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Emission scenarios for large combustion plants under the IED regime

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Cover photo – Coal power plant (RIVM Beeldenbank)

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1 Glossary

AEL	Associated Emission Level (typically from BAT conclusions)
BAT	Best Available Techniques
DEL	Demonstrated Emission Level (typically historically observed)
EC	European Commission
EEA	European Environment Agency
ELV	Emission Limit Value (typically from the IED)
EU	European Union
Fuel efficiency	Fuel needed to generate electricity by a thermal energy conversion plant
GHG	Greenhouse gas
GW	Giga Watt (capacity unit of measure)
IED	Industrial Emissions Directive
IPCC	Intergovernmental Panel on Climate Change
LCP	Large Combustion Plant: Combustion Plant with 50 MW or more thermal capacity
LCPD	Large Combustion Plants Directive
Lifetime (of an LCP)	In the context of this study: number of years that an LCP remains operational
MW	Mega Watt (capacity unit of measure)
NO_x	Nitrous Oxides
PM	Particulate matter. In this study sometimes also named 'dust'.
Replacement (of an LCP)	In the context of this study: closure of an existing LCP and replacement by one or more new LCPs
Retrofit (of an LCP)	In the context of this study: the deployment of air emission abatement techniques without changing the energy conversion cycle
SO_2	Sulphur Dioxide

2 Introduction

2.1 Goal of the study

As from 2016 the emissions of NO_x, SO_2 and dust from Large Combustion Plants (LCPs) are governed by the Industrial Emissions Directive 2010/75/EU (IED). [EC, 2010] The IED sets general emission limit values and defines several specific regimes for certain types of LCPs. In addition, the IED prescribes the use of Best Available Techniques (BAT), which authorities must use to set operating permit conditions for plants. The BAT conclusions on LCPs, which were adopted 31 July 2017, set upper and lower emission limit values for NO_x, SO_2 and dust during the permitting phase of plants. [EC, 2017] These limits must feature in all operating permits across Europe by 1 August 2021 at the latest.

In this study a forward-looking analysis of the potential benefit of implementing the lower emission limits of the 2017 LCP BAT conclusions on air emissions (NO_x, SO_2 and dust) are developed. The focus is on air emissions of these pollutants from LCPs in the power sector for the EU-28 only.

2.2 Approach

The analysis of the potential benefit on air emissions from the IED and BAT conclusions is based on scenario calculations of potential future LCP air emissions up until 2030. To calculate scenario results, the future activity of existing and new LCPs is estimated based on current reported data on fuel use (i.e. from 2016) and predictions made by the consulted energy reference scenario (2016 EU Reference Scenario - Energy, transport and GHG emissions Trends to 2050). Emission limits in the IED and 2017 LCP BAT conclusions are then used to calculate estimated future total pollutant emissions from the power sector in the EU-28.

Since the scenario results are defined by both the future activity level of the LCPs and the emission limits in the regulatory framework, some additional scenarios are developed to decompose the impact these two as well as additional other factors (e.g. contained in the energy scenario) have on the overall results.

Results are presented in annual evolutions of total pollutant emissions. This enables us to consider the effect of various specific IED regimes that are ending between 2016 and 2030[1].

2.3 Structure of this report

The report is divided into several large sections. 'Chapter 3 Data sources' describes the different data sources, which will feed into the scenario calculations. 'Chapter 4 Methodology' describes the methodology for combined data sources, additional assumptions as well as the logic. 'Chapter 5 Scenarios' details the scenarios that are calculated. 'Chapter 6 Results' presents the findings of the study and develops main conclusions based on a comparison of the scenario results.

[1] These specific regimes are transitional national plans, limited lifetime derogations and small isolated systems

3 Data sources

3.1 Reported data on LCPs

Data on the energy input and emissions from LCPs are reported to the European Union since 2004. The European Environment Agency (EEA) has compiled and quality assured the historical time series into a single dataset. [EEA, 2018] As of 2015 (for reporting year 2013), the reporting procedure, quality assurance and data aggregation are done directly by the EEA. Various changes including the addition of several fuel types have taken place for reporting year 2016 to accommodate for the fact that the IED fully applies as of that year.

This database forms an integral part of the study.

3.2 Industrial Emissions Directive

The Industrial Emissions Directive contains a set of rules to which LCPs must adhere in terms of pollutant emissions. [EC, 2010] It also stipulates that operating permits must be set in accordance with BAT, which is developed separately under the supervision of the European Commission.

For this study we will make use of the articles in 'Chapter III: Special Provisions for Combustion Plants' and of Annex 5 which lists emission limit values (ELVs) and desulphurization rates for combustion plants. This text was transformed into a digital ruleset, which can be used in the methodology to perform scenario analysis.

3.3 BAT conclusions of the 2017 LCP BREF

On the 31st of July 2017, the European Commission Implementing Decision (EU) 2017/1442 adopted the BAT conclusions of the 2017 LCP BREF. [EC, 2017] The range of associated emission levels (AELs) contained in these documents therefore became binding and authorities must use them to set permit conditions and incorporate them into existing permits within 4 years.

For this study we will make use of the defined upper and lower AELs from these BAT conclusions. This text will also be transformed into a digital ruleset, which can be used in the methodology to perform scenario analysis.

3.4 EU energy reference scenario 2016

In 2016, the EC published an EU reference scenario with trends up to 2050 for energy, transport and GHG emissions. [EC, 2016] This reference scenario makes use of multiple data sources, policy assumptions, and a toolbox to estimate trends up to 2050. The toolbox includes models such as Prometheus, GEM-E3, PRIMES, CAPRI, GLOBIOM and GAINS.

For this study we will make use of the trend estimates of electricity generation, fuel consumption and investments in the power sector. Each is described in more detail below.

3.5 JRC EU TIMES model

In 2013 the European Joint Research Centre (JRC) published the report 'The JRC-EU-TIMES model: Assessing the long-term role of the SET Plan Energy technologies' on the EU TIMES model they developed. [JRC, 2013] This publication contains a wide variety of parameter information for different energy technologies. Listed among the different parameters is the electrical efficiency and its evolution during the period 2020-2050. We will make use of this information to define replacement LCPs in our methodology.

3.6 Member state consultation

In the methodology section we describe the way in which we estimate the future European LCP fleet based on

- reported LCPs in 2016,
- representative lifetimes for LCPs,
- IED derogations to which they may adhere, and
- a possible breach of the IED specifications.

The result of this is a list of existing LCPs with expected dates for a retrofit or replacement.

This result was communicated to the EIONET National Reference Centre (NRC) on Industrial Pollution. They were given the opportunity to propose revisions for the LCP specific retrofit or replacement dates. This decision can be based on existing measures, policies or known investments/decommissioning. It may result in LCPs being retrofitted or replaced earlier or later. Alternatively, they may close without a replacement. Also, the NRC was able to comment on our assessment of whether an LCP is in breach of IED specifications (based on reported emissions in 2016) and/or if LCPs exit from derogatory regimes of the IED earlier then assumed here.

In addition to the above we also gave Member States the opportunity to provide information on LCPs starting operation in 2017 or 2018 and on potential planned LCPs coming online in the future. To make this information as useful as possible we presented the NRCs with a list of operational specifications on these LCPs. The specifications requested were the following:

- Expected date at which the new plant was or will be operational
- Expected MW thermal output capacity
- Expected fuel type consumed. If multiple fuels are burned, then an indication will be needed whether these fuels are burned in a concurrent or alternating fashion.
- Expected efficiency. If multiple fuels are burned concurrently a combined efficiency is sufficient. If multiple fuels are burned alternating, then an efficiency per fuel will be requested.
- Expected equivalent full load hours on a yearly basis. If multiple fuels are burned alternating, then an indication per fuel type will be required.

4 Methodology

4.1 Overview

This chapter will discuss the methodology to estimate future pollutant emissions for LCPs in the power sector during the period 2016-2030. Figure 4.1 Overview of the methodology presents a birds-eye view on the steps in the methodology to get from the data sources to pollutant emission scenarios.

First off, the future LCP fleet is developed based on a) the LCPs reported in 2016 and b) replacement and retrofit rules as a result of their age and to which extent specific IED derogations apply. The outcome of this exercise is an annual LCP fleet for all years from 2016 up to 2030 including the type and amount of fuel each is projected to consume.

Secondly, we link this fuel consumption to emission factors to calculate total yearly pollutant emissions. These emission factors may either be

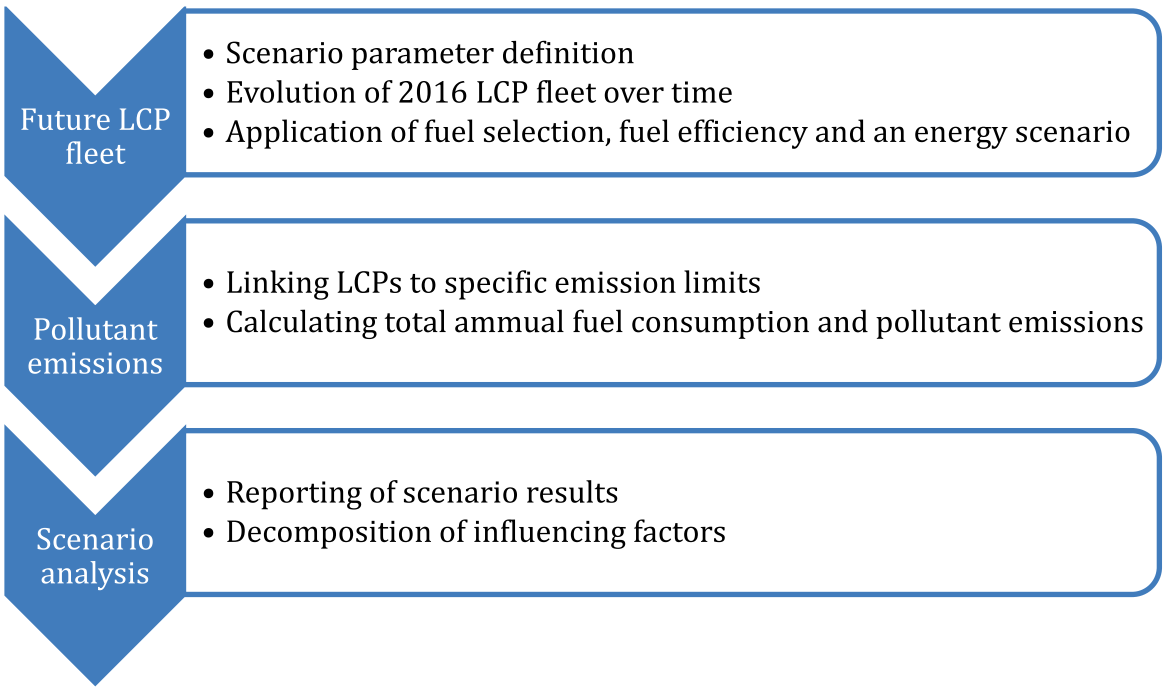
a) demonstrated emission factors calculated from the 2016 reported data,
b) IED Annex V ELVs, or
c) 2017 LCP BAT upper and/or lower AELs.

Both the IED and the 2017 LCP BAT conclusions contain emission limits for multiple different types of LCPs. It is therefore necessary to link specific ELVs and AELs to existing and future LCPs.

Lastly, total annual pollutant emissions are calculated based on this methodology. Part of the analysis includes a decomposition of the result regarding the impact of

a) fuel selection and fuel efficiency,
b) other aspects of the reference energy scenario and
c) chosen emission factors.

Figure 4.1 Overview of the methodology



The methodology results in a set of combinatorial possibilities on LCP evolution, energy scenario aspects and emission factors. Figure 4.2 lists the different combinations possible. The meaning of the columns in the figure is as follows:

- LCP IED allocation: the article of the IED to which the LCP adheres
- Lifetime LCP: how the calculated lifetime compares to the representative lifetime
- Additional specification: mentions possible additional differentiation in the methodology
- LCP population: the action that we assume to take in the specific scenario year for the specific LCP
- Fuel efficiency: whether a possible change in fuel efficiency is considered
- Fuel type selection: whether a possible change in fuel type is considered
- Energy scenario scaling: whether the energy scenario percentage changes are considered
- IED emissions: whether we use the demonstrated emissions from the base year or make use of the ELVs to calculate total emissions for IED scenarios
- BAT emissions before 01/01/2020: whether we use the demonstrated emissions from the base year or make use of the AELs to calculate total emissions for BAT conclusions scenarios for scenario years before 01/01/2020
- BAT emissions from 01/01/2020: whether we use the demonstrated emissions from the base year or make use of the AELs to calculate total emissions for BAT conclusions scenarios for scenario years as from 01/01/2020

Figure 4.2 Schematic summary of the methodology

LCP IED allocation	Lifetime LCP	Additional specification	LCP population	fuel efficiency	fuel type selection	energy scenario scaling	IED emissio	BAT emissions before 01/01/202(	BAT emissions from 01/01/202(
Article 30: default IED emission limit values	<= representative lifetime	not in breach of IED	continued use	no	no	yes	ELV	historic	AEL
Article 30: default IED emission limit values	<= representative lifetime	in breach of IED	retrofit	no	no	yes	ELV	AEL	AEL
Article 30: default IED emission limit values	> representative lifetime		replacement	yes	yes	yes	ELV	AEL	AEL
Article 31: a desulphurisation rate	<= representative lifetime		continued use	no	no	yes	historic	historic	AEL
Article 31: a desulphurisation rate	> representative lifetime		replacement	yes	yes	yes	ELV	AEL	AEL
Article 32: a transitional national plan	<= representative lifetime	scenario date <= 30/06/2020	continued use	no	no	yes	historic	historic	AEL
Article 32: a transitional national plan	<= representative lifetime	scenario date > 30/06/2020	retrofit	no	no	yes	ELV	AEL	AEL
Article 32: a transitional national plan	> representative lifetime		replacement	yes	yes	yes	ELV	AEL	AEL
Article 33: limited lifetime derogation	<= representative lifetime	scenario date <= 31/12/2023 and below operating hours	continued use	no	no	yes	historic	historic	AEL
Article 33: limited lifetime derogation	<= representative lifetime	scenario date <= 31/12/2023 and above operating hours	replacement	yes	yes	yes	ELV	AEL	AEL
Article 33: limited lifetime derogation	<= representative lifetime	scenario date >= 01/01/2024	retrofit	no	no	yes	ELV	AEL	AEL
Article 33: limited lifetime derogation	> representative lifetime		replacement	yes	yes	yes	ELV	AEL	AEL
Article 33(3): limited lifetime derogation in small isolated system	<= representative lifetime	scenario date >= 01/01/2020 and <= 31/12/2023 and below operating hours	continued use	no	no	yes	historic	historic	AEL
Article 33(3): limited lifetime derogation in small isolated system	<= representative lifetime	scenario date >= 01/01/2020 and <= 31/12/2023 and above operating hours	replacement	yes	yes	yes	ELV	AEL	AEL
Article 33(3): limited lifetime derogation in small isolated system	<= representative lifetime	scenario date >= 01/01/2024	retrofit	no	no	yes	ELV	AEL	AEL
Article 33(3): limited lifetime derogation in small isolated system	> representative lifetime		replacement	yes	yes	yes	ELV	AEL	AEL
Article 34: small isolated systems	<= representative lifetime	scenario date <= 31/12/2019	continued use	no	no	yes	historic	historic	AEL
Article 34: small isolated systems	<= representative lifetime	scenario date > 31/12/2019	retrofit	no	no	yes	ELV	AEL	AEL
Article 34: small isolated systems	> representative lifetime		replacement	yes	yes	yes	ELV	AEL	AEL

4.2 Establishing the LCP fleet for each year until 2030

To establish a future LCP fleet, it is important to determine the following key aspects of any one LCP and how they evolve over time. All these aspects will be further explained in sub-sections below.

1) **Plant operating type:** Is the plant in year x a
    a. continued operation of an existing LCP from year x-1?
    b. retrofit of an existing LCP from year x-1?
    c. new (hypothetical) LCP?
2) **Fuel type:** Determined by when the plant began operation in the first place. Based either on fuel type as reported for 2016 (continued operation and retrofits) or the average fuel type predicted by the energy reference scenario for that year (new plants).
3) **Fuel efficiency:** Also determined by when the plant started to operate. Based on efficiency levels observed in 2016 (continued operation and retrofits) or according to JRC-EU-TIMES model (new plants; see below).
4) **Plant output:** Determined solely by projected energy demand according to the energy reference scenario for any given year. Each plant's activity is essentially scaled according to the reference scenario based on its relative contribution to the total in 2016.

4.2.1 Fuel type and efficiency of new LCPs

When an existing LCP is replaced by a new LCP, both fuel type and fuel efficiency can change as indicated above. To implement this, we need both a standard set of replacement LCPs as well as a method to select them.

Replacement LCPs are defined by the average fuel type predicted by the EU 2016 reference scenario. [EC, 2016] For each fuel type a default technology type is assumed.

The fuel type choice is based on figure 41 in the EU 2016 reference scenario. [EC, 2016] The investment in new capacity and the replacement of existing power generation capacity as per the EU 2016 reference scenario is depicted in Table 4.1. Values are expressed in GW electrical output.

Table 4.1 Evolution in net generation capacity (GW_e) in the EU 2016 reference scenario

Fuel type	2011-2020	2020-2030
Solids – new	18	0
Solids – replacement	18	15
Oil (including refinery gas) – new capacity	4	5
Oil (including refinery gas) – replacement	2	2
Gas (including derived gases) – new capacity	19	18
Gas (including derived gases) – replacement	2	23
Biomass-waste – new	6	1
Biomass-waste – replacement	0	0

Source: EC, 2016

The net generation capacity in GW_e listed in Table 4.1 is summed over the subcategories 'new' and 'replacement'. The resulting subtotals are expressed as a percentage of the grand total for each time period in Table 4.2. It is these percentages that are used to define the fuel mix of new investments in LCPs.

Table 4.2 Evolution in net generation capacity (% of total) in the EU 2016 reference scenario

Fuel type	2011-2020	2020-2030
Solids	52.17%	23.44%
Oil (including refinery gas)	8.70%	10.94%
Gas (including derived gases)	30.43%	64.06%
Biomass-waste	8.70%	1.56%

Finally, a new LCP may have a better fuel efficiency than previously existing LCPs. As fuel efficiency has a direct impact on pollutant emissions we need to simulate this effect in our calculations. To do this, we need to make assumptions on fuel efficiency over time. The European Joint Research Centre (JRC) has published an overview of technologies which includes the necessary information in table 25 of the 2013 publication 'The JRC-EU-TIMES model: Assessing the long-term role of the SET Plan Energy technologies'. [JRC, 2013] For periods 2010-2020 and 2020-2030 net electrical efficiency is listed for a wide range of power generating technologies.

To apply the change in fuel efficiency we assume a technology type for each replacement plant that matches a technology type in the EU TIMES model. Next, we will assume a legacy efficiency for the existing LCPs. Once an existing LCP is replaced with a new LCP this will result in an improvement in fuel efficiency equal to the difference between the assumed legacy efficiency and the fuel efficiency in the EU TIMES model.

Assumed legacy efficiencies are presented in Table 4.3. [IEA, 2008]

Table 4.3 Fuel efficiency assumption for existing large combustion plants

Fuel type	Legacy efficiency
Solid fuels	34%
Liquid fuels	37%
Gaseous fuels	40%

Assumed replacement technology and efficiencies are presented in Table 4.4.

Table 4.4 Fuel efficiency for replacement large combustion plants

Fuel type	Replacement technology	Efficiency 2011-2020	Efficiency 2020-2030
Solid fuels	Boiler	45%	46%
Liquid fuels	Boiler	37%	37%
Gaseous fuels	Gas turbine	58%	60%
Biomass	Boiler	34%	35%

4.2.2 Determining the plant operating type

This section develops a decision tree for whether a plant continues operating in any given year, or whether it is retrofitted or replaced by a new plant.

Lifetime

The idea is essentially that a plant continues to operate if it is below its representative lifetime. At the end of its lifetime a plant is then replaced by a new plant as described above. In the EEA report 'Transforming the EU power sector: avoiding a carbon lock-in' expected lifetime values are determined for LCP plants above 200 MW thermal input. [EEA, 2016] Calculations are based on literature, World Power Plant Database (Enerdata) and World Electrical Power Plant Database which result in different lifetime scenarios. We will use the established values for the extended lifetime profile as a starting point for the current study. The values are shown in Table 4.5.

Table 4.5 Representative lifetime values by type of fuel for the extended lifetime profile

Fuel type	Lifetime
Coal	50 years
Gas	45 years
Oil	50 years
Nuclear	60 years

Source: EEA, 2016

For other fuel types we will assume the same representative lifetime as respectively coal, gas or oil depending on the phase of the fuel (solid, liquid, gaseous).

Further on in this study we will compare the representative lifetime with a calculated lifetime. The calculated lifetime is the difference between a point in time and the date at which an LCP is put in operation.

Retrofits and derogations

There are three ways in which a plant may be retrofitted to meet emission limits in place at that time:

1. If they reported emissions for 2016 that are above the IED Annex V ELVs.
2. If they are projected to not meet upper or lower AELs (depending on the scenario applied) of the LCP BAT conclusions in 2021.
3. If a derogation they are subject to runs out before their lifetime does.

The derogations of importance in the context of this study (i.e. for the power sector) are:

- Article 31: a desulphurisation rate (no hard end-date)
- Article 32: a transitional national plan (applies until mid-2020)
- Article 33: limited lifetime derogation (see below)
- Article 33(3): limited lifetime derogation in a small isolated system (see below)
- Article 34: small isolated system (until end-2019)

It should be noted once again that retrofits (like the continued operation of plants) do not assume a change in fuel type or fuel efficiency.

LCPs with a limited lifetime derogation

Article 33 of the IED states that, under certain conditions, LCPs may be exempted from compliance with the default emission limit values or desulphurization rate as stated in the IED. This exemption is valid for a maximum period from 01/01/2016 up to 31/12/2023.

If an LCP with a limited lifetime derogation reaches is representative lifetime, it will be replaced with a new LCP. The new LCP can have a better fuel efficiency and make use of the same or a different fuel, depending on the evolution in the energy scenario. If this is not the case we will assume these existing LCPs to continue operation at the 2016 load hours until the limit of 17500 operating hours will be reached in the period 01/01/2016 to 31/12/2023, or until 31/12/2023, whichever comes first. During the period that 17500 operating hours are reached, we assume as retrofit if the representative lifetime of the plant has not been reached.

LCPs with a limited lifetime derogation in a small isolated system

Article 33 paragraph 3 of the IED states that, under certain conditions, LCPs may be exempted from compliance with the default emission limit values or desulphurization rate as stated in the IED. This exemption is valid if the LCP is part of a small isolated system for a maximum period from 01/01/2020 up to 31/12/2023. The start of the period is defined by the end of the article 34 derogation on small isolated systems end 31/12/2019.

If an LCP with a limited lifetime derogation as part of a small isolated system reaches its representative lifetime, it will be replaced with a new LCP. The new LCP can have a better fuel efficiency and make use of the same or a different fuel, depending on the evolution in the energy scenario. If this is not the case we will assume these existing LCPs to continue operation at the 2016 load hours until the limit of 18000 operating hours will be reached in the period 01/01/2020 to 31/12/2023, or until 31/12/2023, whichever comes first. During the period that 18000 operating hours are reached, we assume as retrofit if the representative lifetime of the plant has not been reached.

4.2.3 Plant output

Once the LCP fleet, its fuel type as well as efficiency have been established, the operational deployment of the LCPs needs to be determined. To be in line with the EU 2016 reference scenario [EC, 2016] we will scale the utilization of the LCP population.

The scaling will be based on the evolution in gross thermal electricity generation from the EU 2016 reference scenario. The percentage change per year is taken from appendix 2 of the EU 2016 reference scenario for the EU 28. The percentages are shown in Table 4.6.

Table 4.6 Evolution in gross electricity production (%) in the EU 2016 reference scenario yearly for each period

Fuel type	2010-2020	2020-2030
Solids	-0.8%	-3.1%
Oil (including refinery gas)	-12.9%	-1.2%
Gas (including derived gases)	-3.1%	+1.2%
Biomass-waste	+3.9%	+2.9%

The percentage above will be applied to fuel consumption, yearly for each year after 2016, to align with the EU 2016 reference scenario. This scaling will be applied to all LCPs if the specific scenario indicates so.

Note that the scaling as described above implies an assumption that the changes in the 2016 EU reference scenario apply equally for thermal generation capacity above and below 50 MW thermal input. As was argued in the study 'Transforming the EU power sector: avoiding a carbon lock-in' in box 1.3, a threshold of 200 MW thermal input installations already covers 90% of projected power generation levels. [EEA, 2016] With the current threshold of 50 MW we will thus at least also cover 90% of the power generation levels which makes the reported trends in the 2016 EU reference scenario representative for the LCPs in the power sector.

In case of LCPs that use multiple fuels, we will scale each fuel separately assuming a proportional spread of emissions of the fuels used. This is a necessary simplification to (1) limit complexity as well as (2) to cope with the lack of emission details per fuel type in multi-fuel fired LCPs.

4.3 Linking the LCP population to ELVs and AELs

To apply ELVs or AELs to LCPs we need to establish a link between them. It is therefore important to note that various aspects required to determine whether an ELV or AEL applies to a certain LCP are based on workarounds, assumptions or omissions.

The following required aspects could be taken from the LCP inventory of the EEA:

- Fuel used
- Technology details of the plant
- Rated thermal input
- Date of LCP going operational
- Operating hours

The following list of aspects however was not readily available:

- LCP permit date
- Fuel high potassium and/or sodium content
- Fuel high sulphur content
- LCP containing units < 20 MW thermal input
- No secondary abatement possible
- Net total fuel utilization
- Nitrogen content of fuel

The lack of the latter LCP properties in the LCP reporting imply that some exceptions to ELVs and AELs cannot be considered in the scenario calculations.

Note that the level of detail for fuel used is not always the same in the IED, BAT conclusions and the LCP database. For the major categories there is no issue but for some specialty fuels further assumptions are necessary to complete the fuel mapping between them.

4.4 Calculating total yearly emissions of LCPs

Once the future LCP population has been established and linked to the relevant emission limits, total annual pollutant emissions were calculated. The steps involved to doing so are:

1. Determining the flue gas volume of any given LCP to determine how annual emissions reported to the EEA LCP inventory relate to emission limits expressed in flue gas concentrations.
2. Calculate emissions based on either ELVs, upper or lower AELs or demonstrated emission factors from data reported for 2016.

4.4.1 Determine the flue gas volume of LCPs

To estimate flue gas volumes there are different possibilities but, in this study, we will make use of the empirical relation between the net calorific value of the fuel and the corresponding volume of the flue gas established by Rosin and Fehling. [Rosin P. and Fehling R., 1929] This methodology has already been used before in EEA studies and allows for an estimation of flue gas volume without detailed assumptions on fuel composition. [EEA, 2008]

The empirical relation between stoichiometric flue gas volume and net calorific value of the fuel is as follows:

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

Where
R = stoichiometric flue gas volume in m^3/kg fuel
NCV = net calorific value of the fuel in MJ/kg

To combust the fuel an amount of air is needed equal to:

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

Where
L = volume of air needed in m^3/kg fuel
NCV = net calorific value of the fuel in MJ/kg

Lastly the IED and BAT conclusions stipulate ELVs and AELs based on the assumption of excess oxygen in the flue gas. This additional amount of excess oxygen results from combustion optimization. To take this into account the following adjustment to the amount of flue gas volume is made:

$$\boldsymbol{R_{total}} = \left(\boldsymbol{R} + \left(\frac{21}{21 - \text{Surplus oxygen (\%)}} - 1\right) \cdot \boldsymbol{L}\right) / \boldsymbol{NCV} \qquad (\text{Unit: m}^3/\text{MJ})$$

Where
R_{total} = flue gas volume in m^3/MJ fuel
R = stoichiometric flue gas volume in m^3/kg fuel
L = volume of air needed in m^3/kg fuel
NCV = net calorific value of the fuel in MJ/kg

To apply the Rosin and Fehling relation we need to determine NCVs for the different types of fuel in the mapping between IED, BAT conclusions and the LCP database. The 2006 IPCC guidelines list an overview of NCVs for most fuels in Table 1.2. [IPCC, 2006] We will make use of the default NCVs in that table.

4.4.2 Calculating total emissions based on ELV or AEL

In some case AELs or ELVs are used to calculate total emissions. In this case the following calculation is used for each pollutant and for each fuel used by the LCP.

$$\boldsymbol{P_{tot}} = \boldsymbol{R_{total}} * \boldsymbol{F_{total}} * \boldsymbol{AEL\ or\ ELV}$$

Where
P_{tot} = total pollutant flow in mg
R_{total} = flue gas volume in m^3/MJ fuel
F_{total} = total amount of fuel used in MJ
AEL = associated emission level in mg/m^3

ELV = emission limit value in mg/m³

4.4.3 Calculating emissions from demonstrated emission factors

In some cases, demonstrated emission factors are used to calculate total pollutant emissions. The following calculation is used to determine the demonstrated emission factors.

$$EF_{dem} = P_{tot} / F_{total}$$

Where
EF_{dem} = demonstrated emission factor in mg/MJ
P_{tot} = total pollutant flow in mg
F_{total} = total amount of fuel used in MJ

The following calculation is used to determine total pollutant emissions.

$$P_{tot} = F_{total} * EF_{dem}$$

Where
P_{tot} = total pollutant flow in mg
F_{total} = total amount of fuel used in MJ
EF_{dem} = emission factor in mg/MJ

4.4.4 Applying the calculation methodology for BAT associated emission levels

For scenarios with LCP emissions defined by BAT AELs we distinguish between the period before 01/01/2021 and the period starting from 01/01/2021.

For the period before 01/01/2021 total emissions are calculated based on the status of the LCP. If it is an existing LCP which continues operation we will use demonstrated emission factors of 2016. If it is a retrofit or new LCP, we will apply BAT AELs.

For the period starting from 01/01/2021 we will apply BAT AELs in all cases.

In case a BAT AEL should be applied but there is no matching BAT AEL available, we will apply the demonstrated emission factors of 2016.

4.4.5 Applying the calculation methodology for IED emission limit values

For scenarios with LCP emissions defined by IED ELVs we apply demonstrated emission factors for all LCPs under an active derogation. In all other cases we will apply IED ELVs.

In case an IED ELV should be applied but there is no matching IED ELV, we will apply the demonstrated emission factors of 2016.

5 Scenarios

5.1 Base year in all scenarios

The proposed analysis starts with reported data in the LCP database. At this moment the LCP database contains reported data for the year 2016. Hence the base year in the proposed analysis will be 2016.

Analysis results for 2016 will reflect the actual reported emissions, fuel consumption, etc. for 2016 and not calculated counterfactual results.

For all future years the analysis will report calculated emissions, fuel consumption, etc. based on the actual reported information of 2016 and the other necessary assumptions as described in the methodology.

5.2 Scenario definitions

The developed scenarios are based on variations in the assumptions to be able to decompose the effects on total pollutant emission to:

1) Effect of the various emission limits (ELVs, upper and lower AELs)
2) Energy effects
   a) Effect of fuel efficiency (JRC EU-TIMES) and fuel type selection (energy scenario)
   b) Effect of energy scenario scaling

Table 5.1 Scenario definition

Scenario 0	Counterfactual	excluding fuel efficiency and fuel type selection + demonstrated emission factors of 2010
Scenario 1	IED all energy	all energy effects + application of IED ELVs
Scenario 2	BAT low all energy	all energy effects + application of BAT conclusion lower AELs
Scenario 3	BAT up all energy	all energy effects + application of BAT conclusion upper AELs
Scenario 4	IED energy investment	excluding energy scenario scaling + application of the IED ELVs
Scenario 5	IED energy operational	excluding fuel efficiency and fuel type selection + application of the IED ELVs
Scenario 6	IED no energy	no energy effects + application of IED ELVs
Scenario 7	BAT low no energy	no energy effects + application of BAT conclusions lower AELS
Scenario 8	BAT up no energy	no energy effects + application of BAT conclusions upper AELS

Scenario 0 of Table 5.1 is intended to compare the possible contribution of the IED and BAT conclusions with a hypothetical situation that the IED was never adopted and the LCPD instead remained the only regulatory regime. Since this is hypothetical, there is no actual data to base this scenario on. To simulate it nonetheless, we calculated the future fuel consumption of the LCP population according to the energy scenario scaling, excluding fuel efficiency and fuel type selection, and apply demonstrated emission factors of 2010 or the first operational year of the LCP, whichever comes last. The reasoning is that we want to take emissions from a time when the IED had not been defined and hence it can be assumed that there was no incentive to improve LCP emission performance beyond the specifications of the LCPD. [EC, 2001]

Scenarios 1, 2 and 3 show the result of the IED and BAT conclusions respectively based on a best estimate of future evolution of the LCP population as described above.

Scenario 4 and 5 allow for a decomposition of the energy scenario effects pollutant emissions with IED ELVs. As a result, scenario 4 only shows the effect of fuel type selection and fuel efficiency changes when a new LCP is constructed while ignoring changes in operational deployment with energy scenario scaling. Scenario 5 on the other hand excludes the effects of fuel type selection and fuel efficiency changes when a new LCP is constructed while it does consider changes in operational deployment with energy scenario scaling. By comparing scenarios 1, 4 and 5 the impact of emission factors, investment decisions and operational deployment of LCPs can be deduced.

Scenario 6, 7 and 8 allow for an analysis of the impact of fuel efficiency, fuel type selection and energy scenario scaling on the total pollutant emissions. This means that the fuel efficiency change and the fuel type switch as described in chapter 4.2.1, as well as energy scenario scaling as described in chapter 4.2.3, is omitted. New LCPs will be assumed to continue the use of the fuel being used in the existing LCP, have the same fuel efficiency, and the fuel mix will not be scaled with the energy scenario.

In conclusion scenario 1, 2 and 3 are the base scenarios; scenario 4 and 5 are intended to decompose the changes in total pollutant emission effect to its constituent energy scenario parts; and scenarios 6, 7 and 8 helps to assess the impact of energy scenario assumptions in relation to emission limit assumptions.

6 Results

6.1 Member state consultation feedback

The questionnaire was sent out to the EIONET NRC Industrial Pollution on 6th of July 2018. The deadline for feedback was initially set at the 31st of August 2018. The last feedback that could be processed was received the 13th of September. In total we received feedback of 8 Member States: Bulgaria, Cyprus, Greece, Hungary, Poland, Romania, Slovakia and the United Kingdom.

Information on expected retrofit or replacement dates was provided by most of the respondents. Technical specifications of new or replacement plants was however not always available or did not have all the information needed to associate these plants with all elements of the methodology.

Considering available Member State feedback and our methodology, we ultimately used the feedback on retrofit or replacement dates but not on technical specifications of those plants.

6.2 Scenario results

In the following sections we will actively compare the years 2016 (base year), 2021, 2025 and 2030. The reason for including the year 2021 is because at that point we assume the LCP BAT conclusions are completely integrated in all new and existing permits for power plants.

First, we will present a total pollutant emission comparison between IED Annex V ELVs and 2017 LCP BAT AELs. Both will also be offset against a hypothetical scenario assuming the IED to be non-existent.

Secondly, we will present a decomposition of the energy scenario impact in the case of IED emission scenarios. In that section we try to determine the relative impact of investment related or operational decisions in the energy scenario.

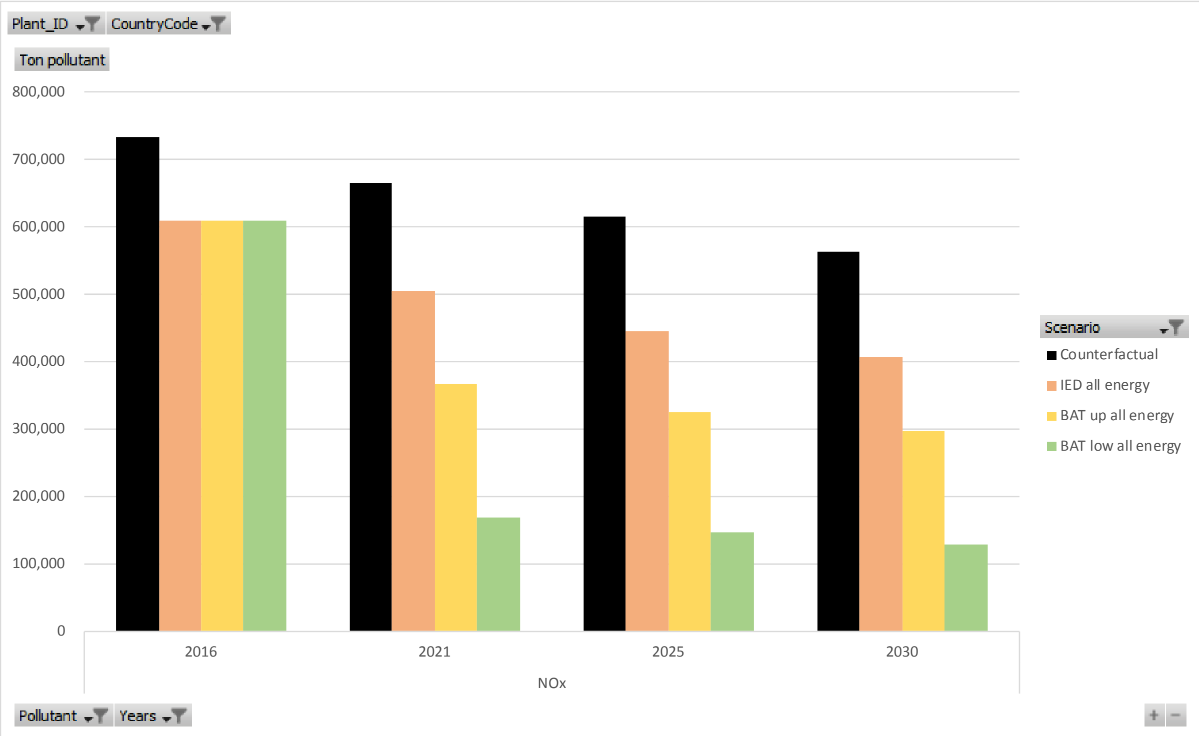
Thirdly we present the relation between the expected future fuel mix consumption and the IED ELV or BAT AEL related emissions.

Finally, we will present the main conclusions based on this high-level analysis and make suggestions for further elaboration in terms of methodology and the analysis conducted.

6.2.1 Comparison IED Annex V ELVs and 2017 LCP BAT-AELs

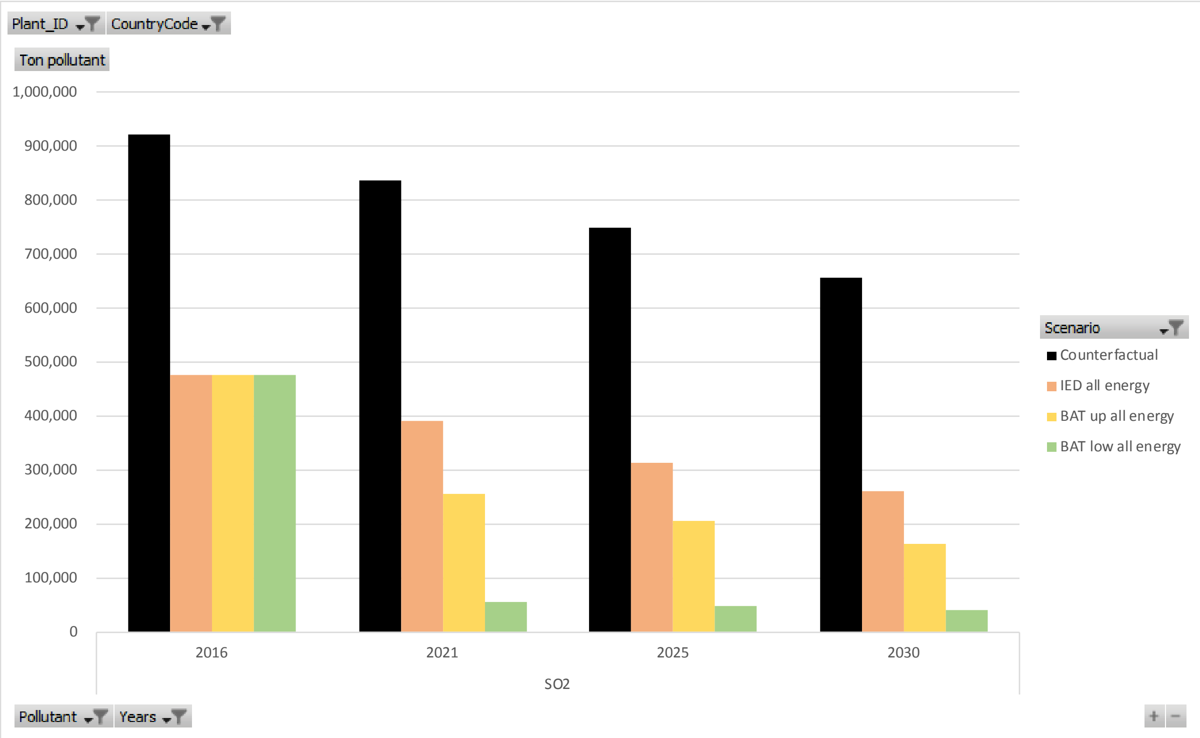
As a starting point for the analysis we compare total emissions for the counterfactual emissions, the IED and the BAT conclusions considering all aspects of the energy scenario. The goal of this comparison is to gain a better understanding of the benefit the IED and BAT conclusions can offer in terms of environmental protection in the near future.

Figure 6.1 Comparison of total NO_x pollutant emissions counterfactual, IED and BAT (ton pollutant)



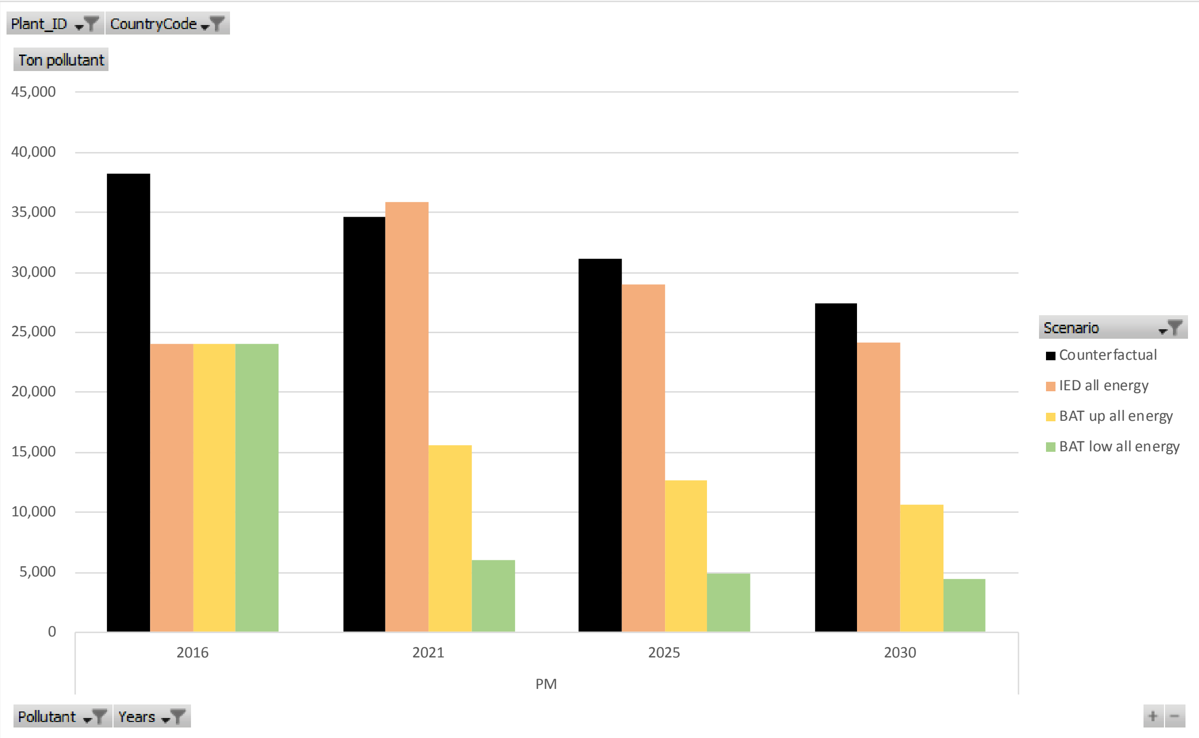
For NO_x emissions (Figure 6.1) the IED provides limited additional benefits in 2016 when compared to the counterfactual scenario (i.e. the hypothetical situation that the IED never replaced the LCPD). In other words, the IED did apparently not go much beyond the level of environmental protection with respect to NO_x already imposed by the LCPD. As from 2021 onward it is clear that the BAT upper AELs are more ambitious then IED ELVs and the BAT lower AELS even more so.

Figure 6.2 Comparison of total SO_2 pollutant emissions counterfactual, IED and BAT (ton pollutant)



For SO_2 emissions (Figure 6.2) it becomes immediately clear that the level of environmental protection achieved by the LCPD was at a significantly lower level than that brought about by the IED by 2016. From 2021 onward, we see a relation between IED ELVs and BAT upper AELs that is comparable to the one observed for NO_x. The BAT lower AELs on the other hand shows an even more pronounced decrease in total SO_2 emissions when compared to the IED Annex V ELVs.

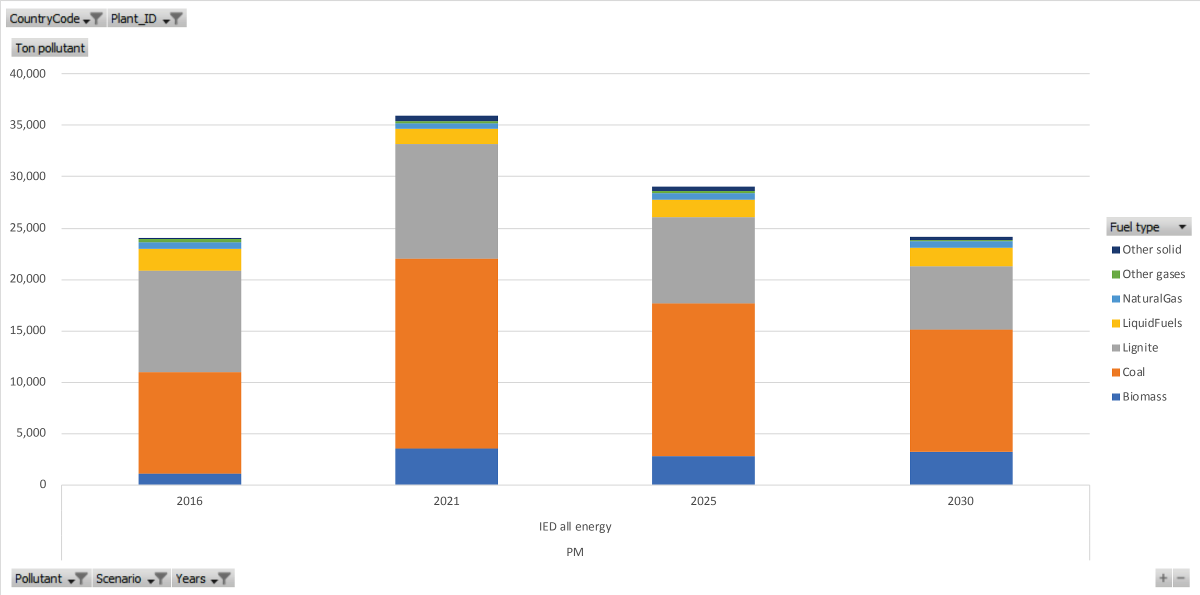
Figure 6.3 Comparison of total PM pollutant emissions counterfactual, IED and BAT (ton pollutant)



For PM (Figure 6.3) we again see a significant difference between the counterfactual emissions and the IED ELV emissions in 2016, although somewhat less pronounced then for SO_2. What is different for PM, as opposed to the situation for SO_2, is that in 2021 the IED ELV emissions are almost similar to those of the counterfactual scenario. This indicates that the real emission level in 2016 was, on average, already better than what the LCPD or the IED required. For PM both the BAT upper AELs as and the BAT lower AELs show significant reductions for PM emissions from the year 2021 onward when compared to the IED ELVs. The BAT lower AELs are again significantly more ambitious than the BAT upper AELs.

Noteworthy in the graph above is the observed increase in IED ELV PM emissions in 2021 when compared to the base year. The underlying reason for this is in the methodology where derogatory LCPs maintain their 2016 historic emissions if the derogation is ongoing. As soon as the derogatory regimes end the IED scenarios apply IED ELVs to the fuel consumed by these plants. This increase therefore shows that demonstrated emission factors for PM are in some case already significantly lower than the emission limit under IED Annex V. Further inspection shows us that the statement above holds especially true for coal fired LCPs. This is clearly shown in the graph below (Figure 6.4) where the coal related PM emissions almost double in 2021 when applying IED ELVs as compared to demonstrated emission factors in 2016. As will be shown further on in Figure 6.12, coal consumption decreases from 2016 to 2021 so the increase in emissions from coal is attributable to the IED ELVs as compared to demonstrated emission factors in 2016. Toward 2030, total emissions decrease again due to the energy scenario shifting away from coal fired thermal electricity production.

Figure 6.4 PM emissions per fuel type in IED all energy scenario (ton pollutant)



6.2.2 Decomposition of the energy scenario impact on IED emissions

A second type of comparison is between IED scenarios where different aspects of the energy scenario have been enabled or disabled. This allows for a decomposition of the effects on projected emissions of (1) the IED Annex V ELVs or 2017 LCP BAT-AELs (2) investment related energy aspects like fuel type selection and fuel efficiency gains, and (3) operational deployment related energy aspects like utilization of plants.

Figure 6.5 Decomposition of energy aspects on total NO_x pollutant emissions (ton pollutant)

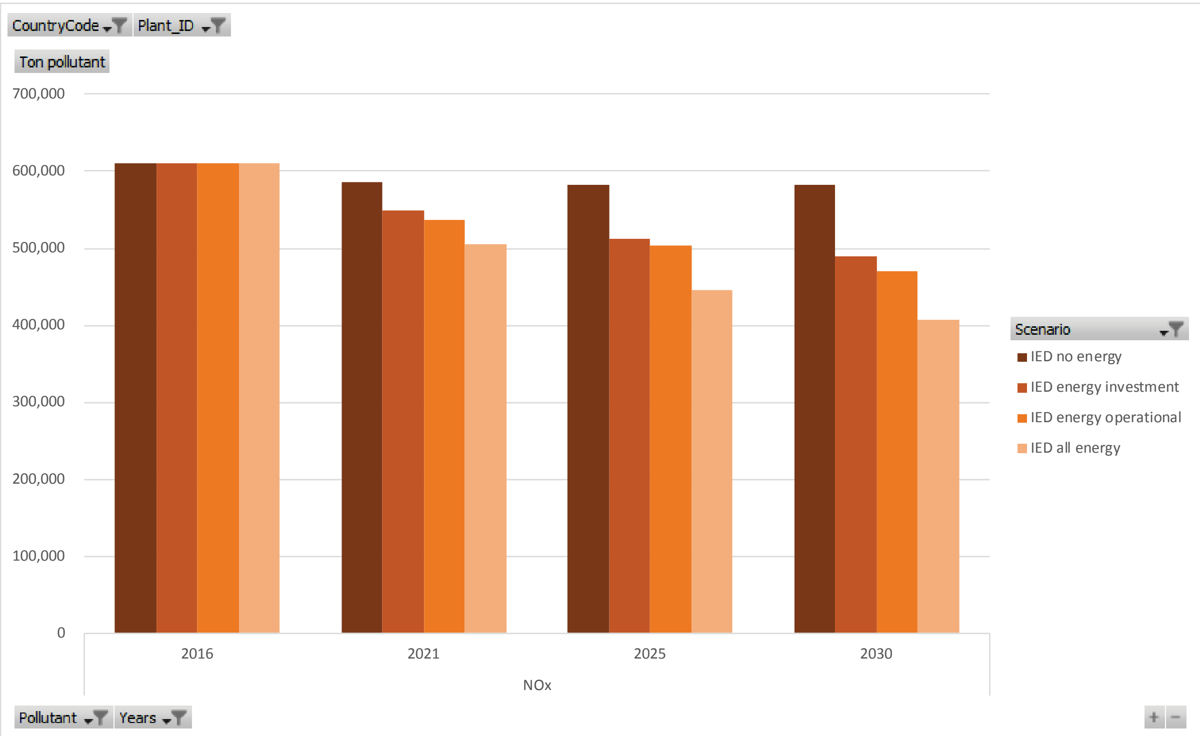


Figure 6.6 Decomposition of energy aspects on total SO_2 pollutant emissions (ton pollutant)

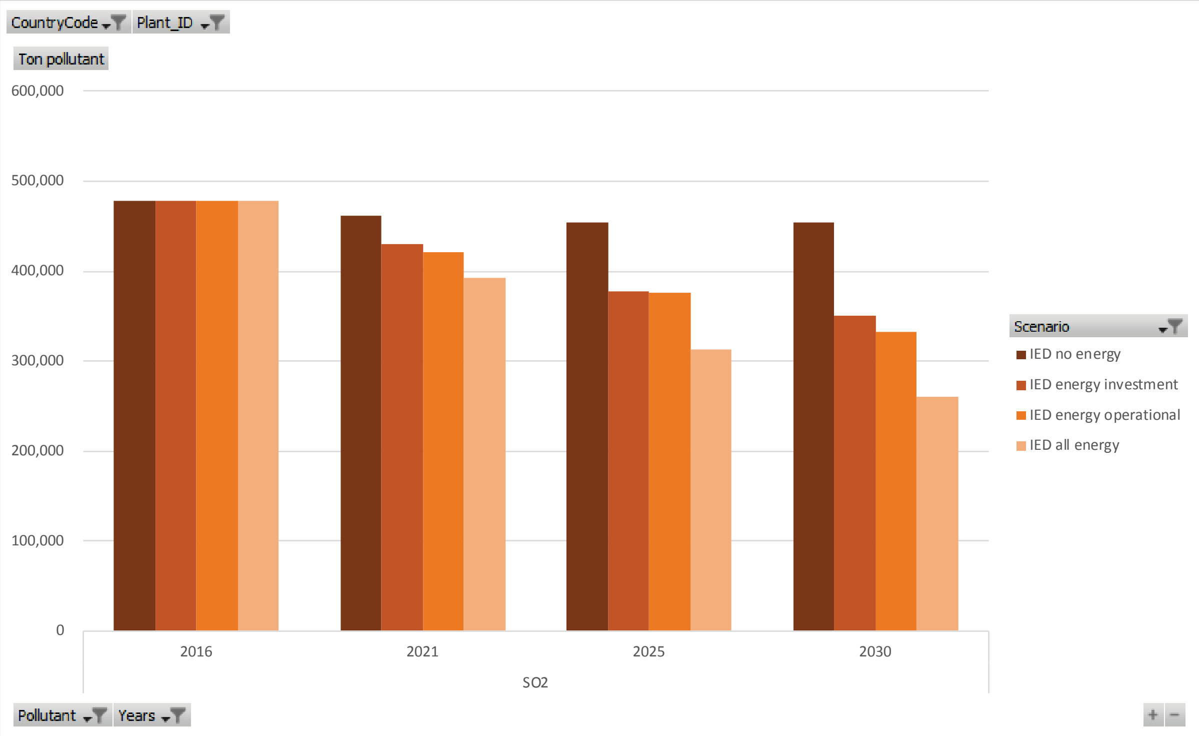
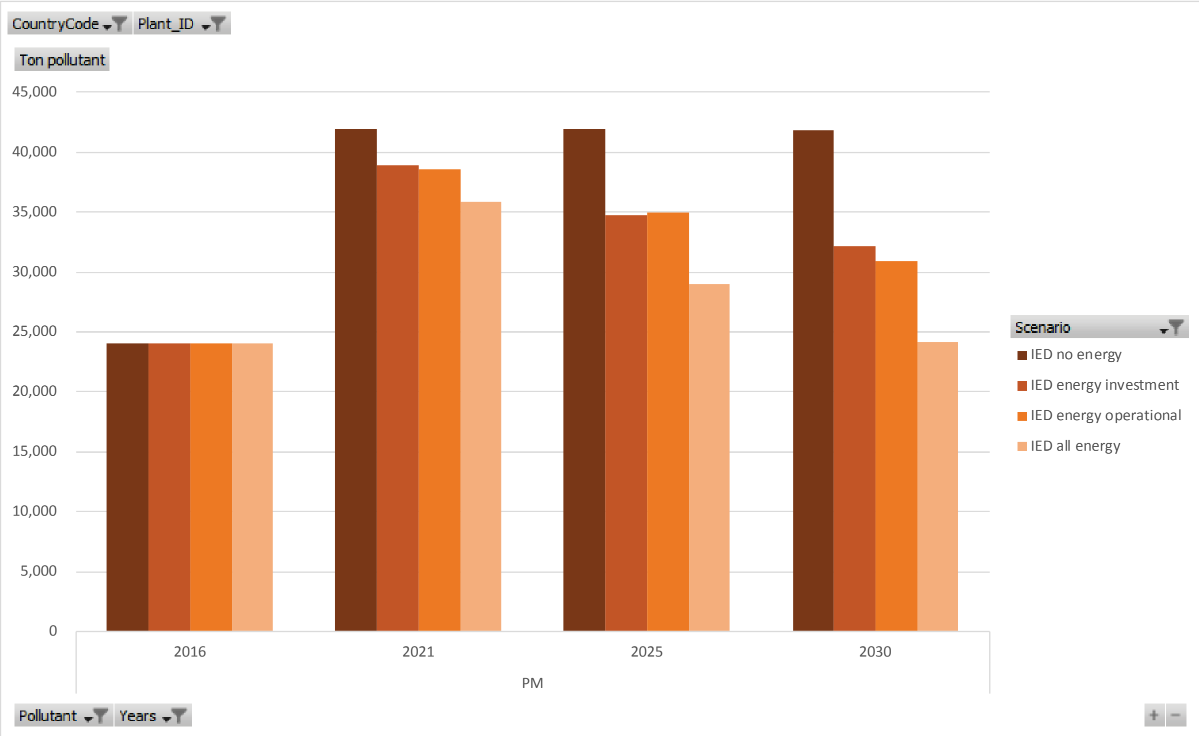


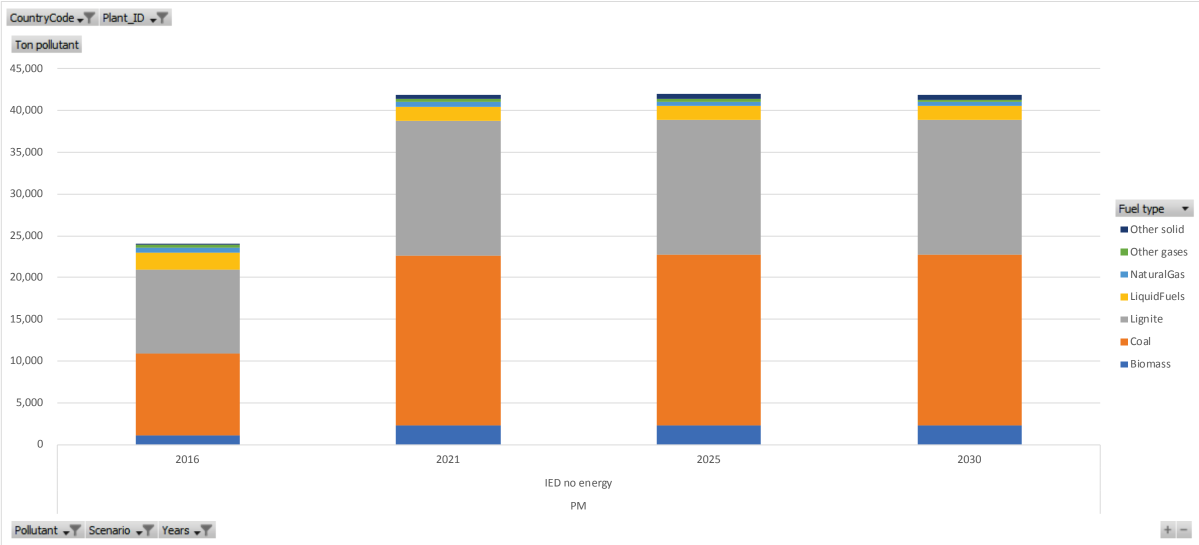
Figure 6.5 and Figure 6.6 illustrate clearly the major impact the energy scenario has on expected NO_x and SO_2 emissions. If (hypothetically) the existing LCPs would continue operating and simply comply with IED ELVs, the expected NO_x and SO_2 emission reduction in 2030 would be approximately 1/3 less than when both investment and operational aspects of the energy scenario and EU-TIMES are considered. Overall operational aspects appear to have a slightly larger impact on emissions than investment related aspects. The main reason for this is likely the expected increase in renewable electricity sources and the reduction in thermal fuel fired electricity generation. In addition, there is also a shift from solid fuels to gaseous fuels in the EU 2016 reference scenario for the remaining thermal fuel fired electricity generation between 2016 and 2030. On the investment side there is also a shift from solid fuel fired capacity to more gaseous fuel fired capacity. As this often coincides with improved fuel efficiency, it also leads to emission reductions.

Figure 6.7 Decomposition of energy aspects on total PM pollutant emissions (ton pollutant)



For PM emissions (Figure 6.7) we observe the same increase in emissions as described in section 6.2.1 when the IED ELVs take effect after derogatory regimes end. In the comparison above this effect is even more pronounced in the scenarios where the energy scenario effects are disabled. The IED no energy scenario result in 2021 gives a very good indication of the effect the application of IED ELVs have on total PM emissions when compared to demonstrated PM emissions in 2016. They are on average almost 1/3 higher. A fuel breakdown analysis shown in Figure 6.8 clearly shows the impact of coal related IED ELVs in 2021 when compared to the demonstrated emission factors for coal in 2016. As the shown scenario is the 'IED no energy scenario', there is no evolution in the energy usage. As such the difference in total emissions is completely attributable to the used emission factors, IED ELVs from 2021 versus demonstrated emission factors in 2016. The use of this scenario without energy impact also means that the total emissions remain almost constant from 2021 onwards.

Figure 6.8 PM emissions per fuel type in IED no energy scenario (ton pollutant)



6.2.3 Fuel mix interaction with the IED and BAT conclusions

In section 6.2.2 above we established the significant impact of the different energy scenario components on IED scenarios, both investment related and operational aspects. In the following graph (Figure 6.9) we present the full impact of the energy scenario and fuel efficiency from EU-TIMES on total emissions for both the IED and the BAT conclusions.

Figure 6.9 Impact of energy aspects on total NO_x emissions (ton pollutant)

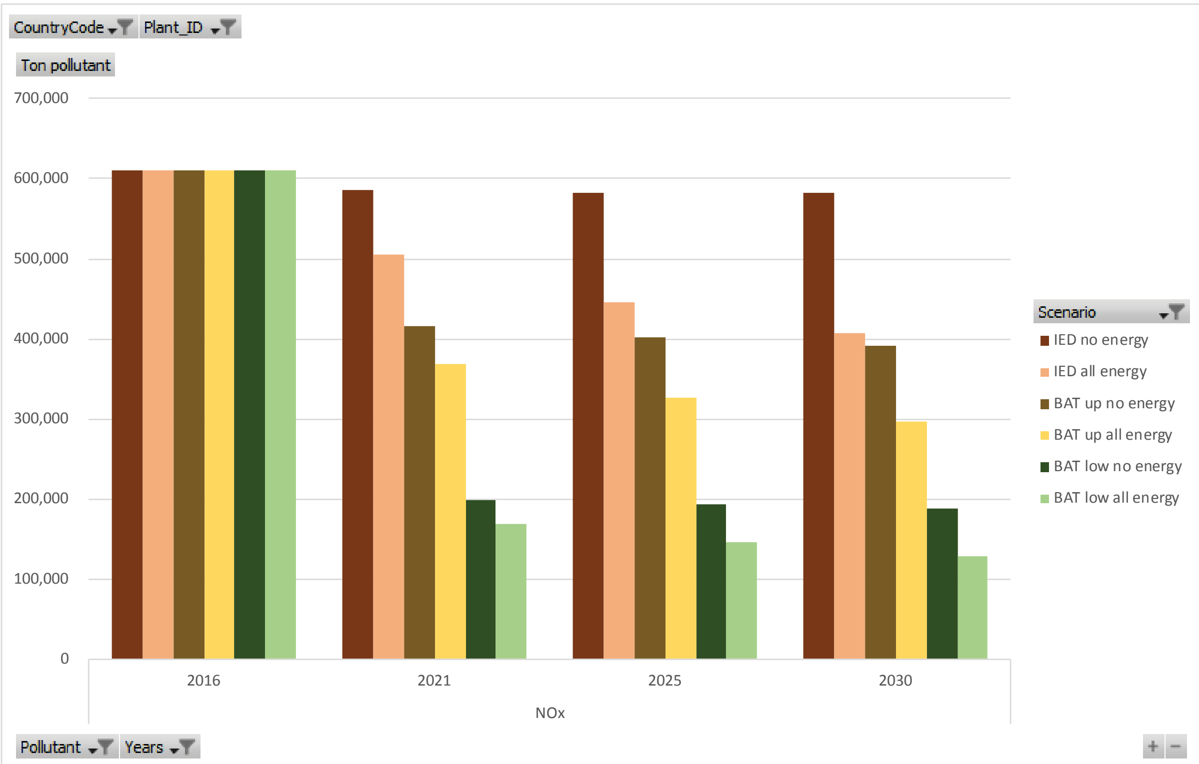
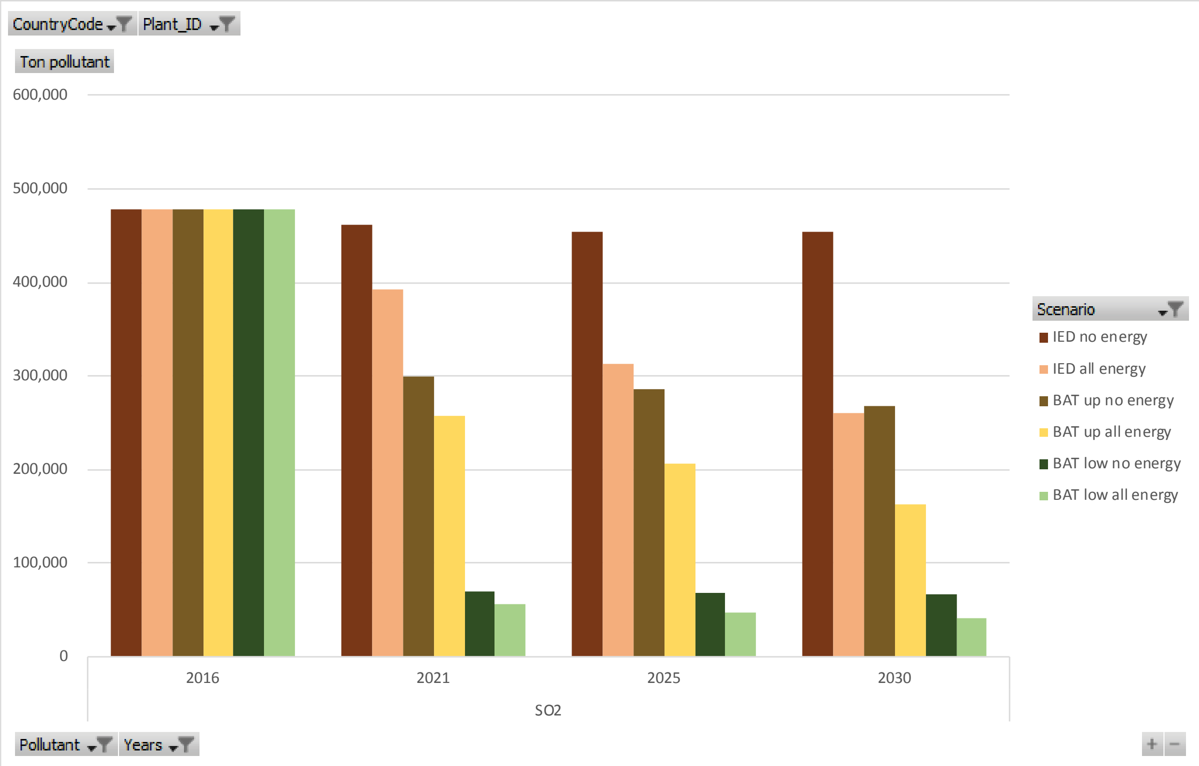
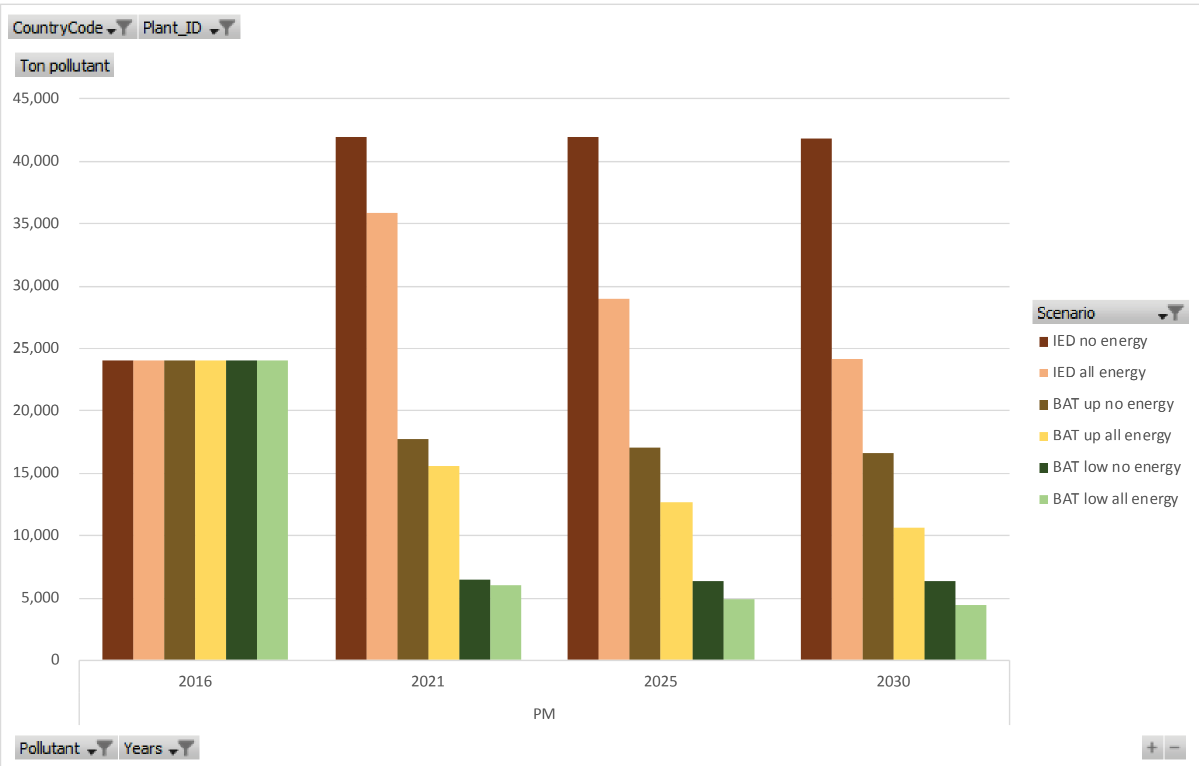


Figure 6.10 Impact of energy aspects on total SO_2 emissions (ton pollutant)



In Figure 6.9 and Figure 6.10 total NO_x and SO_2 emissions are compared for IED ELVs, BAT upper AELs and BAT lower AELs each time with all energy aspects considered and no energy aspects considered. For each of the emission limits considered, the comparison shows roughly the same significant impact of energy aspects. In the case of the IED it is more pronounced than in the BAT upper and BAT lower case.

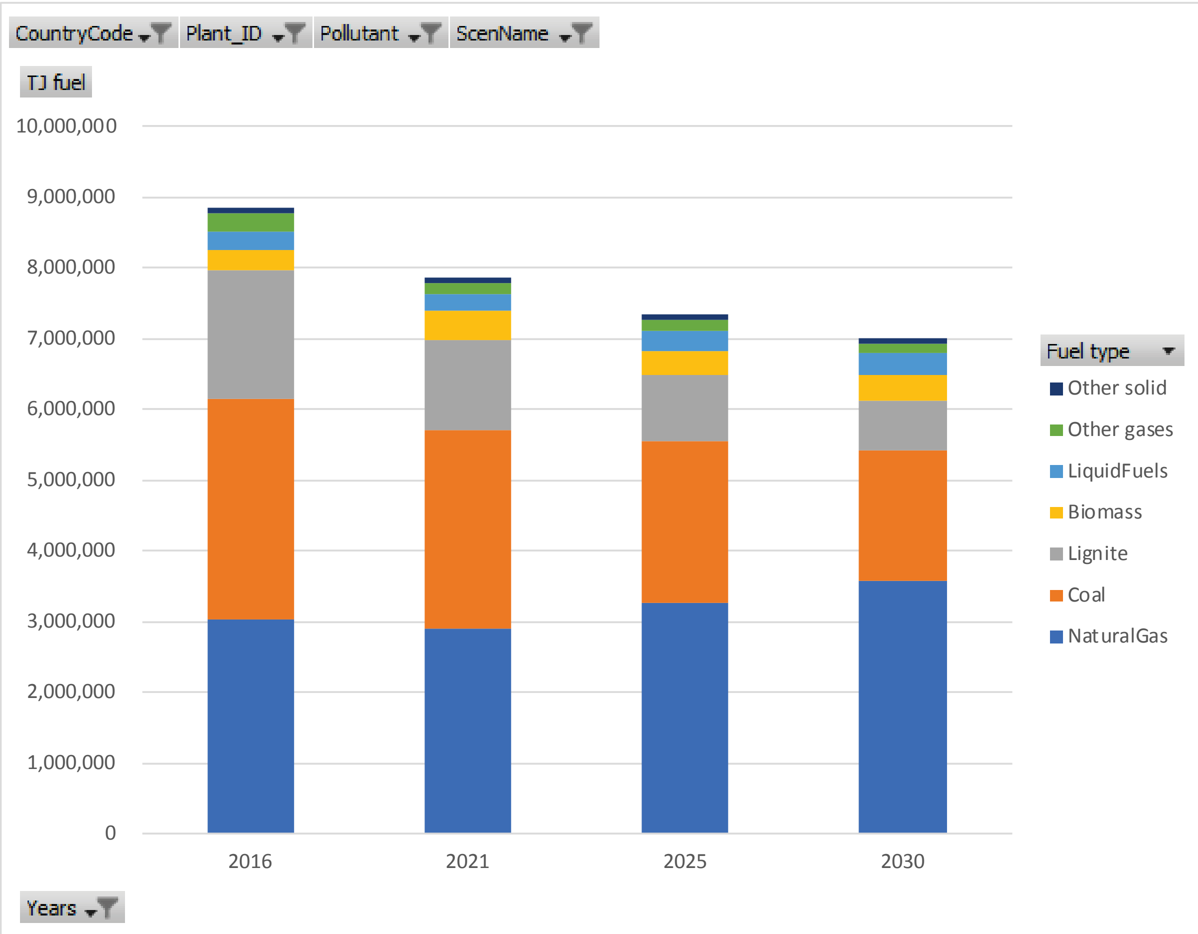
Figure 6.11 Impact of energy aspects on total PM emissions (ton pollutant)



For total PM emissions there is also a significant impact of the energy scenario, just like for NO_x and SO_2 (see Figure 6.11). We therefore again observe the initial increase in PM emission from 2016 demonstrated emission factors to 2021 IED ELVs. The same effect of coal fired electricity generation as described in section 6.2.1 and 6.2.2 can be observed here.

Now that we have established the significant impact of the energy scenario aspects, we present in the graph below (Figure 6.12) the fuel type breakdown of the adopted energy scenario. Since it is the same for both IED and BAT conclusion scenarios, as well as for all pollutants, we don't have to differentiate between different scenarios and pollutant.

Figure 6.12 Fuel type breakdown of the evolution in energy consumption (TJ fuel)



In the graph above we observe a significant reduction in total fuel consumption in the period 2016 up to 2030. The main reason for this decrease is the gradual shift from thermal power plants to renewable electricity generation like wind, photovoltaic, and so on. This decrease already explains a large part of expected total pollutant emission reductions observed earlier. A secondary effect on pollutant emissions is a result of the shift from solid fuel combustion to gaseous fuel combustion. In the graph above there is a significant reduction in coal and lignite combustion coupled with a modest increase in natural gas combustion. Not only does this fuel switch usually leads to lower IED ELVs and BAT AELs, it also leads to increased fuel efficiency since thermal combustion of natural gas usually has a higher electrical output per unit fuel then coal or lignite.

6.3 Conclusions

The scenario analysis and the high-level analysis of the results revealed the following key conclusions for the studied group of LCPs:

- IED ELVs will force limited improvements in total NO_x and SO_2 emissions in the near future while for PM they will have close to no further impact.
- BAT AELs are much more ambitious for all pollutants (NO_x, SO_2 and PM) than the IED ELVs. Hence it is to be expected that they will force a significant decrease in LCP pollutant emissions in the near future.
- Total pollutant emissions are influenced by expected evolutions in energy consumption for thermal electricity production. A conversion to more renewable electricity generation will result in a significant decrease of future pollutant emissions. This is further reinforced by the expected shift from coal to gas based non-intermittent electricity generation.

6.4 Areas for further analysis

The applied methodology and its analysis could both benefit from further elaboration. In Table 6.1 and Table 6.2 we list some opportunities that might be realized in the future.

Table 6.1 Possible elaboration on the methodology

Possible elaboration on the methodology	Complexity	Possible impact
Some of the BAT AELs are assigned on a more detailed LCP profile then we could construct based on the current LCP reporting. Accuracy of the scenarios might be further improved by obtaining a more detailed characterisation of the LCP population on areas like, but not limited to, specific combustion method used (pulverised solid fuel, fluidised bed, gasification…), specific fuel traits (high sulphur, potassium or sodium content…), permitting date of LCPs….	Medium	Low - High[2]
The same remark as the one before holds to a lesser degree for IED ELVs. Here the match is easier than with the BAT AELs though since the LCP reporting has been partially designed to cover this.	Medium	Low
Retrofit, closure and replacement of LCPs is now always defined for the entire LCP while only parts might be subject to change.	High	Low
Fuel efficiency changes have now been based on generic assumptions for existing LCPs. For new LCPs both the combustion method and the resulting fuel efficiency are based on the generic assumptions. Both could be further detailed and elaborated if more information is available.	Medium	Medium
Combined scenarios taking the lowest of demonstrated emission factors, IED ELVs and BAT AELs on an individual LCP level can be developed. Now totals are compared but for individual cases or subgroups these conclusions might not hold.	Low	Medium

[2] Only high if it concerns errors in coal gasification and then mostly for PM

Table 6.2 Possible elaboration on the analysis

<table>
<tr><th>Possible elaboration on the analysis</th><th>Additional analysis needed</th></tr>
<tr><td>In the scenario results, a lot more dimensions are available that could be used to further disaggregate the reported total emissions. Available dimensions of interest are:
Country
Region
Fuel type consumed
Type of combustion plant (boiler, turbine…)
LCP grouping on derogatory regimes</td><td>No, all information is contained in current results</td></tr>
<tr><td>The reason for the observed low demonstrated emission factors, as opposed to IED ELVs, for coal fired PM emissions should be pinpointed. Possible hypothesis are, among others:
Secondary abatement technology was implemented with, at that time, a future BAT AEL in mind
Additional PM emission abatement is realised as a collateral effect of other abatement measures
Coal gasification is confused with coal combustion</td><td>Yes, information on abatement technologies in place and combustion method needs to be gathered</td></tr>
<tr><td>Close to full decarbonisation of the energy system might lead to a significant shift in the mix of fuel types and combustion methods for electricity generating LCPs. The adequacy and level of environmental protection of BAT AELs might be assessed in the context of the following possible future states (a non-exhaustive list):
CCS triggers a focus on solid fuels like coal
Impact of carbon capture on resulting air emission factors
Biomass receives renewed interest as providing some of the necessary flexibility offset for intermittent electricity production like solar and wind energy.
Power-to-gas-to-power and resulting air emissions</td><td>Yes, depending on the future state additional needs might be of a technological nature or simply the construction of alternative energy scenarios to apply emission factors to</td></tr>
</table>

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