' - Great Island Power Station, in LCP reporting, is split as unit 3 and units 1 & 2. All units combust heavy fuel oil and the emissions for all units sharply declined from 2005 to 2007. From 2010 onwards, all units are kept operational, but at a minimal level. This is likely due to the positioning of the station amongst Ireland's fleet, no longer operating as 'base load'[9]. From analysing the fuel input data provided from LCP reporting, the most notable characteristic is the lack of fuel input data for 2009. Sources indicate that the plant was operational, however the plant was sold by ESB to Edensa in 2009, which may explain this gap in reporting[10]. Closure in 2013 enabled the construction of a CCGT plant onsite, which began operating in 2014 under the code IE0029. The plots below show the emissions and fuel input for units 1 & 2.

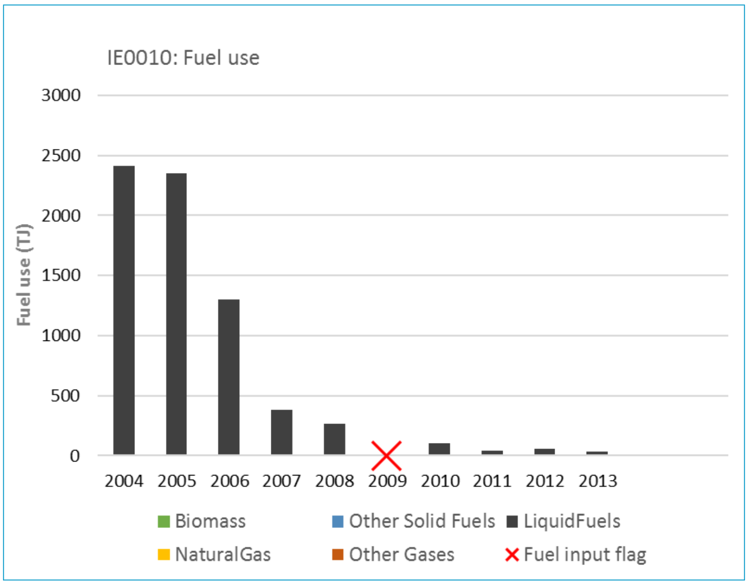


FIGURE 53 - FUEL USE BETWEEN 2004 AND 2013 AT IE0010 GREAT ISLAND.

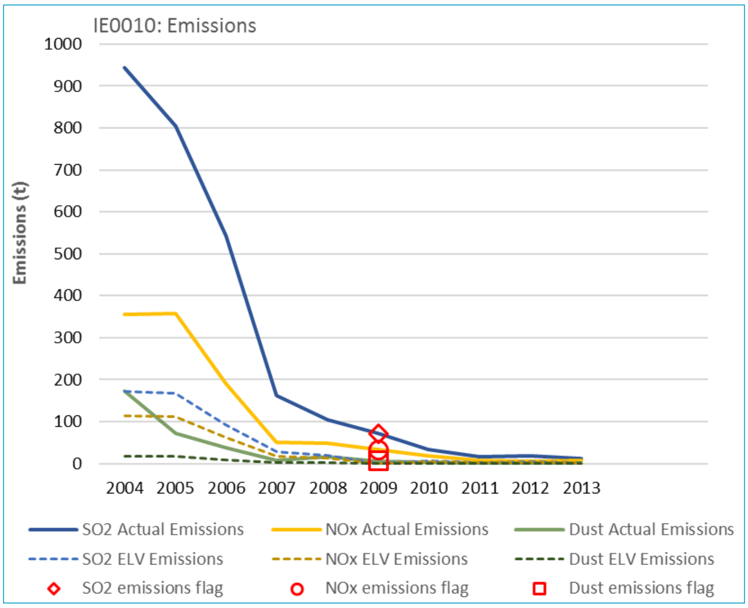


FIGURE 54 - REPORTED EMISSIONS FOR ALL POLLUTANTS BETWEEN 2004 AND 2013 FROM IE0010 GREAT ISLAND.

A similar situation can also be seen at IE0022 Tarbet 1&2 which was also sold by ESB to Edensa in 2009.

[9] Great Island Annual Environmental Report (2010), available at: http://www.epa.ie/licences/lic_eDMS/090151b2803d665c.pdf
[10] Great Island Power Station, ESB, available at: https://esbarchives.ie/portfolio/great-island/

4 Appendices

4.1 Calculation and results spreadsheets

The files Macro-economic decomposition_Complex_v3, Macro-economic decomposition_Simple_v3.xlsx, All_results_complex - For EEA_v2.xlsx, All_results_Simple - For EEA.xlsx, LCP_Decomposition_Analysis_QAQC_v3_ELVs_ForEEA-RB.xlsx and ELV _IEF_Emissions_V3_ForEEA.xlsx have been supplied to EEA via Sharepoint.

4.2 ELV emissions and FGV methodology description:

ELV emissions are calculated according to the empirical relationship defined by Rosin and Fehling in 1929. This relationship combines the net calorific value (NCV) of the specific fuels and the corresponding volume of the flue gas.

The stoichiometric flue gas volume (**R**) is calculated with the following formula, where **NCV** is the net calorific value in MJ/kg.:

$$\mathbf{R} = 1.65 + 0.198 * \mathbf{NCV}$$

The stoichiometric volume of air needed for combustion (**L**) is calculated as follows:

$$\mathbf{L} = 0.5 + 0.225 * \mathbf{NCV}$$

LCPs operate under conditions of surplus oxygen to ensure that enough oxygen is available for combustion. The LCPD lists reference values of 6% surplus oxygen for solid fuels, 3% for liquid and gaseous fuels burned in a steam turbine and 15% for liquid and gaseous fuels burned in a gas turbine. This surplus oxygen will also be in the flue gas and must therefore be accounted for in the total volume. The total flue gas volume including surplus oxygen ($\mathbf{R_{total}}$) is calculated as follows:

$$\mathbf{R_{total}} = \left(\mathbf{R} + \left(\frac{21}{21 - \text{Surplus oxygen (\%)}} - 1\right) \cdot \mathbf{L}\right) \ / \ \mathbf{NCV}$$

The calculation utilises year and country specific NCVs where possible, specifically in the calculation of flue gas volumes from the combustion of “other solid fuels” and liquid fuels. Here the calculation uses calculated NCV values derived from Eurostat[11]. For biomass, the NCV for ‘biomass and renewable wastes’ from the IPCC 2006 guidelines[12] was used. Similarly, the NCV for natural gas from the IPCC 2006 guidelines was applied. For other gases, a combined average NCV was derived using the NCVs for refinery gas, ethane, coke oven gas, blast furnace gas, gas works gas and biogas.

Once the total flue gas volume has been calculated for each LCP and reporting year, the flue gas volume is combined with the emission limit value (ELV), from the LCPD, to calculate emissions. These emissions correspond to the hypothetical scenario where all LCP operate according to the ELVs. The final step of the calculation can be expressed as:

[11] Nrg101a Supply, transformation and consumption of solid fuels - annual data (nrg_101a). Nrg102a Supply, transformation and consumption of oil - annual data (nrg_102a).
[12] 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 2 -Energy, available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html

$$\text{Emission}_{p,y} = \text{Flue gas volume }_{y} \cdot \text{ELV }_{p} \cdot 10^{6}$$

Where: $\text{Emission}_{p,y}$ = Emission of pollutant *p* by LCP in year *y* (Unit: t), Flue gas $\text{volume}_{,y}$ = Flue gas volume of LCP in year *y* (Unit: Nm^3), ELV_p = Emission limit value for LCP for substance *p* (Unit: mg/ Nm^3), *p* = NO_x, SO_2 or dust, *y* = a year in the period 2004-2015.

The ELVs were sourced directly from the LCPD. ELVs were applied according to the MWth of the LCP. Some LCPs within the LCP database have only partial information on MWth, for example, LCPs may begin operation without reporting a MWth value, only for it to be supplied in a later reporting year. A gap-filling exercise used formulae to populate empty cells with the appropriate MWth for the specific LCP, by analysing whether the MWth for the LCP had been reported at a later, or earlier year in the time series. LCPs where no MWth has been defined across the reporting, were excluded from the ELV emission calculation.

Several issues arose in the application of the appropriate ELV. Several categories of ELV are devised within the LCPD for fuel categories which are not defined within LCP reporting. ELVs are also split according to whether they are subject to Article 4(1), Article 4(3) and Article 4(2). This corresponds to the date in which the permit for the LCP entered into force. As such data is not a component of the LCP database, the determination of the correct ELV is limited. This means any calculated ELV emissions are uncertain and therefore the value of using these calculated emissions to identify LCPs subject to abatement technologies or other dynamics, may be limited. The ELV emissions however were useful in identifying large shifts in reported SO_2 emissions, enabling the identification of select cases of FGD.

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