Ricardo Energy & Environment

Technical support for developing the profile of certain categories of Large Combustion Plants regulated under the Industrial Emissions Directive

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Contact:

Tim Scarbrough
Ricardo Energy & Environment
30 Eastbourne Terrace, London, W2 6LA
United Kingdom

t: +44 (0) 1235 75 3159
e: tim.scarbrough@ricardo.com

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Author:

Tim Scarbrough (Ricardo), Jeroen Kuenen (TNO), Stijn Dellaert (TNO), Koen Smekens (ECN), Pieter Lodewijks (VITO), Yoko Dams (VITO), James Sykes (Ricardo)

Approved By:

Ben Grebot

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Abbreviations & Glossary

ACI	Activated carbon injection
BACI	Bromide addition to activated carbon injection
BAT-AEL	Best available techniques associated emission level
BATIS	Best available techniques online information system
BF	Bag Filter (end of pipe dust control technique)
BREF	Best available techniques reference document
CHP	Combined heat and power
DSC	Dry and semi-dry flue gas desulphurisation (end of pipe SO_2 control technique)
EEA	European Environment Agency
ELV	Emission limit value
E-PRTR	European Pollutant Release and Transfer Register
ESP	Electrostatic precipitator (end of pipe dust control technique)
ESP+/ESP++	Advanced / upgraded ESP
FGD	Flue Gas Desulphurisation
GAINS	Greenhouse gas - Air pollution INteractions and Synergies model
Hg	Mercury
IED	Directive 2010/75/EU on industrial emissions
LCOE	Levelised cost of electricity
LCP	Large Combustion Plant
LCPD	Directive 2001/80/EU on emissions from large combustion plants
LCP EI	Emission Inventory of LCPs reported under LCPD
LLD	Limited life time derogation – Article 33 of the IED
LNB	Low NOx burner
MS	EU Member State
MW_e	Electrical capacity in megawatts
MW_{th}	Rated thermal input capacity in megawatts
NCV	Net calorific value
NO_X	Nitrogen oxides
Opt out	LCPs designated under Article 4(4) of LCPD
PRIMES	Price-Induced Market Equilibrium System model of EU energy system
PMS	Primary measures (for NOx control)
SCR	Selective catalytic reduction (end of pipe NOx control technique)
SNCR	Selective non-catalytic reduction (end of pipe NOx control technique)
SO_2	Sulphur dioxide
TNP	Member State Transitional National Plans submitted under Article 32 of the IED
WEPP	Platts World Electric Power Plant database

WSC	Wet flue gas desulphurisation (end of pipe SO_2 control technique)
WSC+	Advanced / upgraded WSC

Executive summary

Introduction

Despite significant reductions in recent years, emissions from large combustion plants (LCPs) still represent one of the largest sources of air pollutant emissions in the EU, particularly coal and lignite fired plants. Extensive EU regulation - including the Ambient Air Quality Directive, the National Emission Ceilings Directive (NECD) and several Directives regulating emissions at source including the Industrial Emissions Directive – has brought down pollution significantly over recent decades. Nevertheless, further reductions are needed. The emission limit values in the IED represent minimum requirements (binding emission limit values) for the main pollutants. The IED also requires LCPs to be operated according to permit conditions based on Best Available Techniques (BAT). At an EU level, these are defined in BAT Reference documents (BREFs). The revision of the LCP BREF started in 2011, and technical work has been completed following a number of years of development and negotiation. The June 2016 Final Draft LCP BREF has been used for this study. The Commission has requested to improve its understanding of emission reduction potentials and the costs of applying the BAT conclusions on solid fuel fired LCPs.

Approach

A bottom-up model of LCPs over $300MW_{th}$ in the EU that are solid fuel fired (>75% biomass, coal or lignite) has been developed, drawing on three main data sources: the Member State reported LCP emission inventories, the Platts Worlds Electric Power Plant (WEPP) database, and E-PRTR. The LCPs have been split into their constituent units, and key characteristics assessed at both unit and plant level: capacity, fuel consumption, load factor, installed pollution abatement equipment, SO_2, NO_X, dust and mercury emissions and emission concentrations. The baseline year of the activity data in the model is 2013. Future years 2020, 2025 and 2030 have been projected as a Reference scenario that accounts for:

- Closures of LCPs opted out of the LCPD and those with LLD under the IED
- Expiry of remaining Accession Treaty derogations from LCPD ELVs
- Planned biomass conversions indicated in WEPP and in the MS TNPs.
- Planned new plants that are forecast in the WEPP database.
- Structural changes (including plant closures) in the power sector due to the impact of climate and energy policies. This has been accounted for by aligning the model totals at MS level with changes in capacity and fuel consumption forecast by the PRIMES model for 2020, 2025 and 2030. The methodology has been designed in such a way so as to avoid double counting of the effects of the IED.

Three scenarios have been considered, as deviations from the Reference scenario in 2020, 2025 and 2030: (1) the IED ELV, (2) upper BAT-AEL and (3) lower BAT-AEL scenarios (BAT scenarios based on BAT-AELs in the June 2016 'Final Draft' LCP BREF). In these scenarios, a least-cost algorithm has been applied to bring LCPs into compliance with the relevant ELV or BAT AEL, through theoretical implementation of pollution abatement techniques to those plants estimated as not meeting the limits. Costs and abatement efficiencies of pollution abatement techniques, as well as their applicability, have been drawn from literature. The costs of the abatement techniques fitted at unit level required for compliance at plant level with limit values, and the associated emission reductions, have been estimated. The monetised health and environmental benefits arising from reductions in SO_2, NO_X, PM_{10} and Hg emissions have been quantified using damage costs.

Key findings

1. The impacts of legacy policies (closures of LCPD opt outs, expiry of Accession Treaty LCPD derogation) and other transitionary changes (closures of plants in a declining coal industry, including IED LLD plants) without imposition of the IED ELVs is expected to have led to substantial emission reductions by 2020 in the reference scenario: reducing 2013 baseline annual SO_2 emissions by 41%, NOx by 27%, dust by 49% and Hg by 24%. These emission reductions represent monetised benefits of €19bn/year in 2020.

2. The costs of abatement techniques to meet the **IED ELVs** from the reference scenario is estimated to be €1.0bn/yr in 2020 (declining to €0.75bn/yr by 2025 and €0.54bn/yr by 2030), comprising predominantly NO_X and SO_2 compliance costs. The costs are estimated to arise mostly from new, additional or replacement techniques rather than upgrades of techniques. Meeting the IED limit values is estimated to lead to further substantial emission reductions of the sector in scope of this study of around 45% reductions in SO_2, 32% NOx and 49% dust, as well as co-beneficial Hg reductions of 8% compared to a reference scenario in 2020. The estimated benefits of these emission reductions (dominated by the valuation of SO_2 emission reductions) sum to €11.2bn/yr in 2020, declining to €9.9bn/yr in 2025 (i.e. a benefit-cost ratio of around 13:1 in 2025) and €6.8bn/yr in 2030. All Member States in scope of this study (apart from Portugal and Sweden) are estimated to need to fit techniques to meet the IED ELVs. In 2025, for all Member States bar one (France), the benefits of emission reductions due to these investments are estimated to outweigh the costs of the techniques. The estimated costs are shown against the benefits for meeting the IED ELVs in 2025 in Figure 1, since the full need to meet stricter BAT-AELs will be after 2020.

3. Meeting the **upper BAT-AELs**, as measured beyond the IED ELV scenario, comprises three categories of plants:
    - Plants whose techniques installed to meet the IED ELVs also enables them to meet the upper BAT-AELs. These plants incur no additional technique compliance costs to meet the upper BAT-AELs.
    - Plants that already met the IED ELVs without incurring compliance costs, but which are estimated to need to fit <u>additional</u> techniques to meet the upper BAT-AELs.
    - Plants that are estimated to fit certain techniques to meet the IED ELVs but which are estimated to need to fit <u>different</u> techniques to meet the upper BAT-AELs. Accounting for the full cost of these techniques is an upper bound of the compliance cost impacts of the upper BAT-AEL scenario. These plants may be expected to incur stranded costs due to the short time frame between incurring costs to meet IED ELVs (2016 at the latest except in cases of derogations) and to meet BAT-AELs, for example if the techniques needed to be installed to meet the upper BAT-AELs implies the need to remove the techniques that were needed to meet the IED ELVs. The marginal cost increment of the different techniques above those needed to meet the IED ELVs could be considered a lower bound of the compliance costs.

    Out of 264 plants estimated to be operational in 2025, 136 plants are estimated to need to fit <u>additional</u> techniques to those already fitted to meet the IED ELVs, and in doing so are estimated to incur costs of €0.32bn/yr to reduce one or more of SO_2, NO_X, dust or Hg.

    On top of this €0.32bn, there are a further 53 plants in 2025 estimated to incur €0.11bn/yr more than the costs already incurred in the IED scenario as <u>different</u> techniques are estimated to be needed to meet the upper BAT-AELs. However, for these plants, the full costs of the techniques to meet the upper BAT-AELs would be €0.27bn/yr, i.e. there could be up to €0.16bn/yr of stranded costs. Furthermore, depending on the techniques fitted, the full cost of €0.27bn/yr may not be incurred if there is no need to remove existing abatement equipment. These plants could potentially be candidates for applications for time-limited derogations under IED Article 15(4).

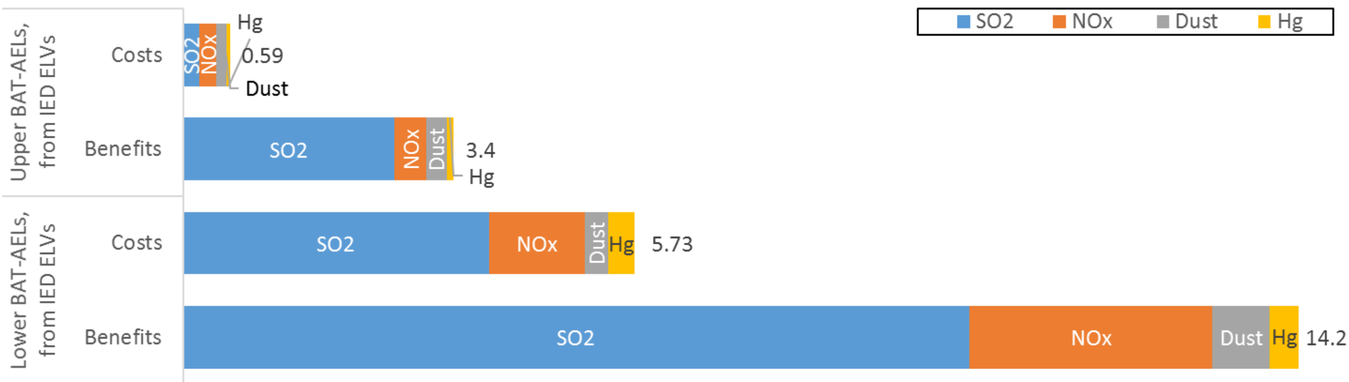
    As a best case, the total compliance cost of meeting the upper BAT-AELs taking into account the plants fitting additional techniques and the marginal additional cost of those plants fitting different techniques to the IED is estimated to be €0.55bn/yr in 2020 falling to €0.43bn/yr in 2025 and €0.32bn/yr in 2030. However, the the total compliance costs of meeting the upper BAT-AELs, after accounting for the full cost of those plants fitting different techniques to the IED, could be higher at €0.79bn/yr in 2020 falling to €0.59bn/yr in 2025 and €0.41bn/yr in 2030. The higher total costs in 2025 are shown in Figure 1.

    The majority of the LCPs in scope of the study are electricity generating plants. The incremental compliance costs of meeting the upper BAT-AELs, when considered as a proportion of estimated Member State average levelised cost of electricity generation, is estimated to vary substantially between Member States. The proportion varies between 0% and 4.1%, depending on the Member State. The upper BAT-AEL compliance costs have been estimated to be smaller than the costs of their CO_2 emissions priced from the EU ETS, typically varying between 2% and 20% of the carbon costs among Member States.

The benefits of the emission reductions of meeting the upper BAT-AELs, estimated based on existing compliance with the IED ELVs, is estimated to be €3.8bn/yr in 2020, declining to €3.4bn/yr in 2025 and to €2.8bn/yr in 2030. As such, the benefits at EU level of reducing emissions to meet the upper BAT-AELs are estimated to outweigh the costs by a factor of more than 5 to 1. In 2025, for all Member States bar one (Ireland), the benefits of emission reductions are estimated to outweigh the costs of the techniques needed to reduce emission levels to upper BAT-AELs. The benefits in 2025 are shown in Figure 1.

4. Meeting the **lower BAT-AELs** is estimated to lead to large SO_2, NO_X, dust and Hg emission reductions from the Reference and IED scenarios. In particular, SO_2 emissions are reduced substantially. The benefits of the emission reductions of meeting the lower BAT-AELs, compared to compliance with the IED ELVs, is projected to be €15.5bn/yr in 2020, declining to €14.2bn/yr in 2025 and to €10.2bn/yr in 2030. The costs of this scenario are estimated to be much higher than the other scenarios: €5.7bn/yr more than the IED ELV scenario in 2025, and compliance costs dominated by SO_2 technique costs followed by NOx technique costs. The costs and benefits of this scenario are shown in Figure 1. The lower BAT-AEL scenario would appear to require high efficiency versions of abatement techniques of wet flue gas scrubbers (WSC), selective catalytic reduction (SCR) and electrostatic precipitators (ESP), as well as dedicated Hg abatement techniques. The total EU benefit-cost ratio of 2.5:1 is lower than for the other scenarios but still with benefits exceeding costs. The benefit-cost ratios vary among the Member States from 4.5:1 for the UK to 0.1:1 (i.e. costs 10 times benefits) for Portugal.

Figure 1 Estimated annual (in 2025) EU compliance costs and benefits of emissions reductions of meeting the upper and lower BAT-AELs from a baseline of already meeting the IED ELVs (€bn/yr)



Uncertainties

Despite the large amount of data available for the LCP sector, the data itself remains a limitation of the modelling. Specifically, although some errors in the source data on emissions were identified and resolved, further errors may persist. In addition, errors may have been inadvertently introduced through incorrect manual linking of datasets covering individual plants and their units. Furthermore, where there were gaps in the data, in-filling techniques were drawn upon, leading to increased uncertainty in the outcomes. For example, of all the pollutants, least information was available on the existing installed NO_X abatement techniques at plants, particularly related to the extent and type of primary techniques used for NO_X reduction. This meant that, compared to SO_2 and dust, there is more uncertainty in the model-selected techniques and thus costs for reducing NO_X.

Estimating future impacts is inherently uncertain. This work is no different; a number of assumptions have been necessary to make in the modelling, and in cases the methodology itself introduces uncertainties. The cost results are most sensitive (-12% to +15%) to the uncertainty in the assumed techniques for compliance, the annualisation of capital costs and the estimation of plant emission concentrations. In addition, the assumed cost of abatement techniques may introduce further uncertainties. The benefits results are most sensitive (-50% to +50%) to the uncertainty in valuing health and environmental impacts, in particular damage costs for SO_2 emissions. However, for the lower BAT-AEL scenario which has the lowest estimated benefit-cost ratio at EU level, even with the most pessimistic assumptions (e.g. benefits valued 50% lower) the benefits still outweigh the costs.

In addition, the forecast reference scenario coal and lignite consumption may be over-estimated as the PRIMES scenario used does not include the effects of the 2030 climate and energy framework which could be expected to lead to a further shift away from coal and lignite consumption from the assumptions used in this modelling study. That further shift could be commensurate with higher carbon costs, which – if the current accounting for CO_2 emissions from biomass burning remain – could lead to further replacement of coal/lignite capacity with biomass. This could significantly alter the estimated compliance costs and benefits, particularly in 2025 and 2030.

A description of each uncertainty and limitation is made in the report. A number of the key assumptions have been included in sensitivity analysis in section 4.

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1 Introduction

1.1 This report

This is the final report from the project "*Technical support for developing the profile of certain categories of Large Combustion Plants (LCP) regulated under the Industrial Emissions Directive (IED)*", under contract 070201/ENV/2015/715370/C4 to the European Commission. This specific contract is service request 18 under framework contract ENV.C.3/FRA/2011/0030. The report describes the methodology and results of modelling to estimate the emission and cost impacts of EU solid fuel fired LCPs of rated thermal input over 300 MW_{th} meeting the BAT-AELs to be included in the forthcoming LCP BAT Conclusions.

1.2 Context

1.2.1 Large Combustion Plants in the context of EU air quality

Large combustion plants (LCPs) are significant sources of air pollution in the EU. The Large Combustion Plant Directive (LCPD) 2001/80/EC, which was repealed and replaced by the Industrial Emissions Directive on 1st January 2016, has already significantly reduced emission levels of SO_2, NO_X and dust from LCPs. Yet in 2013, the public electricity and heat production sector still contributed 48% of SO_X, 18% of NO_X and 4% of PM_{10} emissions in the EU28[1]. Over 95% of the coal and lignite consumption of LCPs in 2013 was in the largest plants – those with rated thermal input over 300MW_{th}. Specifically coal/lignite-fired LCPs continue to levy health and environmental burdens – the EEA (2014) established that 26 power generating plants fuelled by coal/lignite were among the top 30 industrial facilities estimated to cause the greatest damage in the EU between 2008 and 2012.

Coal and lignite burning is also one of the most important sources of mercury emissions into air. The EU emissions of mercury to air were estimated at 4.5% of global atmospheric mercury emissions; around half of these emissions were released from stationary combustion of coal (UNEP, 2013). Based on emissions reported in E-PRTR in 2010, around one third of total emissions of mercury to air originated from ≥50MW_{th} combustion installations (although this is likely to be an underestimate due to reporting thresholds). According to the estimates by the EEA, costs of damage caused by the air emissions from all the E-PRTR industrial facilities – i.e. not just LCPs – for the period 2008-2012 were in the range of €330 to €1,050 billion (EEA, 2014). Mitigating the impacts on public health and the environment therefore remains the key driver for further industrial emission control.

1.2.2 Regulatory framework

Air pollutant emissions

The EU regulatory framework affecting air emissions from LCPs is centred on the **Industrial Emissions Directive (IED) 2010/75/EU**. Emission limit values (ELVs) specified in Annex V to the IED represent minimum requirements, and these came into force from 1 January 2016 for existing plants (Article 30(2)) and from 7 January 2013 for new plants (Article 30(3)). The IED further necessitates compliance with the emission levels associated with the best available techniques (BAT-AELs) which are set out in legally binding "BAT Conclusions" for each sector – Commission Implementing Decisions providing key conclusions on best available techniques and summarising their key characteristics as described in the BAT Reference Document (BREF). Once the relevant BAT Conclusions (Commission Implementing Decision) are adopted, competent authorities in Member States have, for existing plants, a period of 4 years to translate the relevant provisions into permits, and for the permitted facilities to achieve compliance (unless exempt). There are not yet any legally binding BATC for LCPs.

Chapter III of the IED contains flexibility mechanisms for LCPs to comply with the IED ELVs, including:

[1] Sector code 1A1a. EU emission inventory report 1990-2014 under the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP), data viewer at http://www.eea.europa.eu/data-and-maps/data/data-viewers/air-emissions-viewer-lrtap

- **Transitional National Plan (TNP) –** plants listed in Member State TNPs can be exempted from the IED-ELVs during the period from 1 January 2016 to 30 June 2020 and instead have to comply with annual emission ceilings which decrease over the derogation time period. 15 MS have TNPs.
- **Limited life time derogation (LLD)** – this allows plants to be exempted from compliance with IED-ELVs if they do not operate more than 17,500 hours during the period from 1 January 2016 to 31 December 2023 and cease operation by this final date.
- **Derogations from BAT-AELs**, i.e. setting less strict permit limit values than BAT-AELs, can be granted by competent authorities. Such derogations can be granted if the costs of achieving compliance with the BAT-AELs are shown to be disproportionate compared to the anticipated environmental benefits. Results of the review of the IED implementation reports submitted by Member States for the first reporting period (2013) demonstrated that initially at least there was little experience in the EU in evaluating applications for and granting such derogations. However, since then, as more BAT Conclusions have been adopted, a number of Member States have started to receive and assess applications for derogations from specific BAT-AELs from operators and some have been granted and/or put out for consultation by regulators.

In addition to the IED, the recently amended **National Emissions Ceiling Directive (NECD) 2016/2284 (amending Directive 2001/81/EC)** caps annual emissions of NO_X, SO_2, NMVOC, NH_3 and $PM_{2.5}$ in the EU and in individual Member States to 2030 onwards. Whilst ceilings are sector neutral and apply for the Member State as a whole, for a number of pollutants LCPs will have an important role to play in helping to achieve them. The NECD is the EU implementation of the **UNECE Convention on Long Range Transboundary Air Pollution (LRTAP)** and associated protocols including the **Gothenburg Protocol** which sets emission ceilings for 2020 for a range of pollutants including NO_X, SO_2 and PM.

The **Minamata Convention on Mercury** was signed in October 2013 by over 120 countries, including by Member States and the Union and is expected to enter into force by September 2017. Article 8 of the Minamata Convention requires Parties to take measures to control emission of mercury and mercury compounds from relevant sources including from coal-fired power plants. Existing EU legislation does not set emission limit values for mercury emissions from combustion plants in the same way as it does for other air pollutants. Some Member States and countries outside of the EU have introduced such limits (for example in Germany ELVs for mercury will come into force in 2019, and in the United States came into force in 2016). A ratification package was adopted by the Commission in February 2016 which will allow for the EU and Member States to ratify the Convention once the legislative process is completed.

Review of the LCP BREF

The LCP BAT Reference Document (BREF) was initially adopted in 2006. An update to the document, as required by the IED, has been underway since January 2011. In June 2013 the first draft of the LCP BREF was published. The final meeting of the Technical Working Group (TWG) was held in June 2015. The final draft version of the LCP BREF and associated BAT Conclusions were published in June 2016. A formal consultation of the multi-stakeholder IED Forum was held in October 2016. Adoption by the Commission of the BAT conclusions subject to a positive opinion in the Committee of Member State representatives is expected in 2017. Within four years following the adoption, Member States will be required to renew plant permits in order to implement the requirements of the BAT Conclusions.

In this document, unless otherwise stated, 'draft LCP BREF' refers to the June 2016 version marked 'final draft'.

Energy and climate policies

The regulatory landscape around the environmental aspects of power generation is quite complex and in addition to the legislative provisions described earlier, LCPs in the EU are heavily influenced by the EU energy and climate policies, specifically the:

- Renewable Energy Directive 2009/28/EC,
- Energy Efficiency Directive 2012/27/EU, and
- European Emission Trading Scheme (EU ETS) Directive 2003/87/EC.

In 2014, the European Commission adopted the 2030 climate & energy framework. The framework builds on the previous 2020 climate and energy package to target 40% cuts in greenhouse gas emissions (from 1990 levels), 27% share for renewable energy consumption and 27% improvement in energy efficiency by 2030.

To date the key contributor to the abatement of GHG emissions from the power sector has been fuel switching; predominantly from coal to gas (and more recently to biomass). The energy and climate policies have also to some extent driven the fossil fuel plants retrofits (e.g. improved heat exchangers). However, given a relatively low carbon price between 2005 and 2010, the investment in new fossil fuel generation did not diminish in that period in some Member States such as Denmark, Czech Republic or Germany (Agnolucci & Drummond, 2014).

Switching to biomass co-firing is heavily influenced by prevailing climate policies and offers attractive GHG benefits to the operator in the current accounting framework, which increase its cost-effectiveness. A number of large coal-fired power stations have co-fired biomass for a number of years, but in recent years there has been a growing trend in coal-fired power stations to convert combustion units to burn or co-fire biomass, particularly in the UK, Denmark, Belgium and the Netherlands (IEA CCC, 2015). However co-firing influences emission of air pollutants from LCPs and may affect the performance of abatement techniques already installed at a plant.

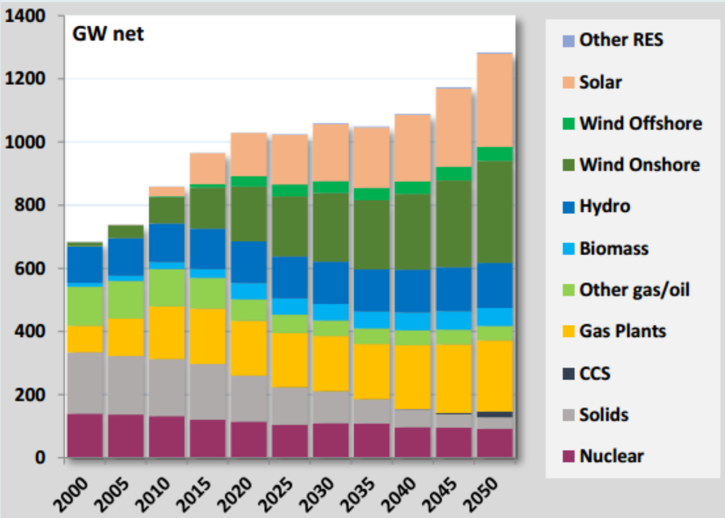
Historically there tended to be a general progression to larger combustion and generating units to achieve electrical efficiency gains. However, the scale of capital investment required for large thermal power plant, the encouragement of renewable electricity generation and promotion of combined heat and power (CHP) as well as the decentralisation of energy production has seen more focus recently on smaller power stations.

1.2.3 Sector background and projections

Solid fossil fuels (i.e. coal and lignite) continue to be used in EU Member States due to indigenous supplies (for cost and energy security reasons); 42% of solid fossil fuels used in the EU are imported. Poland, Germany and the Czech Republic remain the largest solid fossil fuels producers in the EU, with Germany and Poland also listed among the top four EU solid fossil fuels consumers (accompanied by the UK and Greece) (European Commission, 2014). Use of indigenous fuels translates into lower reliance on primary energy imports and contributes to energy security objectives. During 2011 to 2012 a rebound in the use of coal was observed in the EU due to more favourable coal prices compared to gas. This led to a switch from gas to coal fuelled generation especially in Portugal, UK, Spain, France, Ireland and the Netherlands.

In 2016 the Commission published projections of the EU energy systems, reflecting the energy, transport and climate dimensions of EU policies (European Commission, 2016). The projected installed power capacities up to 2050 (Figure 2) show a steady decrease in capacity of solid fossil fuel power generation from 2015 to 2050, and an increase in biomass capacity in that same period. This projection, which models fuel consumption trends separately to capacity trends, expects biomass will attain a share in fuel input in thermal power plants of 16% in 2020, 21% in 2030 and 31% in 2050. Generation from thermal power plants is expected to decrease up to 2045.

Figure 2 Projected installed power capacities up to 2050 in EU 2016 Reference scenario from PRIMES (Source: EC, 2016)



The 2016 Reference Scenario does not however reflect the most recent climate change policy commitments, including the 2030 climate and energy framework and meeting the Paris Agreement, which might otherwise be expected to lead to further reductions in coal and lignite use.

1.2.4 LCP emission levels compared to LCPD ELVs, IED ELVs and BAT-AELs

The European Environment Agency (EEA, 2013) indicated that, in 2009, electricity-generating LCPs appeared to be operating at emissions levels higher than the LCPD ELVs with substantial scope for further emission reductions by application of IED ELVs and lower BAT-AELs from the 2006 LCP BREF. However, it is also recognised that the calculations are subject to some uncertainties regarding specific flue gas volumes. A similar and more recent analysis by Amec Foster Wheeler (2015), for single fuelled LCPs, concluded that in 2012:

- 27% of LCPs appeared to have emissions above the LCPD ELV for SO_2 and 44% of LCPs had emissions below the LCPD ELV but above the IED ELV;
- 16% of LCPs appeared to have emissions above the LCPD ELV for NOx and 55% below the LCPD ELV but above the IED ELV;
- 17% of LCPs appeared to have emissions above the LCPD ELV for dust and 26% were below the LCPD ELV but above the IED ELV.

1.3 Aims and objectives

The aims and objectives of this study were to use existing available data to estimate the impacts – emission reductions, benefits and costs of implementing necessary abatement techniques – of solid fuel fired LCPs >300MW_{th} complying with the IED ELVs and the forthcoming revised LCP BAT-AELs (upper, and lower AELs). The scope of the analysis has been:

- to account for developments in energy and climate policy;
- to quantify key air pollutants NOx, SO_2 and dust and where possible Hg;
- to assess developments in a snapshot fashion for the years 2020, 2025 and 2030;
- to estimate benefits using emission reductions and damage costs;
- to distinguish coal consumption from lignite consumption and, ideally, account for different lignite characteristics where possible;
- to consider reductions in mercury emissions and costs associated with achieving proposed BAT-AELs (upper and lower end of ranges) resulting from co-benefit of abatement techniques to reduce other air pollutants (NOx, SO_2 and dust) and techniques specifically targeted at mercury emissions.

1.4 Structure of this report

The remainder of this report is set out as follows:

- Section 2 describes the methodology.
- Section 3 describes the results.
- Section 4 sets out the uncertainties, limitations and sensitivity analysis.
- Section 5 provides conclusions.

2 Data and methodology

2.1 Overview

The methodology and modelling flow that was followed is summarised in Figure 3 and nomenclature in Figure 4. A **baseline** plant[2] and unit level database with year 2013 data was developed. The baseline was projected to future years (2020, 2025, and 2030) as a **reference scenario** by removing plants that are subject to close due to LCPD and IED transitional changes, and accounting for forecast energy mix changes. A **BAU scenario** was developed by adjusting the Reference scenario to account for compliance with the IED ELVs. Two **policy scenarios** of achieving upper and lower BAT-AELs were generated.

Figure 3 Overview of modelling framework

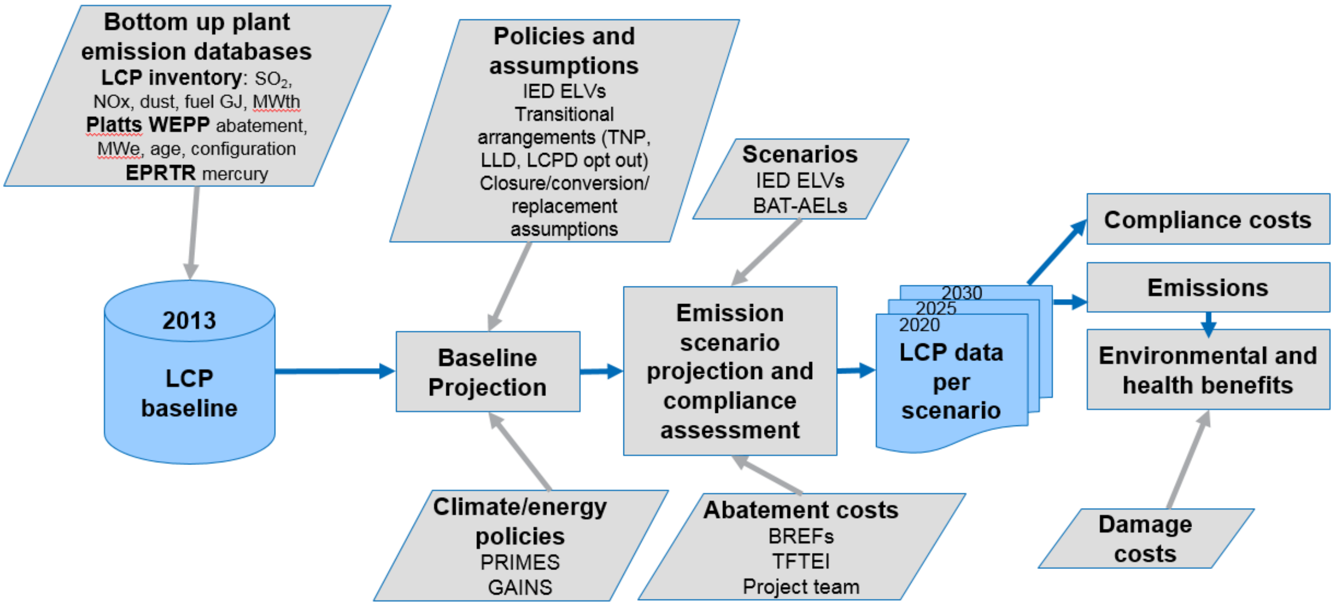
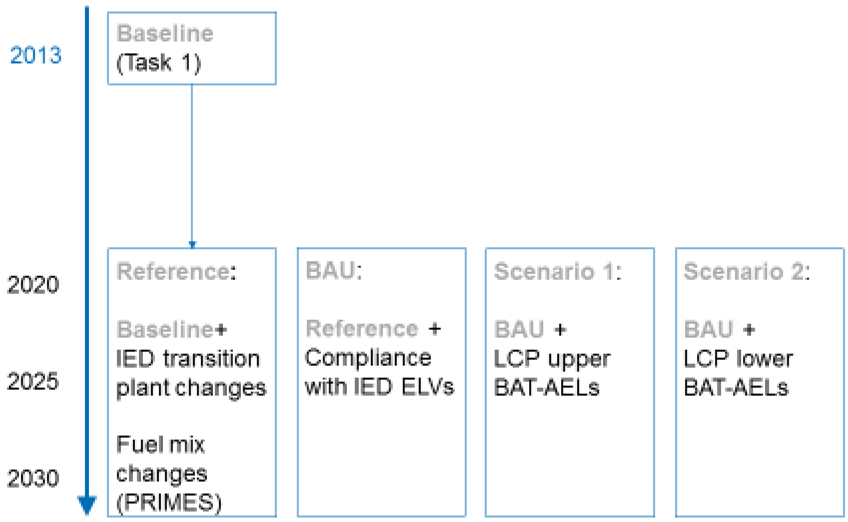


Figure 4 Schematic of the baseline and scenarios



[2] The term LCP has been used interchangeably throughout this report with 'plant', and both of these terms refer to the 'stack level'.

The following subsections describe the methodology in more detail. As an overview, emission levels for each plant in the baseline were estimated from reported data. Future emission levels for each plant were assumed to remain the same in the reference scenario except in cases where the fuel mix of the relevant Member State was forecast to change, in which case the plants' fuel mixes and associated emission levels were adjusted, as shown in section 2.3.4. The reference scenario also added to the database new plants forecast to open, and 'closed' those plants that were either known to be closed or closing, or which the PRIMES forecasts of energy projections indicated the need for capacity reductions in a Member State.

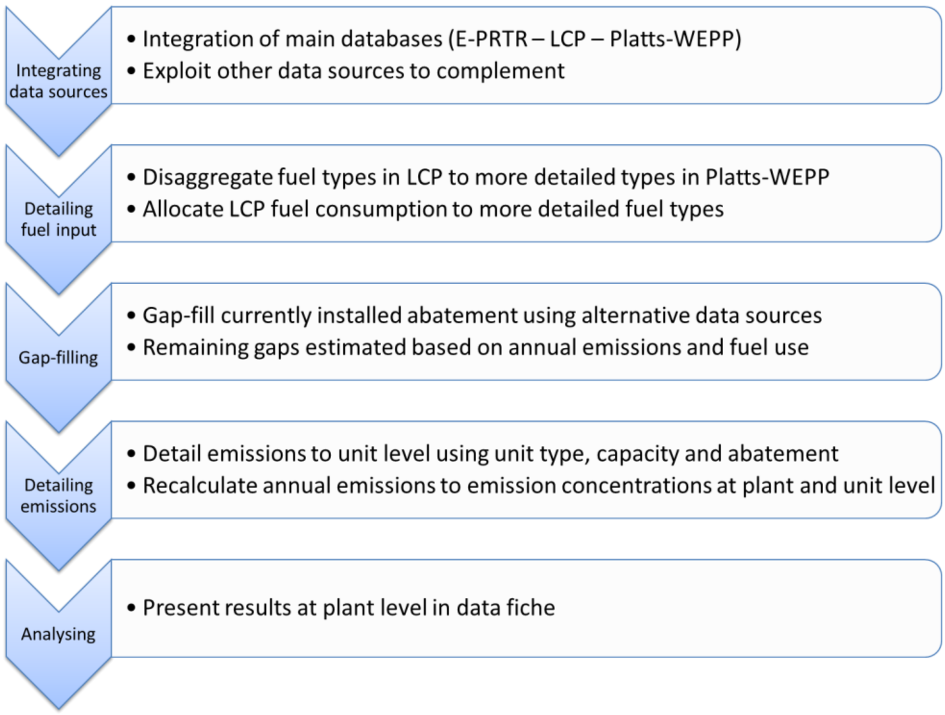
A least-cost optimisation model was set up to compare plant level emission concentrations with IED ELVs and BAT-AELs and – in cases where emission concentrations exceeded limit values – select at unit level, from an array of abatement techniques, the techniques sufficient at all units of a plant for the plant to meet the limit values. The costs of techniques were calculated based on literature values. The emissions reduced from the selected abatement technique(s) were estimated based on assumed abatement efficiencies of the technique(s) also taken from literature. The emissions reduced were monetised as benefits using damage costs.

2.2 Baseline (year 2013)

2.2.1 Summary

This section outlines the methodology used to derive the baseline database, which the future scenarios are based on. Figure 5 shows the steps that were followed. These steps are discussed in detail in the following subsections.

Figure 5 There were five methodological steps to derive the baseline database



The LCPs matching the agreed criteria – a thermal capacity of ≥300 MW_{th} and ≥75% thermal fuel input as biomass and/or solid fossil fuel – were identified from the 2013 LCP emission inventory (LCP EI). Initially this comprised 371 LCPs, although it was decided to exclude the Estonian plants from this study (4 plants) since they use oil shale as a fuel, for which no BAT-AELs have been determined in the draft LCP BREF.

A number of LCPs were reported in the LCP EI in 2013 to have zero fuel input, indicating they were not operational in 2013. However, their inclusion in the LCP EI suggested these plants may not have been closed and therefore the LCP EI from 2012 was inspected for other plants in scope of the study. An additional 8 plants were identified from 2012 data and added to the baseline. No further historical years prior to 2012 were inspected as it was assumed that if plants had zero fuel input in 2012 and 2013 they were assumed to be now closed. If any other plants were on standby in 2012 and 2013 but are otherwise 'open', they have not been included in the database.

In total, **375 LCPs** were included in the 2013 baseline.

2.2.2 Integrating data sources

Three databases – the LCP EI, Platts World Electric Power Plants (WEPP) and E-PRTR – have been used to develop the majority of the baseline database. Table 1 lists the data fields used from each of these three databases, and indicates whether data is available at combustion unit, plant or facility level.

Table 1 Relevant information for the baseline was extracted from three databases

Dataset	Granularity	Relevant information extracted	
LCP EI (2013 dataset, v1.1, published 9 Mar 2016) (EEA, 2016b)	Stack / plant	▪ country ▪ plant name ▪ location ▪ status ▪ sector ▪ thermal capacity	▪ fuel consumption split by main fuel type ▪ mass emissions (SO_2, NO_x and dust) ▪ LCPD ELV derogations and opt-outs
Platts WEPP (version September 2015) (Platts, 2015)	Unit	▪ city ▪ company ▪ electrical capacity ▪ status ▪ start of operation ▪ unit type	▪ fuel type ▪ alternative fuel ▪ boiler type ▪ installed emission control (separately for SO_2, NO_x and dust)
E-PRTR v8 (2013 included) (EEA, 2016a)	Facility	▪ Mercury mass emissions	

The LCP EI, Platts-WEPP and E-PRTR databases each have their own system of plant identification, which means there is no commonly used plant identifier in the raw data. Therefore, in order to combine data from the three databases and match them to specific plants, the databases were mutually linked and integrated.

As a first step, the LCP 2013 EI was linked to the E-PRTR database (both of which are available from the EEA website). Linking these two datasets was straightforward, since the EEA has integrated the link to E-PRTR in the LCP EI. However, a few instances were identified where this link appeared to be incorrect. This was communicated to the EEA on 26 February 2016 but was not corrected in the March 2016 update of the published LCP EI. To correct such links, the link to the correct E-PRTR facility from the LCP stack has been manually updated; these changes have been documented in the baseline.

Secondly, a link has been established between the LCP EI and Platts-WEPP. This is a one-to-many link, as each stack in the LCP EI may consist of multiple units in Platts-WEPP. To make this link, a manual matching has been performed linking the variables in both datasets. In most cases, using the plant name, location, operator and fuel type/technology the stacks were linked to the correct unit(s). In case this was not completely clear, the thermal capacity reported in the LCP EI has been compared with the electrical capacity at unit level published in Platts-WEPP to assess which unit belongs to which stack. In this process, the earlier similar work performed in the EEA project on Carbon lock-in (EEA, 2016c) could not be directly used due to the different versions of the datasets.

Apart from the current operational units, Platts-WEPP also includes units that have been decommissioned (including information on the year that this happened), deactivated (temporarily closed) and units that are under construction or planned to be built in the future. The closed units are not relevant for this study if they have been shut down before 2013. Since the Platts-WEPP dataset contains a snapshot of the plants as of September 2015, units marked as 'deactivated' in Platts-WEPP were not necessarily deactivated in 2013 (the year of the LCP data). Since no information on the unit status in 2013 was available, these units were assumed to have been deactivated in 2013 as well, unless no operational units would then remain for the plant while emissions are reported in the LCP dataset (in that case the deactivated unit would be assumed operational in 2013). The units listed in Platts-WEPP to be opened in the future are included in the dataset as these are relevant to take into account for the future scenarios (see section 2.3), however, these do not get a share of (2013) fuel consumption or emissions.

The limitations from this process are described in section 4.2.1.

2.2.3 Fuel type and fuel consumption

The Platts-WEPP database specifies for each unit what the main and alternative fuel is. This information holds more detail compared to the fuel type categories reported to the LCP EI (biomass, other solid fuels, liquid fuels, natural gas, other gases), particularly for the type of solid fuel used. No further data sources were used for fuel type. For each LCP, the fuel type data at stack level were allocated to the more detailed fuel types used in Platts-WEPP (for instance, 'other solid fuels' may be further specified as bituminous coal or lignite) by inspection of the fuel types of underlying units. The link between fuel types in the LCP EI and in Platts-WEPP is shown in Table 2.

Table 2 Link between fuel type in the LCP EI and more detailed fuel type from Platts-WEPP

Fuel type in LCP EI	More detailed fuel types specified in Platts-WEPP
Biomass	Wood Other biomass
Other solid fuels	Bituminous coal Sub-bituminous coal Lignite Peat Other solid fuel

After defining the more detailed fuel type, the fuel consumption at stack level from the LCP EI was disaggregated to unit level as follows:

- In case there was only one unit linked to the LCP, or only one unit was assumed to have been operational in 2013, all the fuel use was allocated to this unit.
- In case the LCP has multiple units with the same fuel (in Platts-WEPP), the fuel consumption has been distributed among the units according to their electrical capacity MWe.
- In case the LCP has multiple units of different fuel in Platts-WEPP, the fuel use in LCP has been allocated to the units with the corresponding fuel specification. If some of these multiple units use the same fuel type, the fuel consumption has been distributed over the units according to their electrical capacity.

2.2.4 Currently installed abatement techniques

The Platts-WEPP database included information on installed pollution abatement techniques for 66%, 33% and 78% of the number of units for SO_2, NO_x and dust respectively. In terms of installed capacity however, the percentage of baseline with NOx abatement techniques included from WEPP is 53%, which indicates that Platts-WEPP has improved coverage of abatement techniques for the larger installations. It should be noted that Platts-WEPP distinguishes between no abatement installed, and the cases where no information on abatement was available. However, the information specified in WEPP is not exhaustive, and appears to focus on end of pipe techniques.

Further sources were reviewed for additional information on installed abatement techniques at the units for which Platts-WEPP does not indicate abatement techniques. Information from these sources was added manually to the database where available (e.g. by comparing company name, location):

- Data from Annex I of the draft LCP BREF on techniques fitted at specific plants and units. This was not used as a primary source of information for this project, but rather for gap-filling and quality assurance.
- The website of the Global Energy Observatory (GEO, 2016) holds data on a large number of power plants in the world, including some information on installed abatement techniques.
- In some cases, the website of the plant operator was consulted to look for information on installed abatement techniques.

When more information was found available for a plant, often the plant name was not identical to one in the LCP dataset, and/or it was difficult to identify the unit(s) that have the abatement techniques installed. Therefore, the information has only been included in case the identity of the plant/unit and the corresponding link to Platts-WEPP could be assured. Where available, the year that the abatement technique was installed has been included, such that a better estimate can be made regarding the future development of the stack or unit. However, the availability of this information was found to be very limited.

After integrating information from the various sources on currently installed abatement, a significant number of gaps still remained (see Table 4). For these plants without data on installed techniques, a gap-filling method has been developed which compares the reported emissions at plant/stack level to those of hypothetical unabated plants to derive an estimated abatement efficiency, and from this an assumption is made on what abatement technique is installed. This method is as follows:

- The fuel input at unit level (fuel type specified using WEPP) has been multiplied with 'unabated' emission factors (distinguishing between steam and gas turbine) to get an estimate of what hypothetically the unabated emissions would be at unit level. Country-specific unabated emission factors for SO_2 and dust have been collected from GAINS (IIASA, 2016), while default emission factors for NO_x were taken from the EMEP/EEA Guidebook (EMEP/EEA, 2009). The reason for this is that, while the EMEP/EEA Guidebook emission factors are more specific to the fuel and technology type, it lists no country specific emission factors. Since SO_2 and dust are highly influenced by the sulphur content, country specific emission factors from GAINS are used for these pollutants. A complete overview of these emission factors including the reference for each is included in Appendix 3.
- These hypothetical unabated emissions have been aggregated to LCP level and compared with the reported LCP emissions, from which an overall abatement efficiency for the plant is estimated.
- Typical abatement efficiency ranges were derived from literature data and from discussion with DG ENV and the JRC. These were chosen to not overlap, so a certain calculated abatement efficiency would only match with one technology. The assumption that these abatement ranges do not overlap is a necessary assumption but is a limitation of the approach, as it could miss out on combinations of techniques. The abatement efficiency ranges that were assumed are in Table 3. For NOx emissions, distinction is made in the assumed abatement efficiency ranges between coal and lignite plants (also shown in Table 3).
- Every unit of the plant concerned for which installed abatement techniques were not known, was assigned an abatement technique (or none) based on the typical efficiency ranges. The abatement techniques correspond to those detailed in the BREF document.
- Since wet flue gas desulphurisation (WFGD) techniques typically also reduce dust emissions, making an accurate assessment of the dust abatement techniques installed required an approach that takes this co-benefit into account. The abatement techniques are assigned in two steps, first the techniques are determined for NOx and SO_2, after which the dust abatement efficiency achieved by the (dedicated) dust abatement techniques is recalculated using the following equations:
    - Dust removal efficiency of WFGD:[3]

      1 – 3.3 * (1 – SO_2 removal efficiency)
    - Dust removal efficiency of dust abatement:

[3] Formula proposed by JRC in the email of April 4th 2016

1 – (1 – total dust removal efficiency) / (1 – dust removal efficiency of WFGD)

The dust abatement type is then assigned based on this updated removal efficiency and the efficiency ranges provided in Table 3.

This methodology assigns a unit level abatement technique in the baseline by looking at the plant emissions and compares this to the situation with no abatement. Therefore, the resulting estimate of abatement installed is essentially an average for the plant, and all units with no information are assigned the same abatement technique. It should be noted that if the abatement technique is known for one or more units, the plant average may no longer be meaningful for the remaining units.

Summary statistics on the amount of gap-filling and which sources were used to fill the gaps are provided in Table 4.

Table 3 Assumed abatement efficiency ranges and corresponding abatement technique used for gap-filling abatement techniques in the baseline

Pollutant	Abatement efficiency range	Abatement technique	Sources (lower limit/upper limit)
NO_x (coal plant)	10-70%	Primary measures (PMS)	2006 LCP BREF, 2006 LCP BREF and VITO (2009)
	>70%	Combination of PMS and Selective catalytic reduction (SCR)	Upper limit PMS efficiency, lower limit SCR efficiency (EPA (2003) and 2006 LCP BREF)
NOx (lignite plants)	>25%	PMS	Based on observed efficiencies in lignite plants with known abatement type
SO_2	30-50%	In-boiler sorbent injection	2016 pre final draft LCP BREF
	50-70%	Duct sorbent injection (DSI)	2016 pre final draft LCP BREF
	70-85%[4]	Dry and semi-dry scrubbing (DSC)	2016 pre final draft LCP BREF and VITO (2009), Lower limit WSC
	>85%	Wet scrubbing (WSC)	EPA (2000), 2016 pre final draft LCP BREF most efficient SO_2 abatement technique
Dust	90-99.4%	Electrostatic precipitator (ESP)	Based on lowest dust abatement efficiency implied in the baseline database for plants that were known to have ESP installed, lower limit filtration efficiency
	>99.4%	Bag filter (BF)	2006 LCP BREF and VITO (2009), most efficient dust abatement technique

[4] for CFBC boilers sorbent injection; efficiency 80-95% while hybride system (in-boiler injection and DSI); efficiency 70-95% taking into account that hybride system is more relevant for retrofits.

Table 4 Information on installed abatement techniques for units by number and electrical capacity MW_e)

Source of information	Number of units			Electrical capacity of units (MW_e)		
	SO_2	NOx	Dust	SO_2	NOx	Dust
Platts-WEPP	604	302	711	172,190	107,778	183,476
Draft final LCP BREF Annex I*	18	81	12	3,306	13,914	2,972
Global Energy Observatory	4	20	6	200	4,135	2,072
TNP	6	0	12	163	0	332
European Commission	2	2	2	625	625	625
Other sources	6	2	0	666	598	0
Assumption based on other units (boiler or abatement type)	7	3	7	357	295	751
Assumption for new units	17	47	18	4,332	13,789	4,462
Assumption based on calculated abatement efficiency	253	460	149	22,010	62,714	9,159
Proportion data (%)	**70%**	**44%**	**81%**	**87%**	**62%**	**93%**
Proportion assumptions (%)	**30%**	**56%**	**19%**	**13%**	**38%**	**7%**

** Although Annex I includes more data than suggested by the numbers of matched plants, it wasn't used if Platts already had data for a unit. There were also problems encountered with matching the identification of the plants.*

The classifications of types of abatement techniques in WEPP was quite varied and not aligned with categories of abatement techniques as listed in the LCP BREF. It was necessary to ensure a consistent categorisation of abatement techniques was used, to support the later tasks on the project regarding projections. For this, the same abatement class definitions as in the BREF process has been followed. Therefore, the more detailed abatement technologies from WEPP and other sources have been aggregated to the abatement technologies listed in the LCP BREF. An overview of this aggregation can be found in Appendix 5.

Further detailing of abatement techniques for dust and SO_2

For dust, electrostatic precipitator (ESP) abatement technologies were found to represent a wide range of reduction efficiencies. Since ESP dust removal efficiencies can be improved by further investment, on top of the gap-filled dataset we divided the most applied abatement technologies for dust into multiple efficiency categories. For ESPs fitted as existing techniques in the baseline, three ranges were distinguished. The efficiencies corresponding to the different abatement types are in Table 5. The list of unabated emission factors which has been used to make this distinction, including their source, is included in Appendix 3.

Table 5 Baseline dust abatement technologies are assumed to be installed based on abatement efficiencies estimated from plant data

Pollutant	Abatement efficiency	Corresponding abatement technique assumed to be installed
Dust	90 - 98%	ESP
	98 - 99.5%	ESP+
	>99.5%	ESP++ (not applicable for gap-filled techniques)

From this table, the efficiency ranges for ESP are shown to be between 90 and 100%, which is different from the ranges applied in the abatement gap filling (Table 3, 90-99.4% for ESP). The reason to have this, is because for some of the plants where the installed abatement is known (from Platts-WEPP or another source) the calculated efficiency of this ESP is higher than 99.4%. In the database, we account for this high-efficiency ESP by assigning this unit an ESP++ abatement.

On the other hand, in cases where installed abatement was gap filled, ESP efficiencies at unit level will only range between the 90-99.4% specified in Table 3, and this change will not happen. Therefore, for units with gap filled abatement none of them will be assigned an ESP++ since efficiencies > 99.4% are assigned a bag filter in gap-filling (see Table 3).

2.2.5 Thermal capacity at unit level

Rated thermal input data is available at plant level from the LCP EI. The WEPP includes unit level electrical capacities. To be able to estimate unit level thermal input capacity (MW_{th}), it is assumed each unit has the same electrical efficiency. In other words, the ratio of thermal input capacity at unit level and at plant level is assumed to be equal to the ratio of electric output capacity at unit level and at plant level. The latter is calculated from WEPP by taking the electric output capacity for the specific units and the sum of electric output capacities for all units that are part of the plant.

$$MW_{th}^{input,unit} = \left(\frac{MW_e^{output.unit}}{MW_e^{output.plant}} \right) \times MW_{th}^{input.plant}$$

In cases where some units are CHP while others are not, this equation does not hold as a CHP plant may have a much lower electric output compared to the thermal input. Therefore, in known CHP cases (plants SE0032 and PL0099), the fuel input at unit level was used as a proxy, rather than the electric output capacity.

2.2.6 Operating hours

Plant annual operating hours are needed for assigning the appropriate IED ELVs and BAT AELs for the plants, as plants with low operating hours (<1500 hours or <500 hours per year) may have different limit values. Annual operating hours are estimated both at plant- and unit-level, as the ratio between the fuel input (in TJ) and the theoretical maximum fuel input, assuming 100% load and based on the thermal capacity of the unit/plant. The thermal capacity in MW_{th} is multiplied with the number of seconds in one hour to estimate the maximum hourly thermal fuel input in TJ. By taking the ratio between the total fuel input in one year and the maximum hourly input, the number of operating hours has been estimated.

This calculation assumes that whenever a unit or plant is running, it is running at full capacity. In reality, some plants may well operate at lower load, which means that the estimated operating hours are likely an underestimate of the true value, which implies that the number of plants which may have low operating hours could be overestimated. To assess the sensitivity to the load assumption, we compared the number of plants with <1500 hours and <500 hours with 100% load assumption to a case where the load assumptions is reduced to 80%. The number of plants operating <1500 hours reduced from 35 to 27, while the number of plants operating <500 hours reduced from 14 to 12.

2.2.7 Annual emissions at unit level

2.2.7.1 General approach for SO_2, NO_X and dust

Annual mass emissions at unit level have been estimated using the relative bottom-up estimates at unit level to distribute reported stack level emissions. The bottom-up calculation is of the annual emissions of each unit, based on the unit type, capacity and the installed abatement as it was assessed above. The bottom-up calculation of annual emissions relies on:

- Fuel consumption: detailed fuel use at unit level, as it was estimated by detailing the fuel consumption from stack level to unit level;
- Unabated emission factors per installation type from various sources including the GAINS model (provided in a separate file with emission factors, see Appendix 3); and
- Average abatement efficiencies per abatement technique, taken as an average of the upper and lower limit value of the ranges given in Table 3.

From this bottom-up calculation of annual emissions, the relative share of each unit in the annual emissions from the respective stack has been determined for each pollutant. This share is used to distribute the stack level annual emissions as reported in the LCP dataset among the individual units.

2.2.7.2 Approach for mercury

Data sources

The main data source for mercury emissions used in this study is the E-PRTR. Companies are obliged to report on mercury emissions to air when their yearly load exceeds 10 kg (Annex II reporting guidelines E-PRTR). Unlike emissions from other air pollutants (SO_2, NOx and dust), mercury emissions are not reported for all solid fuel fired plants. Also, the E-PRTR reported data are at facility level and hence the mercury emissions reported may be in aggregate for a number of LCP plants at one facility. Mercury is not included in the pollutants reported on in the MS LCP emission inventories.

Data on the mercury content of fuels exists, but in general a rather wide range is reported, especially for solid fuels (all forms of coal). Even within one country or region, the mercury content can vary considerably for different types of solid fuel. As such, a method that is based on the mercury content of the input fuel to derive stack emissions will lead to values which can differ up to factor of 40 or more. Therefore this method for estimating mercury emissions has not been applied.

At a more aggregate level, EU MS report annual national level emissions to EMEP of many pollutants, including mercury emissions to air. These reported data cannot assist in defining unit specific emissions, but they can form a basis for comparison of the results of the mercury emissions estimation.

Methodology applied to estimate unit based mercury emissions

The most disaggregated data available are thus the E-PRTR data by facility. Based on this source, two gap filling methodologies have been developed and implemented to supplement E-PRTR in order to obtain mercury emissions at unit level. Each of them is described below, in the order that they have been applied for the estimation of unit level mercury emissions:

1. **Single facility E-PRTR mercury emission data available**

The mercury emissions are allocated in a proportional way. If for a single facility with only one plant and one unit, mercury emissions are reported, these emissions are allocated to that single unit. If a facility has multiple plants and units, the fuel input allocated to each unit using electrical capacity is utilised. Based on the solid fossil fuel input of the units, the reported mercury emission is distributed proportionally over the units. By doing so, a number of simplifications have been applied:

- For multiple fuel units primarily burning solid fossil fuels, it is assumed that the contribution to mercury emissions from other fuels is negligible compared to those of solid fossil fuels. The rationale behind this simplification is that literature reports on mercury contents of these fuels indicate that they are an order of magnitude smaller than those of solid fossil fuels like coal (e.g. oil: 10 ppb; biomass: 20 ppb). (Huang, 2011; EPA, 2011)
- For units mainly fuelled with oil and biomass, default mercury contents have been applied as a start. (e.g. oil: 10 ppb; biomass: 20 ppb)
- For units consuming only gaseous fuels, the mercury emission is considered to be zero.

For distributing facility level mercury emissions among the LCPs that make up the facility, a similar approach as the step above has been followed, except that the reported mercury emission is distributed according to fuel use of each unit included in these plants.

The key uncertainties in this approach are:

- There is greater confidence in more aggregated mercury emissions (facility→plant→unit).
- If materially different air pollutant abatement techniques are used across different units within one plant, then mercury emissions would not be evenly allocated. The Platts WEPP database indicates that generally (but not always) units do not have different air pollutant abatement techniques. For those plants with differing abatement at unit level, adjustments based on the abatement technologies would alter the emissions slightly but would not decrease the uncertainty, and hence has not been carried out.
- The process to allocate fuel by unit contains an uncertainty, namely that all units will run proportional to their capacity.

With this methodology, mercury emissions for 507 units were estimated from the E-PRTR reported facility emissions. An example of this approach is shown in the box below.

Box – Illustrative example of apportioning mercury emissions from facility level to unit level

An example of approach 1 has been applied to the plants UK0307 and UK0308, both located in power station/facility 'Ferrybridge'. The whole complex exists of four units which are grouped into two LCPs. Each LCP has its own distinct fuel use and emissions, except for mercury where only a single emissions estimate is given at facility level. Each unit consists of a 500 MWe boiler. The table below illustrates the methodology.

Unit	Reported plant fuel consumption	Reported facility mercury emission	Estimated unit level fuel consumption	Estimated unit level mercury emission
1. 500 MW_e	28,308 TJ	97.2 kg	=28,308*500/ (500+500)	= 97.2 kg x unit fuel use / (28,308+60,030 TJ)
2. 500 MW_e			=28,308*500/ (500+500)	= 97.2 kg x unit fuel use / (28,308+60,030 TJ)
3. 500 MW_e	60,030 TJ		=60,030*500/ (500+500)	= 97.2 kg x unit fuel use / (28,308+60,030 TJ)
4. 500 MW_e			=60,030*500/ (500+500)	= 97.2 kg x unit fuel use / (28,308+60,030 TJ)

2. No facility E-PRTR mercury emission available

The methodology is applied to the remaining 435 units which have no facility level mercury emissions available or reported. In order to estimate the emissions for these units, a decision tree approach has been taken. The decision tree approach consists of the following steps or choices:

- Are mercury emissions reported for other facilities in the same MS, using the same type of fuel, and owned by the same company? If so, the average of the known emission factor for mercury (mercury emissions/ fuel input) of the source unit(s) is applied to the unit fuel consumption determined according to step 1 above. As an additional step, an evaluation of the reported SO2, NOx and PM abatement techniques is done, to see if the resulting mercury emission needs to be adjusted. This adjustment can occur in two directions: downwards if the units list better techniques than the source unit(s), upwards if less advanced techniques are mentioned. The adjustment factors are based on the scarce information in literature, see Table 6.
- Are mercury emissions estimated based on E-PRTR for other units in the same MS, using the same type of fuel? If so, an average emission factor per fuel is estimated by dividing the known mercury emissions with the corresponding fuel inputs from the units concerned. For instance, this has been done for lignite or bituminous coal for which often a number of plants and units have mercury emissions determined. A check is made based on the reported abatement technologies, and adjustments applied if seemed probable. The adjustment factors reflect the mercury co-abatement effect of different configurations and are based on information identified in literature, see Table 6.
- If the plants use biomass as main fuel, or a considerable amount of oil, a default mercury content has been applied (oil: 10 ppb; wood biomass: 20 ppb; Hubar, 2001) to estimate gross emissions. Abatement factors are applied after that taking into account the kind of abatement techniques installed.
- If no emission at all is reported in a MS, default Hg emission factors per fuel have been applied. The default can be averages of fuel specific emission factors from other MS, or from literature (USGS, 2010). Again a final check is made based on the reported abatement technologies, and adjustments applied if seemed probable.

Applying this mixed approach[5], resulted in estimates of mercury emissions for all operating units in the baseline. A number of units are reported to start operation after 2013, so they are not included, their emission in 2013 is set to zero. The same is valid for those units that were decommissioned or

[5] An alternative approach would be to start from the mercury content of fuel, and estimate unit emissions from unit level fuel consumption.

mothballed prior to 2013. The mercury emissions for units which ceased operation during 2013 are estimated proportionally to their fuel use.

The mercury co-benefits of abatement techniques for other pollutants are shown in Table 6. The methodology applied to estimate mercury emissions/concentrations after co-abatement is:

After co-abatement = existing / (1 - existing co-abatement efficiency) x (1- new co-abatement efficiency)

Table 6 Mercury co-benefits of SO_2, NO_X and dust techniques

Technique(s) applied	Mercury co-abatement efficiency	Source of assumption
ESP(+)(++)	36%	NRDC (2011), UNEP (2015)
ESP & SCR	44%	NRDC (2011), average of range 1-87%
ESP+(++) & SCR+	48%	Derived from (2)
ESP & WSC	60%, 65%, 70% for WSC, WSC+, WSC++ respectively	NRDC (2011), UNEP (2015)
ESP & SCR & WSC	75%, 80%, 85% for SCR, SCR +, SCR++ respectively	DG ENV and JRC expert judgement (2016)
ESP & DSC	50%	Derived from (5)
ESP & SCR & DSC	60%	DG ENV and JRC expert judgement (2016)
ESP & SCR & WSC+ or WSC++	80%, 85%, 90% for SCR, SCR +, SCR++ respectively	DG ENV and JRC expert judgement (2016)
WSC(+)	50%	Derived from (1) and (5)

The relative improvement of PM/NOx/SO_2 abatement for mercury co-abatement has a higher influence than the absolute co-abatement efficiencies. There is additionally a table indicating the effect of abatement techniques on mercury capture in the final draft of the LCP BREF (Table 5.5, p. 373). A further source which was considered is Rafaj, Bertok & Schoepp (2013) which discusses the GAINS model assumptions on co-abatement of mercury.

2.2.8 Estimating current flue gas concentrations

Flue gas concentrations have been estimated for the baseline at both plant and unit level based on the fuel mix at plant and unit level. Note that since concentrations at unit level are based on estimated emissions at unit level, flue gas concentrations of individual units are more uncertain than plant-level concentrations and should be regarded as indicative only.

Annual average stack flue gas concentrations have been estimated using plant fuel consumption and annual emissions as reported in the LCP database. Flue gas concentrations were calculated by dividing annual emissions by the annual flue gas volume flow. The flue gas volume was estimated by multiplying the fuel input with specific flue gas volumes that depend on fuel type and the reference oxygen concentration in the flue gas at which the emission limit values are expressed. The reference oxygen content is dependent of the type of unit (e.g. gas turbine or boiler). The flue gas volume calculation was based on the empirical relationship developed by Rosin and Fehling and explained in the methodology adopted by the EEA (EEA, 2015c). This method was chosen because it only requires the Net Calorific Value (NCV) of the fuel to make an estimate of the flue gas volume, whereas other methods require additional data on the fuel types which are not available in this study. The required fuel NCVs were taken from the IPCC 2006 Guidelines for National Greenhouse Gas Inventories. For most lignite fired plants, the (plant-specific) NCVs were provided by the Commission, and used to estimate the annual flue gas volume for these plants. When no lignite NCV was available for a specific plant, a country average lignite NCV was calculated from the data provided by the Commission. Appendix 4 gives the fuel specific flue gas volumes used in this study, including the plant specific lignite NCVs and corresponding specific flue gas volumes. A discussion on the uncertainty of this approach is included in Section 4. The modelling was tested for sensitivity to the flue gas volume calculation.

2.3 Projection to 2020, 2025 and 2030 as the Reference scenario

2.3.1 Summary

The Reference scenario has been projected forward to the future years of interest for the study (2020, 2025 and 2030) from the 2013 baseline, by accounting for the following:

- Closures of specific plants/units foreseen due to being opted out under the LCPD (for all years of 2020, 2025 and 2030) or opting for the IED LLD (for at least years 2025 and 2030);
- Any planned opening of new plants;
- Any additional closures and changes in plant energy input – after accounting for LCPD opt outs and IED LLD – required in order to match trends derived from projections from PRIMES/GAINS, to reflect the impacts of the climate and energy policies modelled by PRIMES/GAINS; and
- Changes in plants that were covered by Accession Treaty derogations from the LCPD in 2013 that no longer apply in years 2020, 2025 and 2030.

The methodology has been designed in such a way so as to avoid double counting of the effects of the IED. Each of the above points is described in the following subsections. Similarly to the baseline, the projections were made at unit level and then aggregated to plant level. Plant level concentrations were estimated using the corresponding unit's emissions and flue gas volumes. Results at MS level aggregate results of all existing and new plants.

Note: the 2020 scenarios in this study are assumed to be post-TNP regime.

2.3.2 Accounting for plants/units opting out of LCPD and selecting IED LLD

LCPs that were flagged as opting out of the LCPD under its Article 4(4) had to close by the end of 2015, although many closed before this date. Therefore, some plants that are listed in the baseline as operating in 2013 need to be removed from the Reference scenario for future years. The plants or units that were opted out under the LCPD (Article 4(4)) have been identified from MS submissions to the Commission. Despite the intention of LCPD opt outs being only at plant level, some MS opted out only certain unit(s) of plants. However, from the LCP EI it is often not clear which units within the plants will close. More detailed information regarding the LCPD opt-outs has been collected from the EEA website and included at unit level in the database (EEA, 2016b). The analysis takes into account, where possible, the specific unit(s) which were opted out of the LCPD.

The final lists of the LLD plants for the individual Member States have been made available by the Commission alongside the TNPs for use in this project. These documents have been searched for relevant information, as to which plants and which units thereof are part of the LLD/TNP. In the database, these are marked as such, including the pollutants for which the TNP is relevant. The plants and units which are identified in the baseline database as being included in the IED Limited Lifetime Derogation have been assumed to close by the end of 2023 (i.e. before the year of 2025). IED LLD plants were therefore included in the Reference scenario for 2020, but not in the Reference scenario for years 2025 and 2030, with the exception of those LLD plants that were estimated to close early before 2020 (see section 2.3.4).

Additional information on estimated decommissioning years of individual units, both related to LCPD opt-outs, the IED and other plants in general, has been gathered from the Member State consultation for the EEA Carbon lock-in study (EEA, 2016).

2.3.3 Accounting for known specific new plants from 2013

New units or plants firing coal, lignite and/or biomass fuels that were listed in Platts-WEPP as 'under construction', 'delayed' or 'planned' to open after 2013 were identified. All new units listed in Platts-WEPP, regardless of capacity, were included in the Reference scenario if they are part of plants already in the baseline. However, if the new units are plants not already in the baseline, the plants have been included in the Reference scenario only if the capacity listed in Platts-WEPP is greater than 100 MWe (approximately 300MW$_{th}$). However, some of the new units or plants listed in Platts-WEPP were identified in press reports to have been cancelled (Table 7); these have not been added to the Reference scenario.

Platts-WEPP is not expected to comprehensively list all planned new investments, and hence there will be uncertainty in the approach. In particular, uncertainty is greater for the 2025 and 2030 projections, as Platts-WEPP is expected to have worse coverage of plants planned to open more than five years in the future. Additional searches carried out to verify Platts-WEPP projections are not comprehensive.

Table 7 New units listed in Platts but identified as cancelled

MS	WEPP unit	Detail	Evidence
UK	1263935	White Rose CCS project assumed not to go ahead.	http://infrastructure.planninginspectorate.gov.uk/projects/yorkshire-and-the-humber/white-rose-carbon-capture-and-storage-project/
RO	1235320, 1235321	New planned units at Doicesti removed from WEPP list. Main plant at Doicesti not in scope as no fuel consumption in 2013 and 2012. Appears to be closed.	http://sourcewatch.org/index.php/Doicesti_power_station
RO	1211875	Expansion cancelled	http://www.sourcewatch.org/index.php/Braila_Power_Station_Expansion
GR	1212570	Cancelled	http://www.sourcewatch.org/index.php/Aliveri_VI_power_station
GR	1212571	Cancelled	http://www.sourcewatch.org/index.php/Larimna_power_station
GR	1234142	Status updated from deferred to cancelled	http://www.sourcewatch.org/index.php/Category:Proposed_coal_plants_in_Greece
HR	1119174	LUKOVO SUGARJE coal plant cancelled	http://www.pfie.com/pfi-issue-163/2526.issue?cmd=GoToPage&val=13

New units or plants have been assumed to have the following characteristics:

- Electrical capacity taken from Platts.
- Fuel type taken from Platts.
- Commissioning year taken from Platts, or if not stated assumed to be 2019 based on the assumption that Platts WEPP (which is version September 2015) only has sight of plants less than 5 years in advance.
- Thermal capacity estimated from electrical capacity based on electrical efficiencies as indicated for new plants in the pre-final draft LCP BREF dated February 2016 (pages 955 and 968).
- Fuel consumption based on thermal capacity and assumption of load factor of 53% - based on the average load factor in the baseline of units commissioned since 1990. Note that the load factor is prior to any additional adjustment to match PRIMES.
- Flue gas volumes estimated from multiplying the fuel consumption by fuel specific flue gas volumes. The assumed flue gas volumes are the same as assumed in the baseline.

- Emission concentrations in the reference scenario set at IED ELVs for IED new plants, for units commissioned from 2014 to 2016 and set at upper BAT-AELs for new plants, for units commissioned from 2017.[6]
- Mass emissions estimated from multiplying emissions concentrations by flue gas volumes.
- Abatement techniques of:
  - High efficiency FGD for SO_2 control.
  - PMS and SCR for NOx control.
  - High efficiency ESP for dust control.
  - No dedicated Hg abatement techniques – it is assumed that the SO_2, NO_X and dust techniques will co-abate Hg sufficiently.

2.3.4 Projecting future capacity and fuel consumption, and accounting for changes in energy / fuel mix

2.3.4.1 Using PRIMES and GAINS model outputs for projections

When projecting the baseline from year 2013 to future years, it was necessary to account for projected future changes in the energy mix of the Member States. This is because some Member States are, for example, projecting to diminish their reliance on coal/lignite power stations, whilst others are forecasting to continue relying on solid fossil fuels. To account for national level changes in solid fuel power stations due to climate and energy policies, projections from the PRIMES model have been used, specifically from 'EU Energy, Transport and GHG Emissions Trends to 2050, 2013 Reference Scenario' (EC, 2013). The 2013 version was used as it was the latest available at the time of developing the baseline.[7] The PRIMES model output metrics at a MS level that have been used are:

- For projecting future capacity: 'net generation capacity of solids-fired thermal power', in MWe; and
- For projecting future fuel consumption: "fuel inputs to thermal power generation", in ktoe, for each of "solids" and "biomass & waste".

PRIMES projections are specified in five year increments: the projections for years 2010 and 2015 have been linearly interpolated between in order to develop estimates for base year 2013. Scaling factors were calculated representing the change in each PRIMES metric listed above for capacity and fuel consumption levels in future years 2020, 2025 and 2030 compared to base year 2013. The resulting scaling factors calculated from this process are shown in Table 8 for capacity at EU level, and at Member State level in Appendix 6. There is substantial variation in the scaling factors among Member States.

Table 8 Summary at EU level of capacity scaling factors calculated from PRIMES net generation capacity of solids-fired thermal power, based to year 2013. Member State values are in Appendix 6.

	2013	2020	2025	2030
EU28	1	0.84	0.72	0.62

This approach in using the trend in PRIMES metrics has been adopted instead of using the absolute values to avoid any disparities due to differences in scope between the LCP data and PRIMES. The approach assumes that the trend in PRIMES for all thermal power generation is also applicable to the plants in the study scope of ≥300MW_{th} (considered to be a valid assumption as over 95% of the coal and lignite (solid fuels excluding biomass) consumption of LCPs in 2013 was in plants ≥300MW_{th}).

[6] Hence, for the plants commissioned between 2014 and 2016, they will need to make reductions in the upper BAT scenario.
[7] A more recently published version of 2016 Reference Scenario was published, which compared with the 2013 Reference Scenario shows:

- The two scenarios have very similar projections of future capacity of coal and lignite fired power generation plant.
- The 2016 Reference Scenario forecasts higher coal and lignite fuel input in thermal power generation plant in 2020, 2025 and 2030 than the 2013 Reference Scenario.
- The 2016 Reference Scenario forecasts higher growth between 2020 and 2030 of biomass and waste fuel input in thermal power generation plant, than the 2013 Reference Scenario.

However, the 2016 Reference Scenario also does not take into account the effects of the 2030 climate and energy framework adopted by the EC.

2.3.4.2 Splitting PRIMES projections for 'solid fuel' into coal and lignite

As the PRIMES projections do not differentiate between coal and lignite, GAINS data on fuel consumption for the ENE (Energy) activity sector that are consistent with the PRIMES data (GAINS scenario WPE_2014_CLE) have been used to split the PRIMES fuel consumption projections for solid fuel into coal and lignite. Since the GAINS data are not specifically for the power sector, this approach therefore assumes that the trend applicable for the whole energy sector is applicable also for the LCPs ≥300MW_{th}.

GAINS distinguishes between eight solid fuel types:

1. BC1 Brown coal/lignite grade 1
2. BC2 Brown coal/lignite grade 2 (also peat)
3. HC1 Hard coal, grade 1
4. HC2 Hard coal, grade 2
5. HC3 Hard coal, grade 3
6. DC Derived coal (coke, briquettes)
7. OS1 Biomass fuels
8. OS2 Other biomass and waste fuels

The PRIMES category of 'solid fuels' has been assumed to comprise GAINS categories 1 to 6 (as biomass is a separate fuel type in PRIMES). The proportion that coal (HC1+HC2+HC3) consumption in GAINS makes up out of the total of coal plus lignite (BC1+BC2) at Member State level was used to split out the PRIMES consumption data for 'solid fuels'. The GAINS projections for the total Energy sector of coal from lignite are summarised in Table 9 at EU level, and at Member State level in Appendix 6. The results from these factors effectively identify that brown coal (primarily lignite) is relevant as a fuel stock for the following countries: Bulgaria, Czech Republic, Finland (may be peat), Germany, Greece, Hungary, Ireland (may be peat), Poland, Romania, Slovakia, Slovenia and Sweden.

Table 9 Hard coal as a proportion of total hard coal and brown coal (lignite, peat) – source: GAINS (scenario WPE_2014_CLE). Member State values used in the modelling are shown in Appendix 6.

	2013	2020	2025	2030
EU28	**67%**	**68%**	**66%**	**71%**

The fuel type categories from GAINS differ from the fuel type categories in PRIMES and in the baseline. The table below summarises how the fuel types are assumed to map across the sources.

Table 10 Solid fuel types in the baseline mapped to PRIMES and GAINS.

Baseline fuel type	PRIMES fuel type	GAINS fuel type
Coal bituminous Coal sub-bituminous	Solid fuel	Hard coal (grades 1, 2, 3)
Coal lignite Peat	Solid fuel	Brown coal (grades 1, 2)
Other solid	Solid fuel	*(Not mapped, i.e. not added to either of hard or brown coal.)*
Biomass wood Biomass other	Biomass & waste	*(Not mapped as not needed in the methodology)*

Combining the PRIMES trends for solid (fossil) fuel consumption with the coal/lignite split from GAINS (Table 9) provides the separate coal and lignite consumption scaling factors for the reference scenario – shown in Table 11 alongside the scaling factors for biomass.

Table 11 Fuel consumption scaling factors calculated from PRIMES projections of biomass & waste fired power generation, and PRIMES projections of solids fired fuel consumption split into coal and lignite using GAINS at EU level. Member State level factors, used in the modelling, are shown in Appendix 6.

	Biomass				Coal				Lignite			
	2013	2020	2025	2030	2013	2020	2025	2030	2013	2020	2025	2030
EU28	1	1.18	1.2	1.23	1	0.84	0.73	0.59	1	0.83	0.79	0.48

The PRIMES projections of capacity are for all solid fuelled-fired thermal power, whereas this study is concerned with only those plants greater than $300MW_{th}$. The 2013 LCP EI indicates that the vast majority (>95%) of the capacity and fuel consumption of coal/lignite fired power stations is in the $300MW_{th}$+ category, hence it is considered appropriate to use the PRIMES capacity projections in this study. However, the use of the PRIMES projection of fuel consumption of biomass has greater uncertainty as the PRIMES projection is for all biomass-fuelled thermal power plants, whereas the 2013 LCP EI indicates that around half of the total biomass consumption from LCPs comes from plants in the category 50-$300MW_{th}$.

2.3.4.3 Projecting future capacity and fuel consumption

The methodology that has been followed for projecting future capacity and fuel consumption of the LCPs in scope of this study is as follows:

1. Updates to the baseline were made regarding known (reported on in the press) closures of certain units / plants not captured by Platts (Table 12). These units / plants were marked as not operating in the future years. Note that this web search was not comprehensive.

Table 12 Plants/ units identified to have closed or planning to close and not captured by Platts-WEPP in the baseline

MS	Plant	Status	Evidence
UK	Ferrybridge C	Closed in 2016	http://www.bbc.co.uk/news/uk-england-leeds-35927009
UK	Longannet	Closed in 2016	http://www.theguardian.com/environment/2016/mar/24/longannet-power-station-closes-coal-power-scotland
UK	Rugeley	Closed in 2016	http://www.rugeleypower.com/?article=19
BE	Langerlo	Closed in 2016	http://www.caneurope.org/can-and-press/952-belgium-says-goodbye-to-coal-power-use http://www.climatechangenews.com/2016/04/05/belgium-quits-coal-power-with-langerlo-plant-closure/
AT	Dürnrohr	Only one unit already closed. Remaining $352MW_{th}$ unit planned to close in 2025.	http://www.caneurope.org/can-and-press/953-austria-s-biggest-power-company-to-quit-coal-by-2020

2. The four units indicated in the UK TNP as planning to convert to biomass were assumed to remain at the same capacity as in the baseline but the fuel input quantity switched from coal to biomass (no other MS reported biomass conversions). Or, in the case where not all units at a plant were planned for conversion and some units were part way through conversion during the base year, the total fuel consumption for the plant in the projection years was assumed to be the same as the total for the plant in the baseline, and split evenly across units. SO_2, NO_X and dust emission levels for units that were assumed to be converted to biomass firing between 2014 and 2016 were set equal to IED new plant ELVs[8]. Mercury emissions were based on an

[8] Hence, for the plants converted to biomass firing between 2014 and 2016, they will need to make reductions in the upper BAT scenario.

average mercury content of biomass of 0.02 ppm. Emission levels of units that already converted to biomass firing before the baseline year have emission levels estimated similarly to all units.

3. All units operational in the baseline are initially presumed operational in the Reference scenario unless otherwise indicated (e.g. LCPD opt outs). The sum electrical capacity of coal- and lignite-fired units in the baseline, at Member State level, is multiplied by the scaling factor representing change in MS capacity between 2013 and relevant future years as projected by PRIMES. This multiplication produces a 'target capacity' for the Reference scenario for each of 2020, 2025 and 2030. A manual process to identify and not include (i.e. 'close') individual units in the Reference scenario is undertaken at MS level and for each year until the sum electrical capacity of coal- and lignite-fired units in the Reference scenario matches the target capacity as closely as possible. Units are identified for 'closure' in the following order: units opted out of LCPD (these are all always closed), plants opting for the LLD in the IED (these are all always closed from 2025, and could be closed earlier), age reaches 50 years (regardless of whether in TNP or not), units in TNP, units not in TNP.
4. The sum of each of biomass, coal and lignite consumption in the baseline, at Member State level, is multiplied by the scaling factor representing the change in MS fuel consumption between 2013 and future years as projected by PRIMES. This multiplication produces a 'target consumption' for each fuel type for each MS for the Reference scenario for each of 2020, 2025 and 2030. The biomass, coal and lignite fuel consumption from the baseline of the units remaining in the Reference scenario are multiplied by MS scaling factors such that total fuel consumption at MS level matches the PRIMES fuel consumption target. The scaling factors are also used to scale the annual mass emissions (i.e. assuming constant emission concentrations) and annual operating hours. The scaling factors have been capped at unit level at a maximum equivalent to 90% of maximum unit load factor, and are also capped for units in plants opting for the Limited Lifetime derogation under IED at the load factor equivalent of 2,188 hours per year (17,500 hours divided by 8 years).
5. The previous step is not carried out for biomass fuel consumption if separate evidence on biomass fuel consumption changes was identified from either a MS TNP or from Platts. Separate evidence was identified for Belgium, the Czech Republic, Denmark, Finland, France, Germany, Poland, Sweden and the United Kingdom i.e. the step 4 was carried out for the remaining MS, although since there was no biomass consumption in the baseline for some of those remaining MS, the only MS that had their biomass consumption scaled were Bulgaria, Hungary, Italy, Netherlands, Romania and Slovenia, which together made up 10% of the biomass consumption in the baseline. Hence the total EU biomass consumption is not very sensitive to the approach taken for these MS.

Projecting future plant capacity and fuel consumption is by its nature highly uncertain. The main uncertainties in the approach taken are:

- The projection of the **amount of plant capacity that will close or remain open in a MS**, i.e. from the PRIMES projections, is uncertain. This would affect the costs estimates in the study in terms of the number and capacity of plants that would need to make investments to comply with the scenario limits.
- The **amount of capacity that will be replaced** in each MS in the projection years of the study affects the projected compliance levels with the scenarios in the study as new plants would be expected to meet at least limit values from the IED. To some extent replacement is taken into account by the inclusion of planned new plants in combination with matching total MS capacity with PRIMES projection trends, although this is more limited for potential new plants after 2020.
- The selection of **which units will close** and hence which will remain open in a MS is uncertain. In reality the main factors affecting operators' decisions will be operational costs, profit margins, and other market conditions, rather than the primarily age-based approach taken. The future emissions and fuel consumption of existing plants has been based on data from the baseline year, although the process to scale to match PRIMES fuel consumption projections should mitigate the issue of selecting plants based on capacity without considering load factor. This uncertainty also has an implication for costs of scenarios as the algorithm for selection of units does not account for emission levels – i.e. implicitly it assumes that the costs of compliance with scenario limits are small compared with the existing plant operational costs.

- The **amount of future fuel consumption**, and the particular fuel mix, is uncertain. This affects the projected total future emissions, as well as affecting some operational costs of compliance techniques. Related to this is the resulting impacts on load factor of the fuel consumption scaling, as a different set of plants are assumed to have load factors less than 1500 hours per year in the future scenarios compared to the baseline. This has an impact on the relevant limit values applied to them.

2.3.4.4 Estimating changes in emissions from fuel mix changes in multi-fuel plants

The primary assumption made was that emission concentration levels will not change over the years compared to 2013 for existing plants unless the fuel mix changes. Due to different amounts of fuel used and to the extent the units remain in operation, the mass emissions may change for 2020, 2025 and 2030.

The scaling factors applied separately for biomass, coal and lignite to match PRIMES can result in changes in the fuel mix at unit level. This might then be expected to affect the emissions of the unit. The approach taken to make a first order estimate of the revised emissions in each year of the Reference scenario, given that the baseline cannot distinguish emissions from combustion of each fuel in multi-fuelled units, is to make the following assumptions for each pollutant:

- NOx: emission levels from combusting coal, lignite and biomass are most affected by boiler type and combustion conditions than by the fuel type. Hence future NOx emissions are scaled according to total fuel consumption changes.
- Dust: emission levels from combusting coal, lignite and biomass are most affected by plant abatement technique than by the fuel type, as evidenced by similar BAT-AELs. Hence future dust emissions are scaled according to total fuel consumption changes.
- Hg: emission levels are affected substantially by dust control equipment, as evidenced by BAT-AELs for biomass being similar to coal/lignite. Hence future Hg emissions are scaled according to total fuel consumption changes. For those units which converted from coal use to biomass, the same approach as applied in the baseline has been used: based on a default mercury content for biomass and taking into account the mercury co-abatement effects of the installed abatement technique, a new emission and derived concentration estimate has been made.
- SO_2: changes in the mix of coal, lignite and biomass will be taking place in plants that already have SO_2 abatement techniques. So flue gases from for example increased biomass firing will also be passed through the desulphurisation equipment. Hence SO_2 emissions are scaled by the change in coal/lignite consumption.

2.3.5 Accession Treaty derogations from LCPD ELVs

Some plants or units were still subject to Accession Treaty derogations from meeting certain LCPD SO_2, NO_X and/or dust ELVs in the baseline year 2013. These plants or units would therefore be expected to have higher emissions in the baseline than would be expected in the Reference scenario – i.e. after expiry of the Accession Treaty derogations but before the BAU scenario assumes compliance with IED ELVs. Four MSs had plants or units with Accession Treaty derogations still applicable in 2013: Bulgaria, Croatia, Poland and Romania.

For Bulgaria, Croatia and Romania, the specific units (if stipulated in the Accession Treaty) are identified. For Poland, the plants containing the specific units mentioned in the Accession Treaty are identified and the whole plant is assumed to be subject to the Accession Treaty derogation.

Of those units still expected to be operational in the Reference scenario in 2020, the estimated annual average emission concentrations in the baseline of the units which have derogations from the LCPD ELVs have been compared to the relevant LCPD ELVs. LCPD ELVs have been determined based on the plant level thermal capacity, and have been converted to estimated annual rather than monthly averages (see description on this conversion in section 2.4.1). From this comparison, the percentage reduction that would be necessary to achieve compliance with LCPD ELVs is applied as a reduction factor to the unit emission concentration and unit mass emission to apply in the Reference scenario years 2020, 2025 and 2030. Additional abatement techniques are assumed to apply for compliance with the LCPD limit values: wet FGD for SO_2 and dust control, and PMS for NOx (dust control techniques already in place).

The assumption that units which are not included in the Accession Treaty meet LCPD ELVs is a worst case assumption, which could lead to emission reductions and costs being overestimated.

2.4 Assessing the impacts of the IED ELVs and BAT-AELs

2.4.1 Determining IED ELVs and BAT-AELs for plants

The relevant IED ELVs and BAT-AELs were determined in order for the BAU and policy scenarios to compare existing emission levels to the limit values. The IED ELVs and BAT-AELs have been determined individually for each plant in each year of 2020, 2025 and 2030 in order to take into account the specific fuel mix estimated in that year at that plant. The determination of the correct ELVs and BAT-AELs takes into account the following:

- Thermal capacity
- Fuel type(s) and fuel mix: for multi-fuel plants, the ELVs and BAT-AELs are weighted averages of the individual fuel-specific limits, weighted according to the thermal input of each fuel. This follows the approach outlined in the IED.
- Commissioning year
- Estimated annual operating hours
- (where known) if the boiler type is fluidised bed combustion

Plant level thermal capacity, fuel consumption and mass emissions are summed from constituent units. The commissioning year of the 'plant' is taken as the earliest commissioning year of the plant's constituent units. Annual operational hours at plant level are determined from comparing the estimated plant level fuel consumption and what the maximum fuel consumption would be if the plant thermal capacity operated at 100% load.

The IED ELVs are expressed as monthly averages. The ELVs need to be adjusted to be expressed as estimated annual averages, so that they can be comparable with the annual average emission concentrations that have been estimated. This adjustment is undertaken assuming that annual averages are 10% lower than monthly averages.[9]

Three exceptions are made:

- For plants applying a LLD and which are not estimated to be already closed by 2020, no IED or BAT-AEL targets are imposed, i.e. assuming that no further investment occurs in the scenarios in these plants.
- For plants estimated to operate fewer than 1500 hours per year, no annual average BAT-AELs are assumed to apply as specified in the draft BREF (even though the draft BREF does specify *daily* average values apply to plants operating more than 500 hours per year). For these plants, an IED safety net is assumed to apply, i.e. for the BAT-AEL scenarios, in the absence of an applicable BAT-AEL, the IED ELV is assumed to apply.
- There are five existing plants that are identified in the LCPD emission inventories as preferentially applying the desulphurisation approach rather than SO_2 ELVs (Annex III nota bene) and which are still operational in the Reference scenario and which are specified as firing lignite in the baseline. No new plants are assumed to apply this approach. The five existing plants are assumed to also adopt the relevant desulphurisation approaches under IED or the BATC in the relevant scenarios. Their desulphurisation targets have been estimated as follows:
  - For the IED, the desulphurisation target to be achieved as a monthly average is 96%. An annual-equivalent factor is estimated using the same factor as for estimation of annual ELV averages, using the formula 1-0.82*(1-96%), generating an annual desulphurisation target of 96.7%.
  - For the BATC, the annual average abatement efficiency target is 97%, and in addition an annual average ceiling of SO_2 emission level of 320mg/Nm^3 applies.

[9] Personal communication, DG ENV. Consideration was given to using the method proposed to the LCP BREF TWG by the Dutch Ministry together with Eurelectric (authors van Aart & Burgers) of deriving monthly emission levels from 0.45*Daily emission level + 0.55*Yearly emission level, using the daily and annual BAT-AELs from the draft BREF. However, that method was found to generate untenable results of IED ELVs when converted to annual averages being lower than the monthly BAT-AELs.

2.4.2 Modelling compliance with IED ELVs and BAT-AELs

The combination of unit-level abatement technique(s) that is lowest cost at plant level is selected.

An algorithm has been developed that identifies all the combinations of specified abatement techniques for a plant (consisting of up to 14 units) that would lead to compliance at plant level with the IED ELVs or BAT-AELs. The lowest cost combination of techniques for a plant, expressed as a total of capital and operating costs over the lifetime of the technique, is selected by the algorithm. Techniques are applied to plants which are still open in 2020, 2025 or 2030, and which have estimated emission levels above the relevant limit values. The algorithm works as follows:

1. Abatement techniques are divided into groups according to the primary pollutant being abated (e.g. SCR, SNCR and PMS for NOx; ESP for dust; etc.).
2. For 2020, 2025 and 2030 the optimisation is run for each pollutant and for each plant the gap between the estimated emission concentrations in the reference scenario and the IED ELV, BAT upper and BAT lower is calculated.
3. For those plants with emission concentrations estimated to be above the limits, the algorithm calculates resulting emission concentrations with all the possible combinations of abatement techniques at unit level. (See next paragraph for the possible options.)
4. Those combinations of abatement techniques which will lead to compliance (or over-compliance) are selected and, from these, the combination with the lowest total annualised cost is selected, taking into account the costs over the economic lifetime of the abatement technique. Costs are annualised with a 4% discount rate (source: EC, 2014) and an economic lifetime of 20 years (source of lifetime: GAINS model).
5. Final emission concentrations and emissions are calculated taking into account technique impacts on other pollutants (e.g. SO_2 abatement techniques like wet scrubber will also abate dust emissions).

In order to calculate the annual mass emissions [tonnes] and emission concentrations [mg/Nm³] after abatement, the emissions from the reference scenario are multiplied by [1 minus the abatement efficiency of the most cost effective abatement technique].

A fixed order of abatement techniques (first NO_x, then SO_2, dust and finally mercury) is assumed. This order is important as the impact of SO_2 abatement techniques such as wet scrubbers on dust emissions is taken into account. For example, if the model selects an SO_2 abatement technique that co-abates dust, the remaining dust emissions and dust concentration will be compared to the IED ELV, BAT upper and BAT lower limit values. If the plant already complies with the dust limit values no further investment in a specific dust abatement technique will be made. If the plant does not yet meet the limit values, the model will then select the most cost effective combination of additional dust techniques.

Plant operators may identify more specific techniques for their plants to comply with limit values. For example, switching to lower sulphur coal is not considered by the algorithm as an available option, whereas in reality it may be possible, for example, to shift completely or partly to the use of fuel(s) with lower sulphur content to meet the SO_2 BAT-AEL. For plants using hard coal this can be an option as hard coal is transported worldwide, but it may not be an option for plants/units using lignite.

The following additional assumptions have been made (and agreed with the Commission):

- If a plant exceeds the IED ELV or BAT-AEL, even by a very small degree, the plant is assumed to need to fit abatement techniques.
- No margin of uncertainty is assumed for the IED ELVs or BAT AELs (e.g. the 20% and 30% uncertainty values quoted in the IED Annex V Part 5 are not accounted for).
- For 2020, plants opting for the LLD are excluded from fitting abatement techniques.
- The full (fixed) abatement efficiency of a technique is applied, leading to over-compliance.

Member States' TNPs include some information on the techniques specific plants expect to fit to meet the IED ELVs following cessation of the TNP. For some plants, this information mentions a precise technique, and in other cases has a more general description. For other plants, the information mentions techniques that are not among those considered as options available to the model (in Table 15, Table

16 and Table 17). The techniques that the model selects in some cases matches the specific information in the TNP and in other cases does not.

Four distinct economic cases are distinguished for estimating the impact of IED ELV or BAT-AELs, taking into account abatement techniques already installed. These are shown in Table 13.

Table 13 Four economic cases considered in the algorithm

Case for compliance	Costs taken into account	Abatement efficiency
1. Upgrade technique. Existing technique has at least 6 years' economic life remaining.	Marginal cost of the upgrade technique	Marginal abatement efficiency of the upgrade technique
2. Additional technique.	Cost of the new (additional) technique	Abatement efficiency of the new (additional) technique
3. Replacement technique. Existing technique still has economic life remaining.	Marginal cost of new technique over existing technique plus sunk cost of remaining lifetime of existing technique	Marginal abatement efficiency of the new technique over the existing technique
4. New technique. Existing technique has no economic life remaining.	Marginal cost of new technique over existing technique	Marginal abatement efficiency of the new technique over the existing technique

The installation date of the existing abatement techniques installed at each unit informs the algorithm's decision whether to consider upgrade techniques or additional/new/replacement abatement techniques. Data on installation dates of abatement techniques at a plant level was extracted from BATIS. When BATIS did not provide this information for a plant, the historic emission levels of that plant (from the LCP EI) were inspected, separately for SO_2, NO_x and dust. The year in which the trend line of the emission factors (emissions divided by the fuel input) showed a discontinuity was assumed to be the installation year for the abatement technique. If no relevant break in the available time series could be identified, it was assumed that the abatement technique was already in place before the start year of the time series (2004). This approach may not identify fuel switching (e.g. to a lower sulphur coal), and may be limited to the identification of a single abatement technique. For each of the techniques the lifetime was assumed to be 20 years.

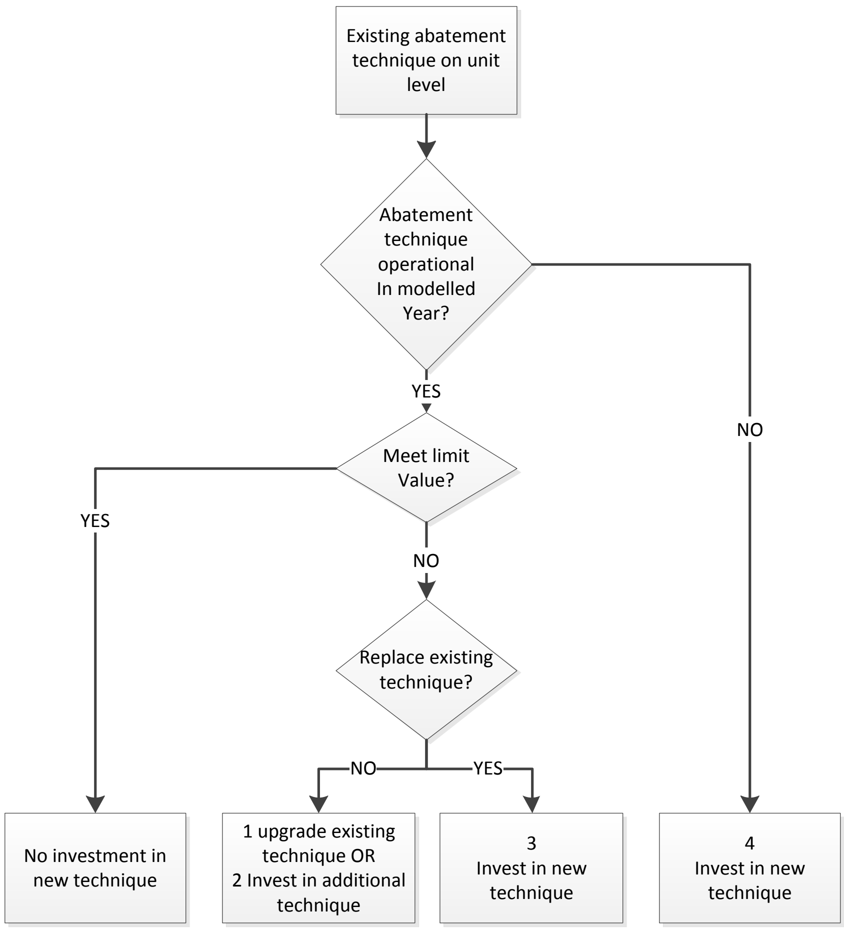
Table 14 shows the number of plants for which the existing abatement techniques on at least one of the operational units are estimated to be at the end of their economic life in 2020, 2025 and 2030 and therefore need to invest in new techniques (case 4 in Table 13).

Table 14: The number of plants with SO_2, NO_x or dust abatement techniques that are estimated to be at the end of their economic life in 2020, 2025 and 2030.

Pollutant	2020	2025	2030
	(out of 300 open plants)	(out of 264 open plants)	(out of 232 open plants)
SO_2	15 plants	54 plants	107 plants
NO_X	6 plants	49 plants	69 plants
Dust	18 plants	71 plants	154 plants

Figure 6 depicts the options the model has when an existing abatement technique was already installed at a unit.

Figure 6 Model decision tree for determining whether an existing technique should be upgraded, supplemented or replaced



The model selects the most cost effective option to meet the limit value across the four cases shown in the above diagram: whether it will be upgrading an existing technique (marked as '1' in the above diagram), fitting an additional technique (2), replacing an existing technique (3), or fitting a new technique (4). The costs of abatement techniques are listed in Table 16 and their abatement efficiencies in Table 17 for cases 2, 3 and 4.

1. **Upgrading an existing technique**

Upgrading an existing, still operational, abatement technique (i.e. retrofit) has been assumed to be a compliance option for four common existing abatement techniques: ESP, SCR, SNCR and WSC, if the estimated remaining lifetime of the existing technique is at least 6 years (i.e. one third of the total lifetime[10]). Table 15 shows the upgrade options and their assumed costs and efficiencies.

The costs to be accounted for in this case are the costs of the upgrade of the technique. The emissions impacts are estimated using the abatement efficiency of the upgrade technique which is specified as the additional removal efficiency that installing the upgrade technique would provide assuming the base technique is already installed.

Case 1 example: existing wet scrubber is upgraded

An existing scrubber was fitted at a unit in 2007. In the modelled year 2020, the scrubber has 7 years economic life left. The model identifies the most cost effective compliance option is upgrading the scrubber with additional spray banks.

The cost taken into account is the full annualised cost of the additional spray banks, from Table 15, i.e. €8,775/MW_e capex plus €999/MW_e/yr opex. The emissions reduced by the upgrade are derived using the abatement efficiency of the additional spray banks from Table 15, i.e. a further 40% reduction on existing SO_2 emission levels.

[10] Personal Communication with JRC, 12 July 2016

Table 15 Options for upgrading existing techniques that have a remaining economic lifetime of at least 6 years

Existing abatement technique	Improvement of existing technique	Abatement efficiency [%]	Capital cost (€2015)	Operating cost (€2015)	Source
ESP ESP+ ESP++	Adding an electrostatic field	40% dust	11,600 /MW_e	194/MW_e/yr	MPMD (2012)
SNCR	Slip catalyst	50% NO_x	31,120 /MW_{th}	3,544 /MW_{th} /yr	TFTEI (2015) with assumption that Capex is 1/3 less than SCR
SCR	Adding catalyst (0.0275 m^3/MW_{th}) + reagent (0.0735 t/MW_{th}/a)	50% NO_x	0	46.4/MW_{th}/yr	TFTEI (2015)
WSC WSC+	Additional spray bank	40% SO_2	8,775/MW_e	999/MW_e/yr	MPMD (2012)

2. Investment in an additional technique

If an existing abatement technique is still operational in the modelled year, and an additional technique is needed on top of the existing one to meet limit values, the full cost of this additional technique is taken into account (costs shown in Table 16).

The emissions impact has been calculated using the abatement efficiency of the additional technique (shown in Table 17) applied to the reference scenario emissions i.e. applied to the emissions that already account for the impacts of existing abatement techniques.

Case 2 cost example: PMS already installed; SCR is additionally fitted

An existing PMS technique is already fitted at a unit and has not come to the end of its economic life. The model identifies that SCR is additionally needed to meet the limit value.

The cost taken into account is the full annualised cost of the new SCR, listed in Table 16, i.e. capital costs of €30,834/MW_{th} plus operating costs of €3,098/MW_{th}/yr. The emissions reduced are derived using the abatement efficiency of the SCR (85%, from Table 17) applied to the existing emission levels.

3. Replacement of existing technique

If an existing abatement technique is still operational in the modelled year, and another technique is needed to replace the existing technique to meet the limit values, the sunk cost of the existing technique is taken into account. The sunk cost is a cost that has already been incurred and thus cannot be recovered, and represents the remaining value of the existing technique that is replaced earlier than originally envisaged and before its economic life has been reached. The costs of the existing technique have been assumed to be those of the least advanced versions of ESP, SCR and WSC and the average costs for the other techniques (costs in Table 16).

The cost of the replacement technique is equal to the capex of the replacement technique minus the capex of the replaced technique plus the sunk cost of the replaced technique.

Case 3 cost example: existing wet scrubber is replaced with a new wet scrubber

An existing wet scrubbing technique with a remaining lifetime of 5 years (of a total of 20 years) is selected by the algorithm to be replaced with a new wet scrubber.

First, the cost of the existing technique is deducted from the costs of the new (more efficient) technique. This calculation is done assuming that the plant would have replaced the existing technique with a new one of the same type anyhow at the end of the life of the existing technique, i.e. the approach aims to capture only the additional cost due to meeting the limit values.

Second, the cost of the new wet scrubber is inflated with 5 years of annualised investment costs of the existing wet scrubber (from Table 16), representing the amortisations (sunk cost) that are still relevant for the 5 years remaining lifetime if the technique would not have been replaced.

Cost of replacement = [total annualised cost of new wet scrubber] – [total annualised cost of existing wet scrubber] + [sunk capital cost of existing wet scrubber]

The emissions reduced are based on the marginal efficiency of the new technique compared to the existing technique. Table 17 indicates that the existing scrubber is assumed to have had an 85% SO_2 removal rate, and the new scrubber a 95% removal rate. I.e. for a plant with unabated emissions of 1000 tonnes per year, if the existing abated emissions had been 150 tonnes per year, the new emissions with the new scrubber would be 50 tonnes per year.

The emissions impact requires an assumption on the average abatement efficiency for the existing technique to calculate back to the unabated situation as the existing technique will be replaced. The assumed efficiencies of both existing and new techniques are shown in Table 17.

4. **Investment in a new technique**

If an existing abatement technique is estimated to be older than 20 years in the modelled year and the algorithm identifies that a plant needs to fit a technique to meet the limit values, no sunk costs are taken into account. However, the cost of investing in the same type of technique as the existing one is deducted from the cost for a new technique – and the new technique is assumed to have higher efficiency than the existing one. This deduction is made because it is assumed that the plant would have replaced the existing technique with a new one of the same type anyhow in a business-as-usual case (i.e. same assumption as case 3 ‘replacement of existing technique’), and only the additional cost attributed to the change in limit values is sought.

The emissions impact requires an assumption on the average abatement efficiency for the existing technique to calculate the hypothetical unabated emissions. These are shown in Table 17.

Case 4 example: existing wet scrubber (WSC) is replaced with a new wet scrubber (WSC+)

An existing wet scrubbing technique which was installed more than 20 years ago is selected by the algorithm to be replaced with a new more efficient wet scrubber.

The costs that are taken into account from Table 16 are the costs of the new wet scrubber (capital cost of €97,071/MW_{th} and operating cost of €6,281/MW_{th}/yr) minus the costs of the existing wet scrubber (capital cost of €72,000/MW_{th} and operating cost of €3,427/MW_{th}/yr).

The emissions reduced are based on the marginal efficiency of the new technique compared to the existing technique. Table 17 indicates that the existing scrubber is assumed to have had an 85% SO_2 removal rate, and the new scrubber a 95% removal rate. I.e. if the existing emissions had been 150 tonnes per year, the new emissions with the new scrubber would be 50 tonnes per year.

Table 16 Abatement techniques available to the model and their assumed capital and operating costs (EUR2015)

Abatement technique abbreviation	Abatement technique	Target pollutant	Other pollutants affected	Existing / replaced technique capital cost (€/MW_{th})	New / replacement technique capital cost (€/MW_{th})	Existing / replaced technique operating cost (€/MW_{th}/yr)	New / replacement operating cost (€/MW_{th}/yr)	Source
ACI	Active carbon Injection	Hg		455	909	329	1,225	NRDC (2011)
BACI	Bromide addition to active carbon injection	Hg		1,000	1,625	275	1,031	EPPSA (2015a)
PMS	Primary measures	NOx		4,207	6,070	123	178	TFTEI (2015)
SCR	Selective catalytic reduction	NOx	Hg	30,834	30,834	3,098	3,098	TFTEI (2015)
SCR+	High efficiency selective catalytic reduction	NOx	Hg	-	46,681	-	3,563	TFTEI (2015)
SCR++	Highest efficiency selective catalytic reduction	NOx	Hg	-	52,793	-	3,742	TFTEI (2015)
SNCR	Selective non-catalytic reduction	NOx		11,207	15,619	774	904	TFTEI (2015)
COMBI2	Combi PMS & SCR	NOx	Hg	35,041	52,751	3,222	3,741	TFTEI (2015)
COMBI3	Combi PMS & SNCR	NOx		15,414	21,689	898	1,082	TFTEI (2015)
ESP	Electrostatic precipitator	Dust	Hg	58,424	58,424	2,196	2,196	TFTEI (2015)
ESP+	High efficiency electrostatic precipitator	Dust	Hg	58,424	84,707	2,196	3,164	TFTEI (2015)
ESP++	Highest efficiency electrostatic precipitator	Dust	Hg	58,424	122,814	2,196	4,804	TFTEI (2015)

Abatement technique abbreviation	Abatement technique	Target pollutant	Other pollutants affected	Existing / replaced technique capital cost (€/MW_{th})	New / replacement technique capital cost (€/MW_{th})	Existing / replaced technique operating cost (€/MW_{th}/yr)	New / replacement operating cost (€/MW_{th}/yr)	Source
DSC	Dry and semi dry scrubbing	SO_2	Hg	10,320	30,960	1,079	2,472	BREF LCP draft (section 3.3.3) (2016)
WSC	Wet scrubbing	SO_2	Dust, Hg	72,000	72,000	3,427	3,427	LCP BREF
WSC+	High efficiency wet scrubbing	SO_2	Dust, Hg	72,000	97,071	3,427	6,281	MPMD (2012)
WSC++	Highest efficiency wet scrubbing	SO_2	Dust, Hg	-	122,143	-	9,136	MPMD (2012)

Note: The replacement of use of hard coal in all or part of the plant by low-sulphur hard coal to reduce SO_2 emissions was not considered as an option. In practise this could be a possible compliance option as hard coal is traded worldwide. However, the decision to use low sulphur coal is not only driven by air pollutant legislation as it has a large impact on costs of operation of a plant and the possibility to import or use low-sulphur coal depends on location of the coal plants and on trade treaties between different parties.

Table 17 Abatement technique efficiencies used in the modelling

Technique	NO_X abatement efficiency (%)		SO_2 abatement efficiency (%)		Dust abatement efficiency (%)		Hg abatement efficiency (%)		Source
	Existing / replaced	New / replacement	Existing / replaced	New / replacement	Existing / replaced	New / replacement	Existing / replaced	New / replacement	
ACI							50%	70%	Draft LCP BREF (Table 3.15)
BACI							92%	92%	EPPSA (2015a and 2015b)
PMS	10%	39%							Draft LCP BREF (section 3.3.3)
SCR	70%	75%					Hg co-abatement in Table 6		US EPA (2003)
SCR+	-	85%					Hg co-abatement in Table 6		Draft LCP BREF (section 3.3.3)
SCR++	-	95%					Hg co-abatement in Table 6		Draft LCP BREF (section 3.3.3)
SNCR	30%	40%							Draft LCP BREF
COMBI2 (SCR+PMS)	70%	97%							Expert judgment based on PMS and SCR efficiency
COMBI3 (SNCR+PMS)	52%	63.49%							Expert judgment based on PMS and SNCR efficiency
DSC			70%	78%			Hg co-abatement in Table 6		Draft LCP BREF (section 3.3.3) – furnace sorbent injection
ESP					95%	95%	Hg co-abatement in Table 6		Lowest ESP efficiencies calculated in the baseline
ESP+					95%	99.45%	Hg co-abatement in Table 6		Expert judgment
ESP++					95%	99.99%	Hg co-abatement in Table 6		Expert judgment
WSC			85%	95%		83.5%	Hg co-abatement in Table 6		SO_2: IEA CCC (2013); Dust: EIPPCB Pers. Comm., 2016
WSC+			85%	97%		90.1%	Hg co-abatement in Table 6		SO_2: Draft LCP BREF (section 3.3.3); Dust: EIPPCB Pers. Comm., 2016
WSC++			-	99%		96.7%	Hg co-abatement in Table 6		SO_2: Draft LCP BREF (section 3.3.3) Dust: EIPPCB Pers. Comm., 2016

Mercury considerations in IED scenario

There is no IED ELV for mercury. However, mercury emissions are affected by the SO_2, NO_X and dust abatement techniques selected by the model for IED ELV compliance. Therefore, the set of abatement techniques required for compliance with the IED limit values is compared to the set of techniques in the reference case. Due to lack of literature information identified on mercury co-abatement effects by all possible configurations of techniques, estimates have been made of the co-abatement effect of combinations with different techniques for NO_x- or SO_2-removal (presented earlier in Table 6 in section 2.2.7). This includes a higher co-abatement effect for upgraded NO_x- and SO_2-scrubbers. By applying technology mix specific co-abatement percentages, the mercury effect of a change in abatement can be estimated.

Mercury considerations in BAT scenarios

Under the BAT scenarios, an upper and lower AEL exists for mercury which has to be met at plant level. Before applying dedicated mercury abatement, first the effects on mercury by the selected SO_2, NO_X and dust abatement techniques selected by the model is estimated. This is done by comparing the co-abatement efficiency of the mix of techniques selected in the BAT scenario with the mix of techniques in the reference scenario.

Emissions after co-abatement = existing emissions / (1 - existing co-abatement efficiency) x (1- new co-abatement efficiency)

This exercise is performed at unit level and then aggregated to plant level. The plant concentration of mercury is estimated as:

Plant co-abated concentration = sum of plant's units' emissions after co-abatement / sum of plant's units' flue gas volumes

This concentration is then compared to the upper or lower BAT AEL, depending on the scenario. If the co-abatement concentration is already below the AEL, no further mercury-specific abatement techniques are needed. If the co-abated concentration is above the BAT AEL, dedicated mercury reduction techniques are assumed to be needed by these plants for compliance.

Two dedicated mercury abatement techniques are available as options to be implemented to achieve compliance: activated carbon injection (ACI), and bromide addition to activated carbon injection (BACI). The costs and abatement efficiencies of these techniques are shown in Table 16 and Table 17. These techniques are applied at unit level to achieve plant compliance with BAT-AEL. The techniques are assumed to be implemented on a least cost basis: ACI (the cheaper technique) is assumed to be implemented first, and applied to as many units in a plant as needed for the plant to achieve compliance with the BAT-AEL. Hence in multi-unit plants the technique may not necessarily be assumed to be fitted at all units, and overachievement of mercury reduction is thus avoided. If applying ACI on all of a plant's units does not reach plant compliance, BACI is applied. In some multi-unit plants, BACI replaces ACI on some but not all units, if this results in lower costs per plant. Plant level compliance with the mercury BAT-AELs can almost always be achieved with the installation of BACI. There are very few exceptions where, according to the modelling, the lower BAT-AEL cannot be reached with BACI.

2.5 Monetising impacts of changes in emissions

The changes in cost of damage to health and the environment in monetary terms resulting from the changes in air pollutant emissions has been estimated using damage costs. The abatement technique that is assumed to be installed under each scenario – whether to meet IED ELVs or BAT-AELs according to the scenario – is used to estimate the changes in emissions of air pollutants. The method to monetise emission reductions that has been used is an established method developed under the EU's Clean Air for Europe (CAFE) programme and updated in later work programmes. The damage costs were derived by the EEA using the bottom-up impact pathway approach. The impact pathway approach accounts for the dispersion of pollution around the source, its chemical transformation in the environment, and the exposure of relevant populations (human, environment) to elevated concentrations. For further details on the impact pathway approach see EEA (2014), and the ExternE project webpages[11].

[11] http://www.externe.info/

The damage costs that have been applied take into account the main substantial health and environmental impacts resulting from emissions of SO_2, NOx, dust and Hg.

The damage costs that are used for SO_2, NO_X and dust are from EEA (2014) and are expressed as EUR/tonne emission. Damage costs are estimated by multiplying [the changes in] emission quantities by the damage costs; emission reductions (i.e. negative emissions) result in negative costs (i.e. benefits). The damage costs for SO_2, NO_X and dust are specified separately for each MS and have been applied in this way.

EEA (2014) specify in detail the health and environmental impacts that are and are not accounted for in the damage costs – summarised in Table 18 and Table 19 respectively. Principally, the quantified impacts that are accounted for are:

- health impacts from exposure to $PM_{2.5}$ (chronic and acute impacts), NO_2 (acute and some but not all chronic impacts), ozone (acute but not chronic impacts); and
- environmental impacts of crop exposure to ozone and SO_2 degradation on utilitarian buildings.

Table 18 Health and environmental impacts quantified in SO_2, NO_X and PM damage costs

Burden	Effect	
Human exposure to $PM_{2.5}$	Chronic effects on: • Mortality ○ Adults over 30 years ○ Infants • Morbidity ○ Bronchitis in adults ○ Bronchitis in children	Acute effects on morbidity: • Respiratory hospital admissions • Cardiac hospital admissions • Consultations with primary care physicians • Restricted activity days • Work loss days • Asthma symptoms in children
Human exposure to ozone	-	Acute effects on: • Mortality • Morbidity ○ Respiratory hospital admissions ○ Cardiac hospital admissions ○ Minor restricted activity days
Human exposure to NO_2	Chronic effects on: • Morbidity: Bronchitis in asthmatic children	Acute effects on: • Mortality • Morbidity: Respiratory hospital admissions
Exposure of crops to ozone	Yield loss for: barley, cotton, fruit, grape, hops, millet, maize, oats, olive, potato, pulses, rapeseed, rice, rye, seed cotton, soybean, sugar beet, sunflower seed, tobacco, wheat	
SO_2 effects on utilitarian buildings	Degradation of stone and metalwork, particularly zinc, galvanised steel	

Table 19 Health and environmental impacts not quantified in SO_2, NOx and PM damage costs

Burden	Effect
Health	• Ozone: chronic mortality and morbidity • NO_2: chronic mortality • Direct effects of SO_2, NMVOCs • Social impacts • Altruistic effects
Agricultural production	• Direct effects of SO_2 and NO_X • N deposition as crop fertiliser • Visible damage to marketed produce • Interactions between pollutants, with pests and pathogens, climate etc. • Acidification/liming
Materials	• Effects on cultural assets, steel in reinforced concrete • PM and building soiling • Effects of O_3 on paint, rubber
Ecosystems	Effects on biodiversity, forest production, etc. from excess O3 exposure, acidification and nitrogen deposition
Visibility	Change in visual range
Drinking water	Drinking water supply and quality

The damage costs have been uplifted to 2015 prices using the World Bank's GDP deflator (which provides the rate of price change in the economy as a whole) for the EU28[12].

The damage costs from EEA (2014) for SO_2, NOx and PM are expressed as a range to reflect alternative methods of valuation of mortality, with the lower value representing the low estimate of the approach considering the value of a life year (VOLY) and the upper value representing the high estimate of the approach considering the value of statistical life (VSL)[13].

For mercury, the damage costs presented in EEA (2014) of €910/kg (2005 prices) was discarded as it represents IQ loss only and excludes more dominant mortality impacts. Instead, a damage cost of €52,129/kg (2013 prices) was assumed as the central value, taken from Nedellec & Rabl (2016) which does include mortality impacts. Nedellec & Rabl (2016) estimate that mortality effects make up more than 90% of the Hg damage cost, although not all effects are taken into account (e.g. the value excludes damage from intake of marine seafood). The Hg damage cost is assumed to be the same across all EU MS. Sensitivity analysis on the mercury damage cost is carried out: 50% is added to/subtracted from this central value, to match the extent of variation in the SO_2, NO_X and dust damage costs.

The damage costs have not been uplifted in future years, i.e. it is assumed there are no increases in willingness to pay with economic growth in future years (this is likely to underestimate the benefits).

As the particulate emissions and reductions in the database have been expressed as dust – i.e. total suspended particles – and the particulate matter damage costs are expressed for the PM_{10} fraction, PM_{10} emission changes have been estimated from the dust emission changes. The PM_{10} emissions have been estimated using an assumption from Eurelectric (2008) that 80% of total dust emissions are size fraction PM_{10} for coal combustion plants without FGD, and 95% are PM_{10} in case of plants with FGD fitted.

The SO_2, NOx and PM_{10} damage costs for each Member State are presented in Appendix 7.

[12] http://data.worldbank.org/indicator/NY.GDP.DEFL.KD.ZG/countries/EU?display=graph

[13] EEA (2014) describe these methods as follows: *The value of statistical life (VSL) — an estimate of damage costs based on how much people are willing to pay for a reduction in their risk of dying from adverse health conditions. The value of a life year (VOLY) — an estimate of damage costs based upon the loss of life expectancy (expressed as potential years of life lost, or YOLLs). This measure takes into account the age at which deaths occur by giving greater weight to deaths at younger age and lower weight to deaths at older age.*

3 Results and discussion of central case

This chapter provides the results of the central case – i.e. for the variables which are subject to sensitivity analysis, choosing the central or average value. Section 4 provides the sensitivity analysis.

3.1 2013 Baseline and 2020/2025/2030 Reference scenario

3.1.1 Number of LCPs

The baseline of this study has 375 LCPs, with 839 operational units in 2013. This is estimated to decline in future years in the reference scenario to 300 LCPs in 2020, 264 in 2025 and 232 in 2030 after accounting for forecast new plants/units and closures.

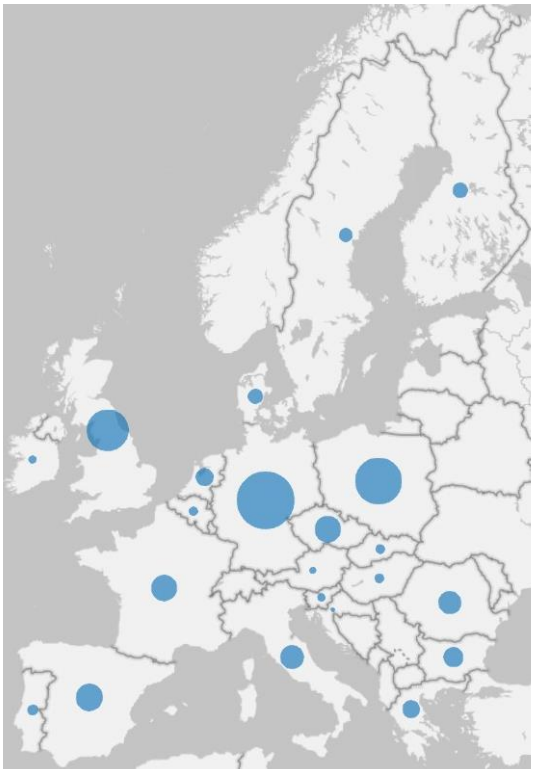
Around three quarters of the plants in the baseline and reference scenarios are single fuelled plants, and one quarter multi-fuelled plants, if 'single fuelled' is defined as at least 95% of total fuel consumption from one fuel type.

The vast majority of the LCPs in the study generate public power. Other minority sectors represented among the LCPs include pulp/paper production (7 LCPs), chemical industry (9 LCPs), refining (1 LCP), mixed coal/waste incineration (1 LCP assuming co-firing) and brickworks (1 LCP).

3.1.2 Capacity

The total thermal capacity of the LCPs in scope of this study in the 2013 baseline is 528 GW_{th}. This represents 38% of the total reported LCP capacity (i.e. 50MW_{th} and above) in the LCP EI in 2013 of 1399 GW_{th}. The distribution of thermal capacity in the baseline across the MS is shown in Figure 7.

Figure 7 Rated thermal input capacity in the baseline in 2013 represented by area of circles.



Member State	Rated thermal input (GWth)
Germany	138
Poland	91
United Kingdom	73
Spain	30
Czech Republic	29
France	28
Italy	23
Romania	22
Bulgaria	16
Netherlands	13
Greece	13
Finland	10
Denmark	9
Sweden	8
Portugal	5
Hungary	4
Slovakia	4
Belgium	3
Slovenia	3
Ireland	3
Austria	2
Croatia	1
Total	**528**

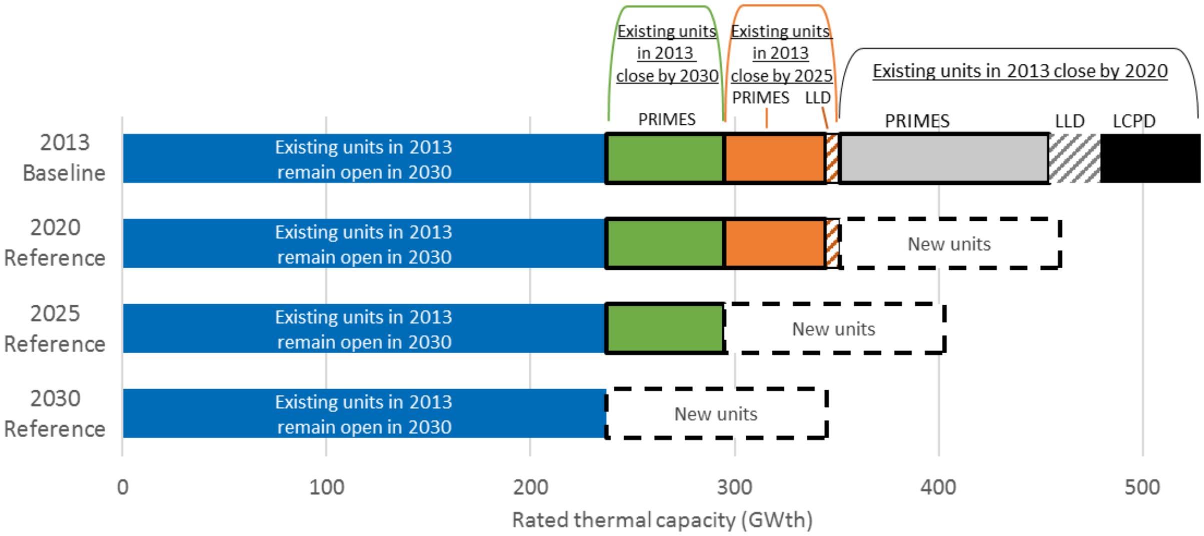
Note: MS without LCPs in scope of this study are not necessarily mapped.

Figure 8 shows the projected changes in total installed rated thermal input across the EU for the plants in scope of the study from the baseline in 2013 to the reference scenario in 2020, 2025 and 2030. The figure differentiates the capacity by the age of units in terms of units that estimated to close by 2020, by 2025 or by 2030. The capacity of the new units is also shown – note that all new units identified from

Platts-WEPP are estimated to be commissioned by 2020, hence the capacity of the new units is fixed over time.

The figure indicates that, in order to match the PRIMES projections (methodology described in section 2.3.4), most plants that have limited lifetime derogations (LLD) are assumed to close by 2020 rather than 2025. However, the majority of the closures in both 2020 and 2025 are due to the methodology of matching the PRIMES projection rather than the LCPD opt outs or plants with LLD.

Figure 8 Change in installed thermal capacity from the baseline to the reference scenario



3.1.3 Fuel consumption

Figure 9 shows the fuel consumption for the baseline plants in 2013, aggregated per Member State and per fuel type. For some Member States, no relevant LCPs are in the scope of this study, therefore these MS are not shown. The figure shows most of the fuel consumption is bituminous coal and lignite, and that the majority of fuel consumption of the plants in scope is in Germany, Poland and the UK.

Figure 9 Baseline (2013) fuel consumption in the LCP plants selected for this study, per MS and per fuel

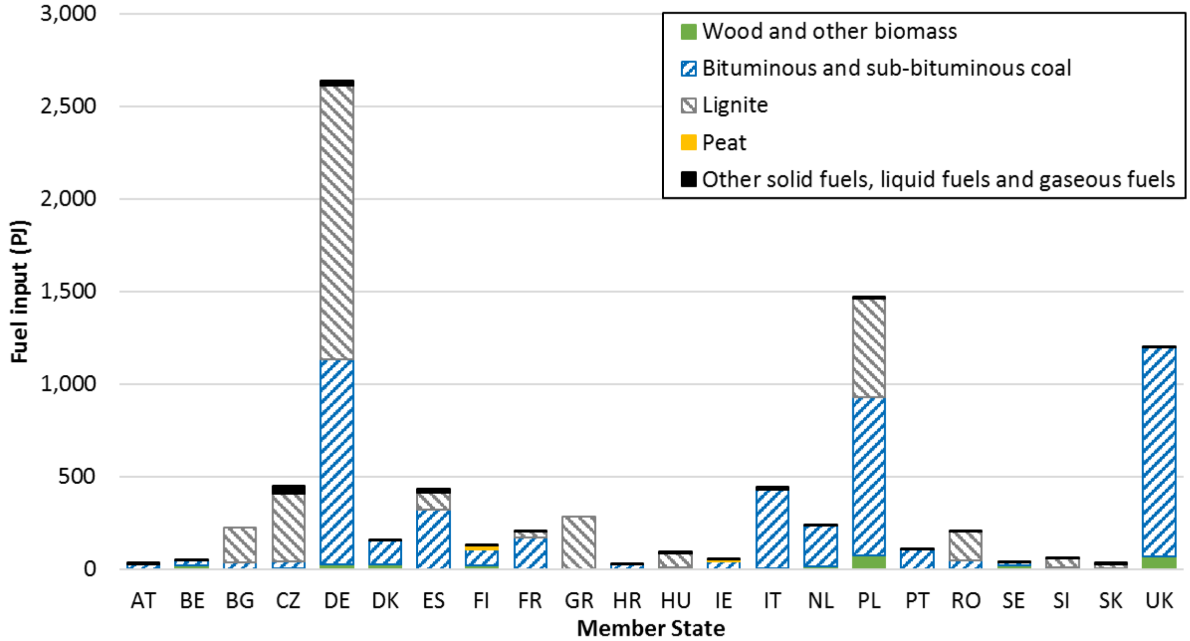
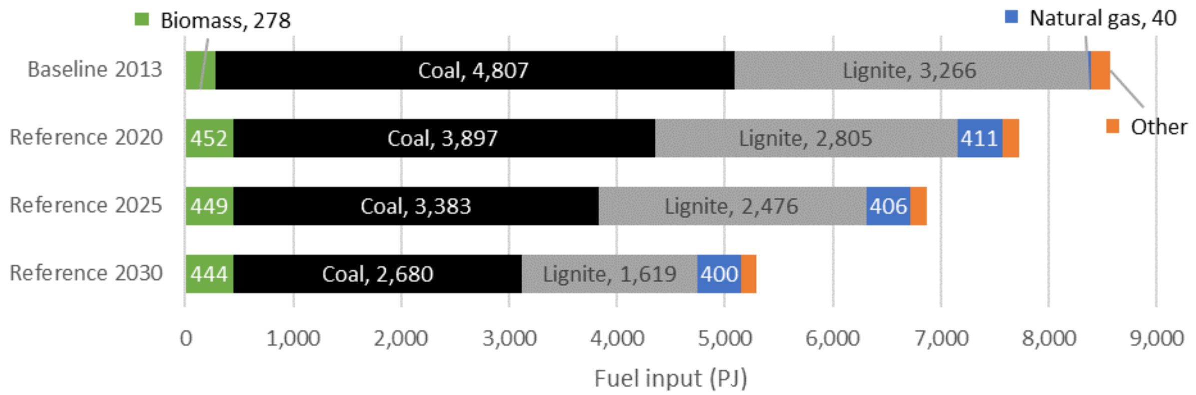


Figure 10 shows how the total fuel consumption from the plants in scope in the baseline are projected in the reference scenario to 2020, 2025 and 2030. The figure differentiates the total by fuel type. The results show a decline in total fuel consumption from the plants in scope of the study. The coal and lignite consumption is projected to steadily decline over the period 2013 to 2030. Biomass consumption is estimated to increase from the baseline in 2013 to the Reference scenario in 2020. Due to an absence of new biomass plant forecasts identified the biomass consumption is then estimated to remain steady to 2030. Natural gas consumption at the 'coal/lignite' plants in scope of this study is projected to increase ten-fold – this is due to the projected opening of new gas-fired units at existing coal/lignite installations which are already in the baseline.

Figure 10 Fuel consumption of the Baseline and Reference scenario



3.1.4 Operating regime

The annual estimated operating hours of LCPs in each of the baseline and reference scenarios are shown, as a function of total installed capacity for the respective years, in Figure 11.

Figure 11 Operating hour regime of 2013 baseline and 2020/25/30 reference scenarios, as a function of installed thermal capacity

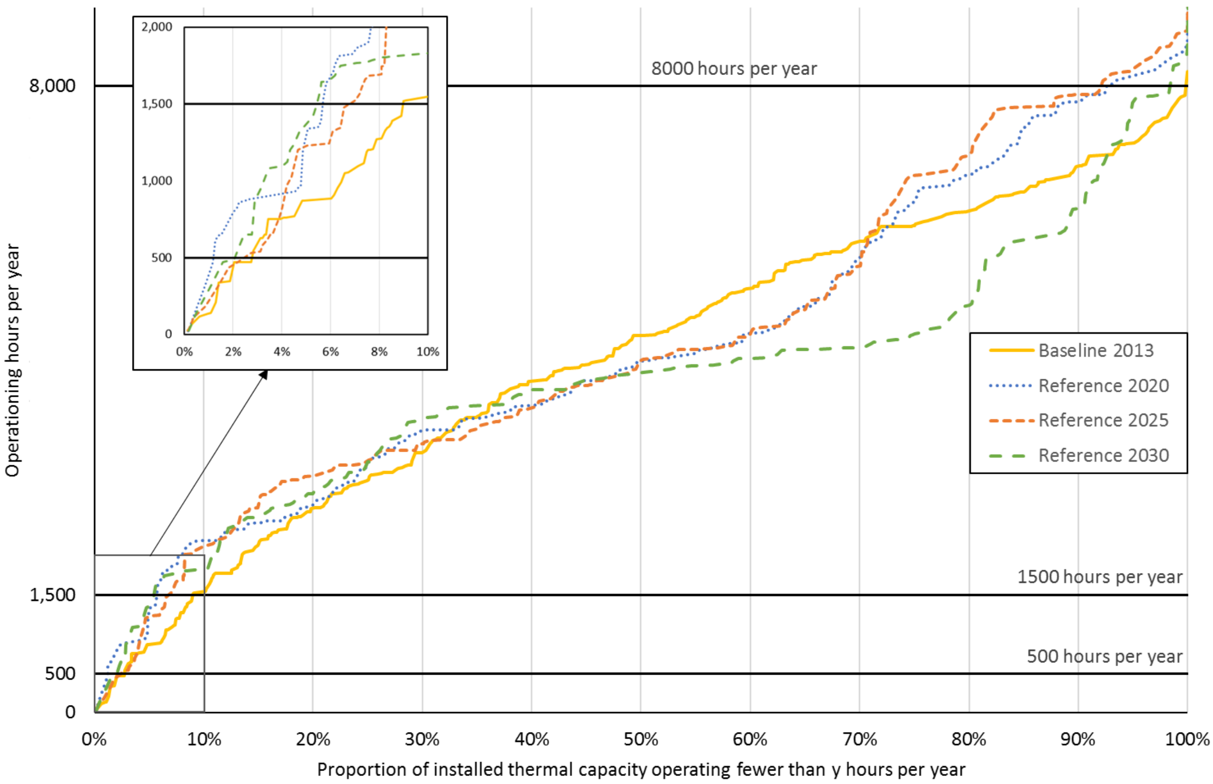


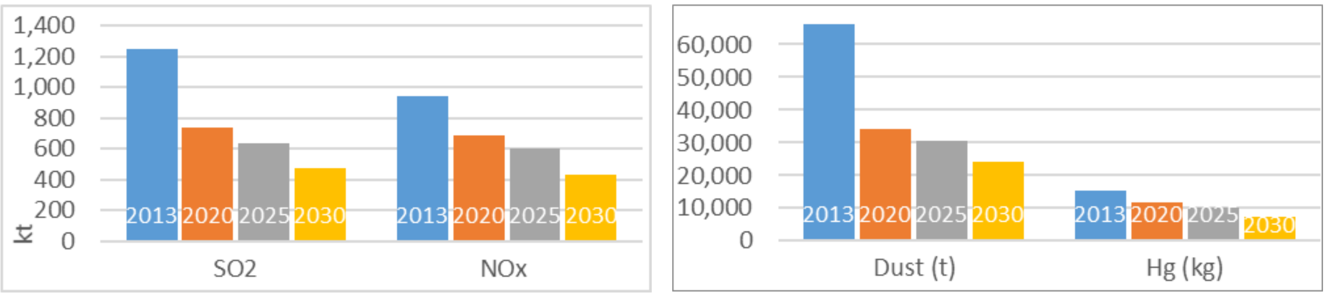
Figure 11 shows that the adjustments made to the load factor of plants by carrying out the methodology to match the PRIMES fuel consumption trends has not significantly altered the spread in load regimes among the LCPs in each year. Compared to the baseline, the reference scenario has a smaller proportion of installed capacity that is estimated to operate fewer than 500 or 1500 hours per year. This could be due to the closure of low load plants by 2020 which are LCPD opt outs or IED LLD plants or are simply uneconomic low load plants. Above 1500 hours per year, the 2030 reference scenario shows the largest departure from the load regimes in the baseline: around 50% of the capacity operating in earlier years at higher loads are estimated in 2030 to reduce load factors. This is a direct result of the methodology for adjusting unit fuel consumption at MS level to match PRIMES trends in fuel consumption.

3.1.5 Emissions

The total SO_2, NOx and dust emissions of the LCPs in scope of this study in the 2013 baseline are 1251, 940, and 66 kilotonnes respectively. These respectively represent 82%, 75% and 77% of the total reported LCP emissions in the LCP EI in 2013 respectively (of 1,518 kt SO_2, 1,248 kt NOx and 86 kt dust).

The SO_2, NOx, dust and Hg emissions from the LCPs in this study baseline and reference scenarios are shown in Figure 12 at EU level, and at Member State level in Figure 14, Figure 15, Figure 16 and Figure 17 and SO_2, NO_X, dust and mercury respectively. Appendix 8 tabulates the Member State results. They show sharp declines, particularly for dust, between 2013 and 2020 reflecting the closures of some of the most polluting plants which were LCPD opt outs, followed by continued declines to 2030 reflecting the reduction in capacity of solid fuel plants estimated to be operating. Mercury emissions are estimated to be 54% lower in 2030 than in 2013 without the IED ELVs.

Figure 12 Total EU emissions for the plants in the baseline and reference scenario



The SO_2, NO_X, dust and Hg average EU level emission factors (per unit fuel input) are shown in Figure 13. The emission factors also show marked drops between 2013 and 2020 – particularly for SO_2 and dust – and then relatively stable emission factors from 2020. This is expected to be strongly linked to closures of the more polluting plants between 2013 and 2020, which is driven by the LCPD requirements. But it is also reflecting the closures of plants which opted under the IED for the LLD and which are estimated to use up their limited operational hours by 2020.

Figure 13 Average EU emission factors for the plants in the baseline and reference scenario

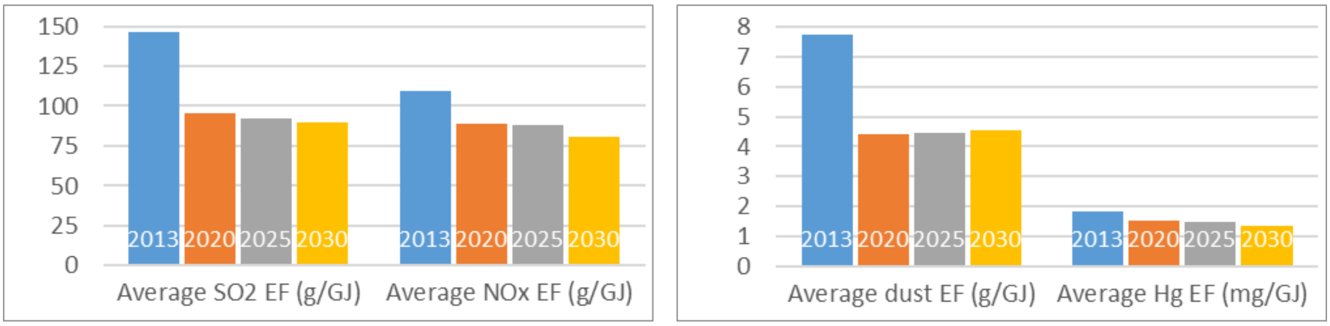
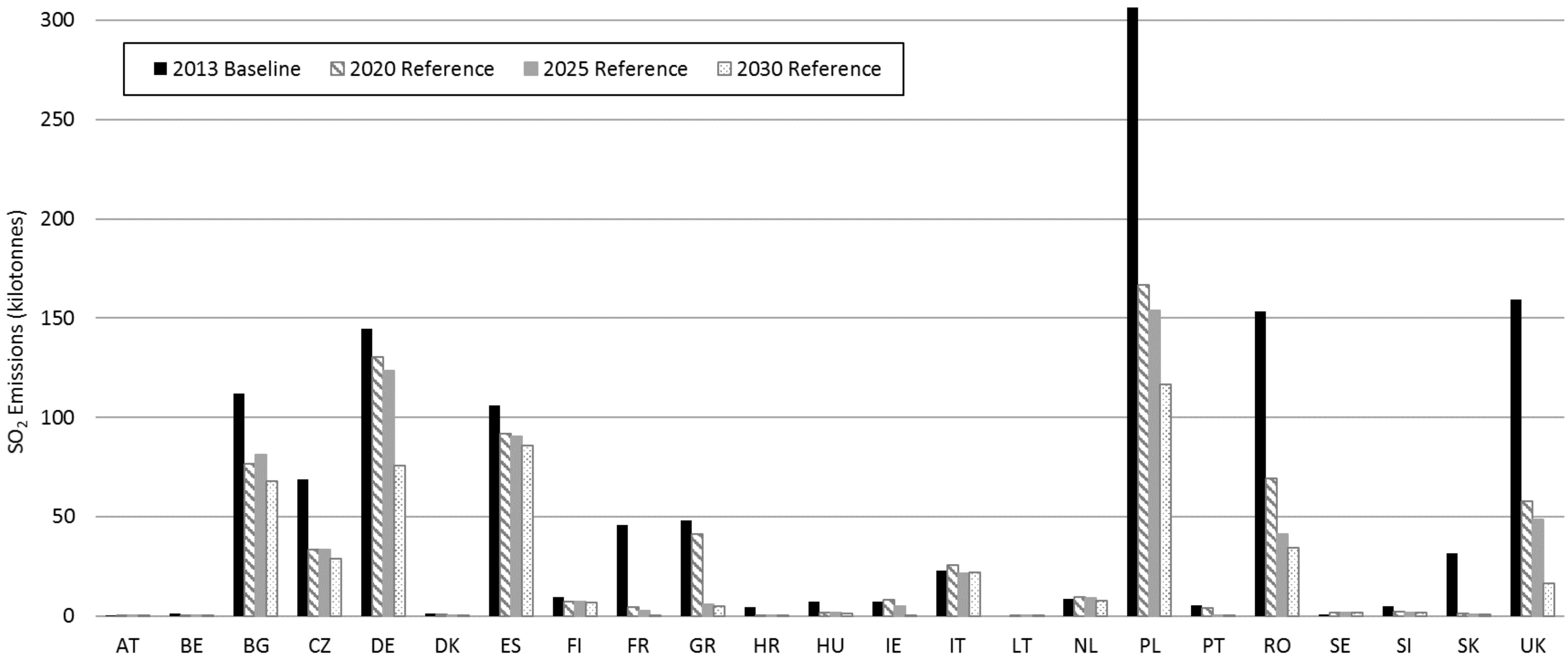


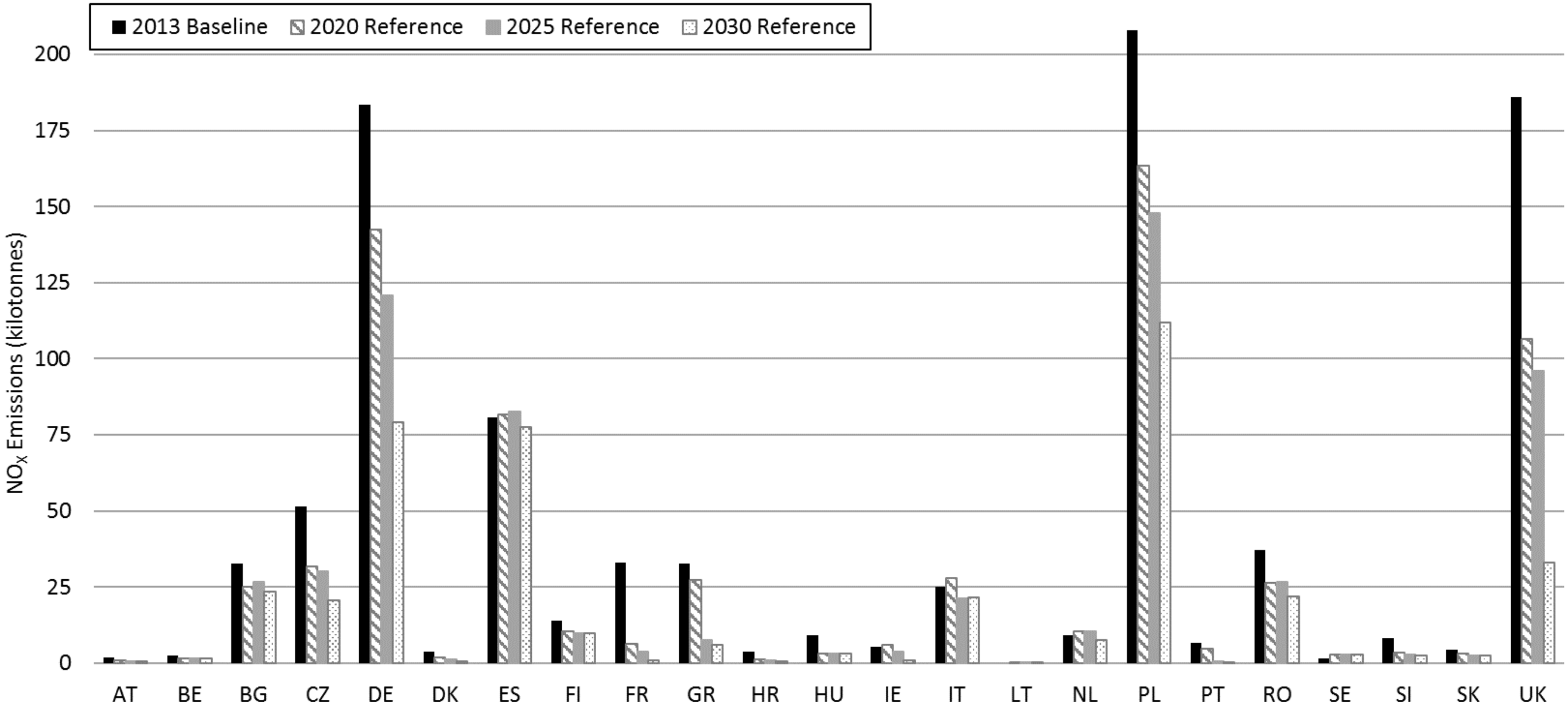
Figure 14 Member State level SO_2 emissions for the plants in the baseline and reference scenario



SO_2 emissions from the LCPs covered in this study were estimated at 1251kt in the baseline in 2013, reducing in the reference scenario to 736kt in 2020, to 632kt in 2025 and to 475kt in 2030. Bulgaria, Germany, Poland, Romania, Spain and the UK are the MS with the largest LCP SO_2 emissions in 2013 (78% of EU total); in 2030 the MS with the largest LCP SO_2 emissions are estimated to be Bulgaria, Germany, Poland and Spain (73% of EU). Many MS are estimated to see a considerable reduction of LCP SO_2 emissions: the six MS with largest SO_2 emissions in 2013 are estimated to see their emissions reduce by between 19% and 90% by 2030. [14]

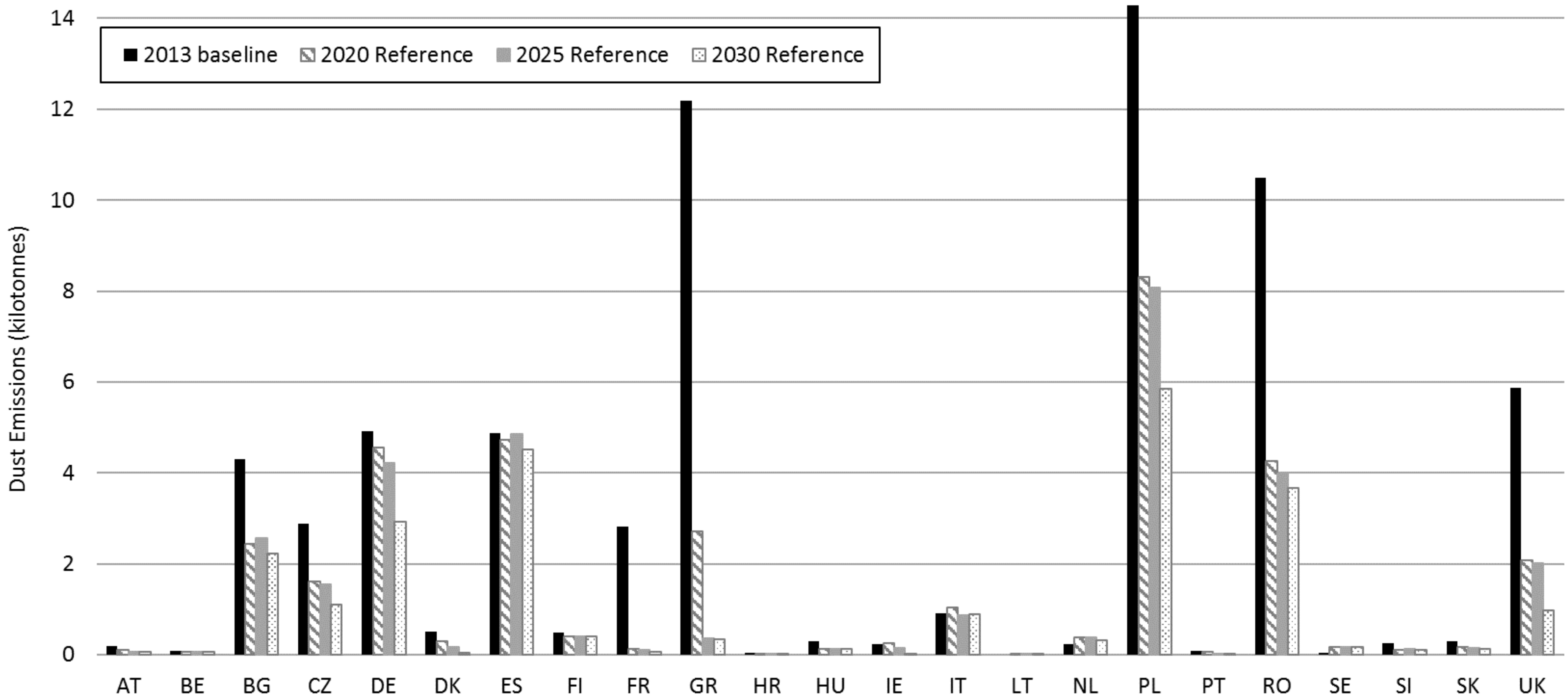
[14] Planned new capacities lead to increases in SO_2 emissions. In particular, the five new biomass plants projected to open between 2014 and 2016 are assumed to operate with emission levels equal to the IED ELVs, which leads to above-expected SO_2 emissions. This approach leads to the effect of one Member State (Sweden) estimated to have higher SO_2 emissions from the LCPs in scope of this study in 2030 than in 2013.

Figure 15 Member State level NO_X emissions for the plants in the baseline and reference scenario



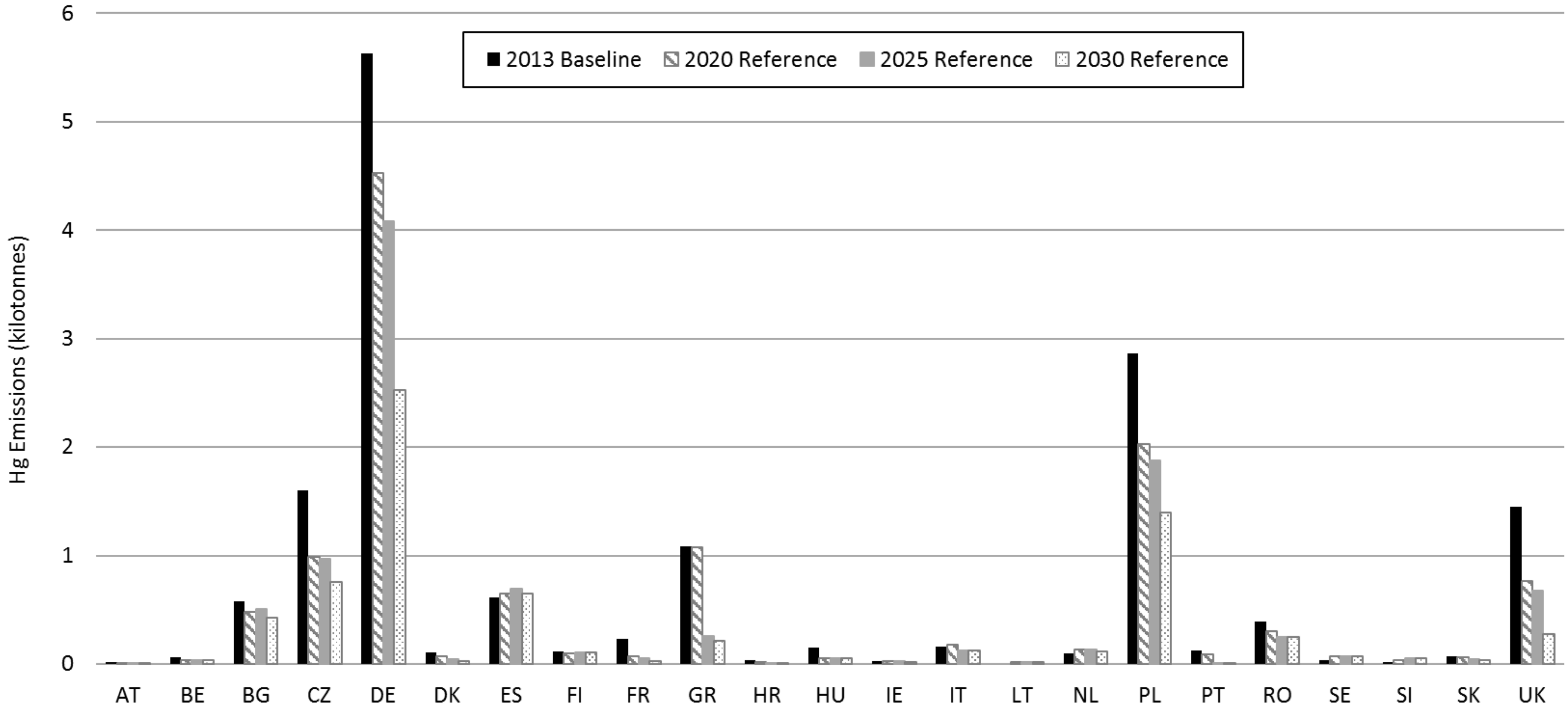
NO_X emissions from the LCPs covered in this study were estimated at 940kt in the baseline in 2013, reducing in the reference scenario to 689kt in 2020, to 603kt in 2025 and to 423kt in 2030. Germany, Poland and the UK are the MS with the largest LCP NO_X emissions in 2013 (61% of EU total); in 2030 the three MS with the largest LCP NO_X emissions are Germany, Poland and Spain (63% of EU). Most MS are estimated to see a considerable reduction of LCP NO_X emissions: the three MS with largest NO_X emissions in 2013 are estimated to see their emissions reduce by between 46% and 82% by 2030. Spain, which is a high emitter in 2013, is estimated to increase NO_X emissions between 2013 and 2025, followed by a slight decrease to 2030. The main driver for this is the projected continuation of coal firing in Spain, projected by PRIMES, which is used to project the baseline to future years. Small increases for some MS over time (e.g. SE) are attributed to forecast new plant.

Figure 16 Member State level dust emissions for the plants in the baseline and reference scenario



Dust emissions from the LCPs covered in this study were estimated at 66kt in the baseline in 2013, reducing to 34kt in the reference scenario in 2020, to 30kt in 2025 and to 24kt in 2030. Greece, Poland, Romania and the UK are the MS with the largest LCP dust emissions in 2013 (65% of EU total), although the Greek LCP emissions decline considerably to 2030 such that the MS with the largest LCP dust emissions in 2025 are Germany, Spain, Poland and Romania (70% of EU total). Many MS are estimated to see a considerable reduction of LCP dust emissions: the four MS with largest dust emissions in 2013 are estimated to see their emissions reduce by more than half by 2030 (-59 to -97%). Not all MS are estimated to have reduced dust emissions from the solid-fired LCPs: two MS (Netherlands and Sweden) are estimated to have higher dust emissions in 2030 compared to 2013. Three MS (including one high emitter, Spain) is estimated to reduce dust emissions by less than 10% between 2013 and 2030. The main drivers for these are the change in capacity and activity levels projected by PRIMES, which is used to project the baseline to future years – these are shown in Appendix 6.

Figure 17 Member State level mercury emissions for the plants in the baseline and reference scenario



Mercury emissions from the LCPs covered in this study were estimated at 15.3t in the baseline in 2013, reducing to 7.0t in the reference scenario in 2030. Germany and Poland remain the MS with largest LCP mercury emissions through all years assessed. Most MS are estimated to see a considerable reduction of LCP mercury emissions; the five MS with largest mercury emissions in 2013 are estimated to see their emissions reduce by more than half by 2030 (-51 to -81%). Not all MS are estimated to have reduced mercury emissions from the solid-fired LCPs: four MS (not the major emitters) are estimated to increase mercury emissions in 2030 compared to 2013 (the Netherlands, Slovenia, Spain and Sweden). The main reason for this increase is new units beginning operation after 2013. The other minor reason is that, due to matching with PRIMES projections, a few units' fuel consumption and hence emissions increase over the years. The absolute amount in increase for these MS is small compared to the EU total.

The emissions estimates for the reference scenario shown in Figure 14, Figure 15, Figure 16 and Figure 17 for SO_2, NO_X, dust and Hg are expressed as a percentage of the 2013 baseline in the following Figure 18, Figure 19, Figure 20 and Figure 21 respectively. Planned new capacities lead to increases in emissions. This approach leads to the effect of one Member State (Sweden) estimated to have higher emissions from the LCPs in scope of this study in 2020-2030 than in 2013.

Figure 18 SO_2 emissions of the reference scenario per Member State, expressed as % of 2013 baseline

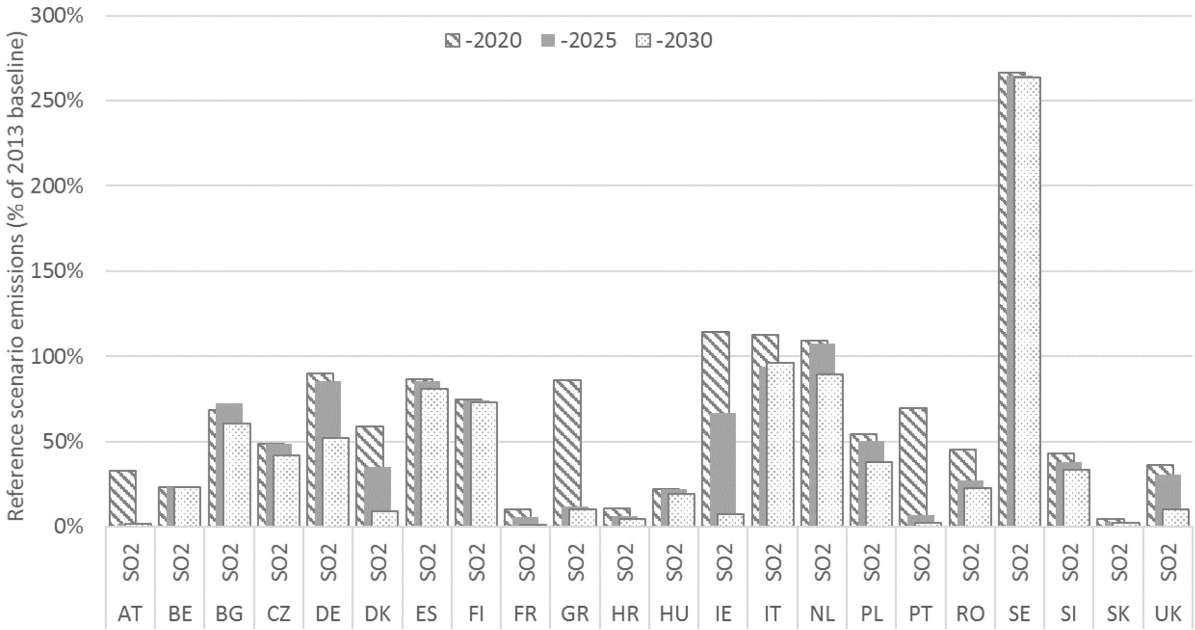


Figure 19 NO_X emissions of the reference scenario per Member State, expressed as % of 2013 baseline

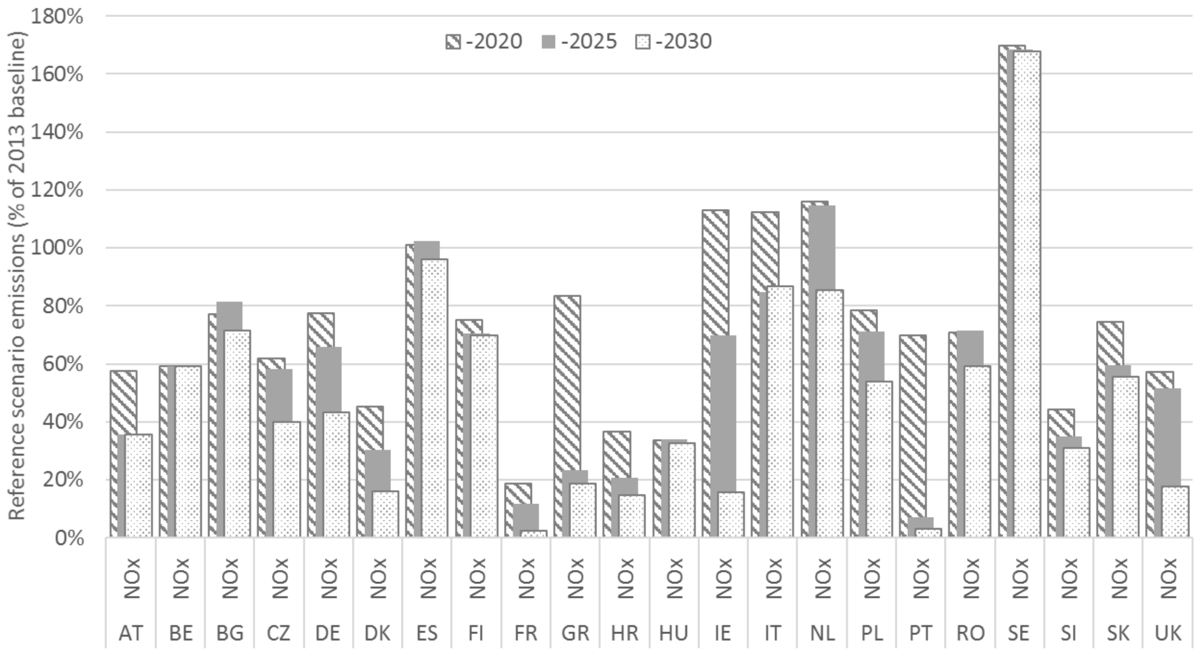


Figure 20 Dust emissions of the reference scenario per Member State, expressed as % of 2013 baseline

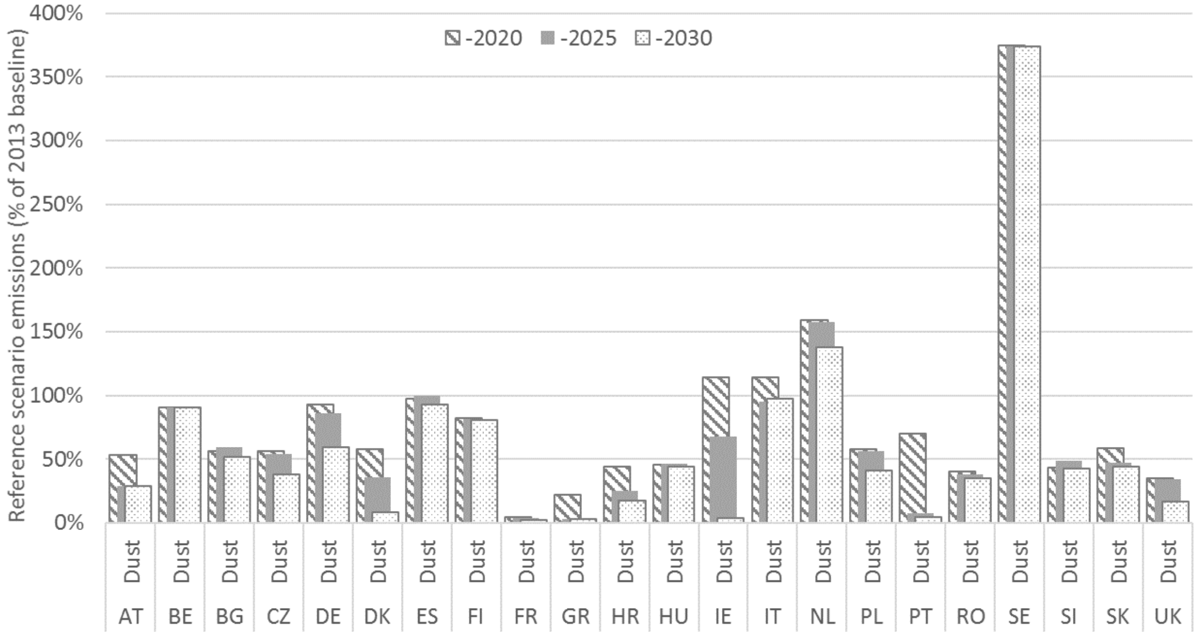
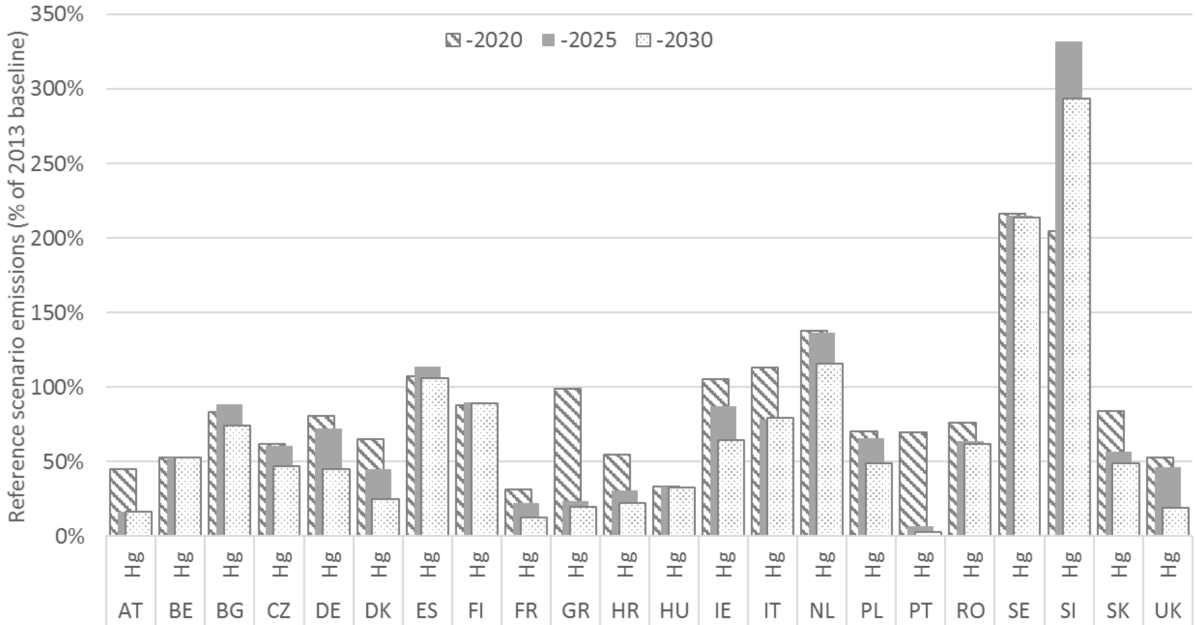


Figure 21 Hg emissions of the reference scenario per Member State, expressed as % of 2013 baseline



3.1.6 Emission levels compared to limit values

To assess the 2020 performance of all the plants with respect to both IED ELVs and BAT-AELs, Table 20 shows the percentage of installed thermal capacity of plants that are estimated to have emission levels below the different limit values (ELV, BAT upper and lower AEL) in 2020 in the reference scenario. The figures show that for SO_2 and NO_x emissions, in 2020 a little over half of the plants by capacity are estimated to have emission levels below the IED ELVs while a little under half were estimated to have emission levels at or below the upper BAT-AELs. Larger proportions of capacities are estimated to have emission levels at or below the dust IED ELVs and dust and mercury upper BAT-AELs. Very small proportions of capacities are estimated to have emission levels at or below the lower BAT-AELs.

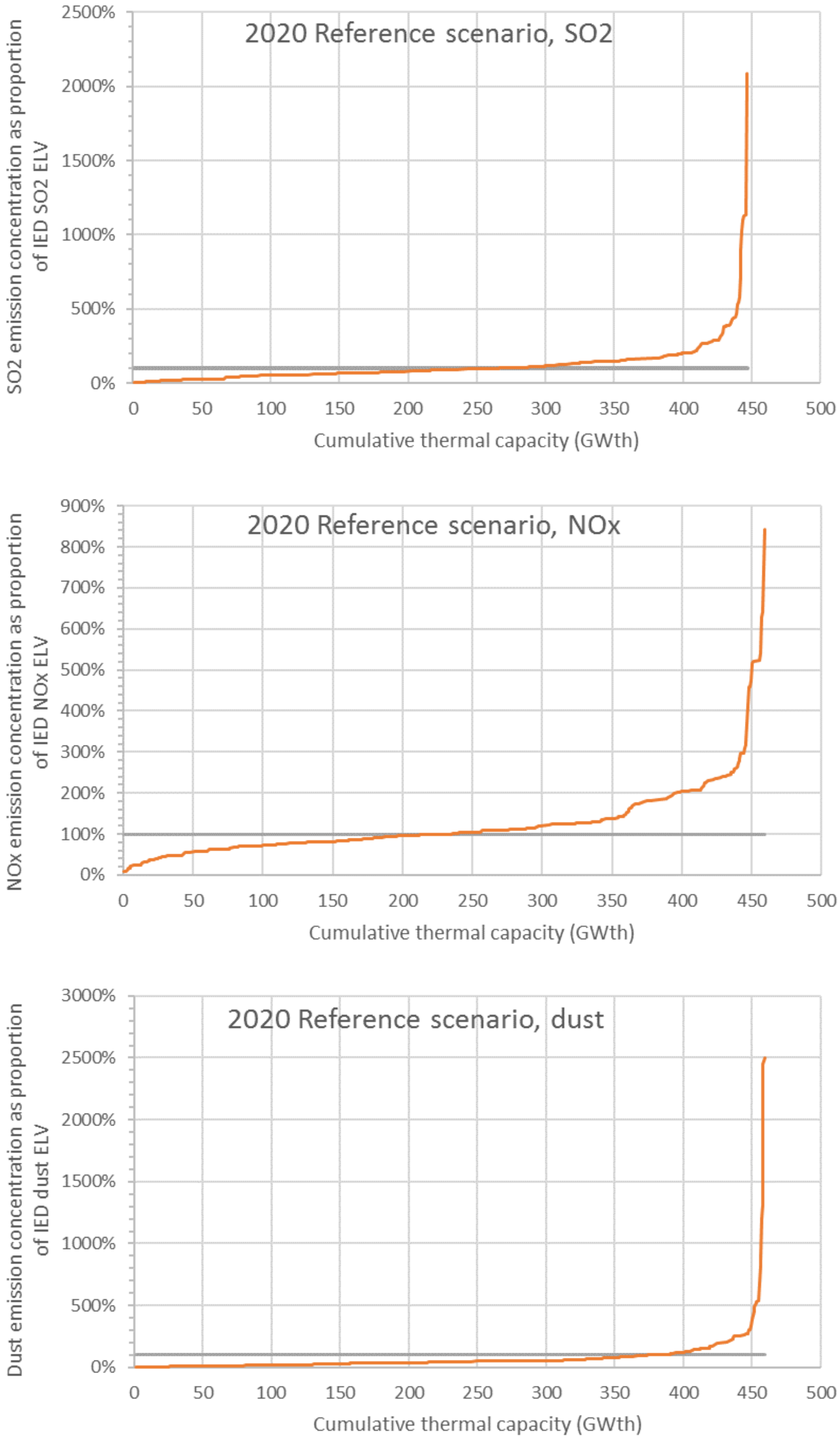
For mercury, about 75 plants exceed the upper BAT-AEL level in 2020, of which most are located in Germany, Poland and the Czech Republic. 273 plants exceed the lower BAT-AEL level in 2020.

Table 20 Percentage of installed capacity with average annual emission levels in 2020 in the reference scenario at or below the IED ELVs and upper and lower BAT-AELs

	SO_2	NO_x	Dust	Mercury
IED ELVs	61%	51%	85%	N/A
Upper BAT-AEL	40%	44%	61%	79%
Lower BAT-AEL	3%	8%	15%	8%

Figure 22 then shows in more detail the spread of estimated Reference scenario (2020) annual average flue gas concentrations divided by the annual average IED ELVs for NO_x, SO_2 and dust. A value below 100% indicates that the estimated flue gas concentration of the plant is lower than the ELV, while a value higher than 100% indicates that the estimated flue gas concentration is higher than the ELV. For all pollutants there are a majority with emissions around the ELV level or below, and minority with emission levels higher than the ELVs. For NOx emissions, there is a higher proportion of installed capacity exceeding the ELVs by larger margins. The five LCPs which opt for the desulphurisation rate rather than the SO_2 IED ELV are not included in Figure 22.

Figure 22 Calculated flue gas concentrations in the 2020 reference scenario for all plants divided by applicable IED ELV



3.1.7 Abatement techniques installed

Table 21 shows the number of units with each abatement techniques for SO_2, NO_x and dust, and also the installed electric capacity associated with them. It shows that the majority of SO_2 installed capacity has a wet scrubber, and for dust most of the installed capacity has an ESP based abatement. For NO_x, there is a large subset of plants with PMS, but also a significant amount of the stock (both in terms of plant numbers and installed capacity) has SCR techniques installed to abate NO_x emissions.

Table 21 Number of units, and their capacity share, with each abatement technique in the 2013 baseline

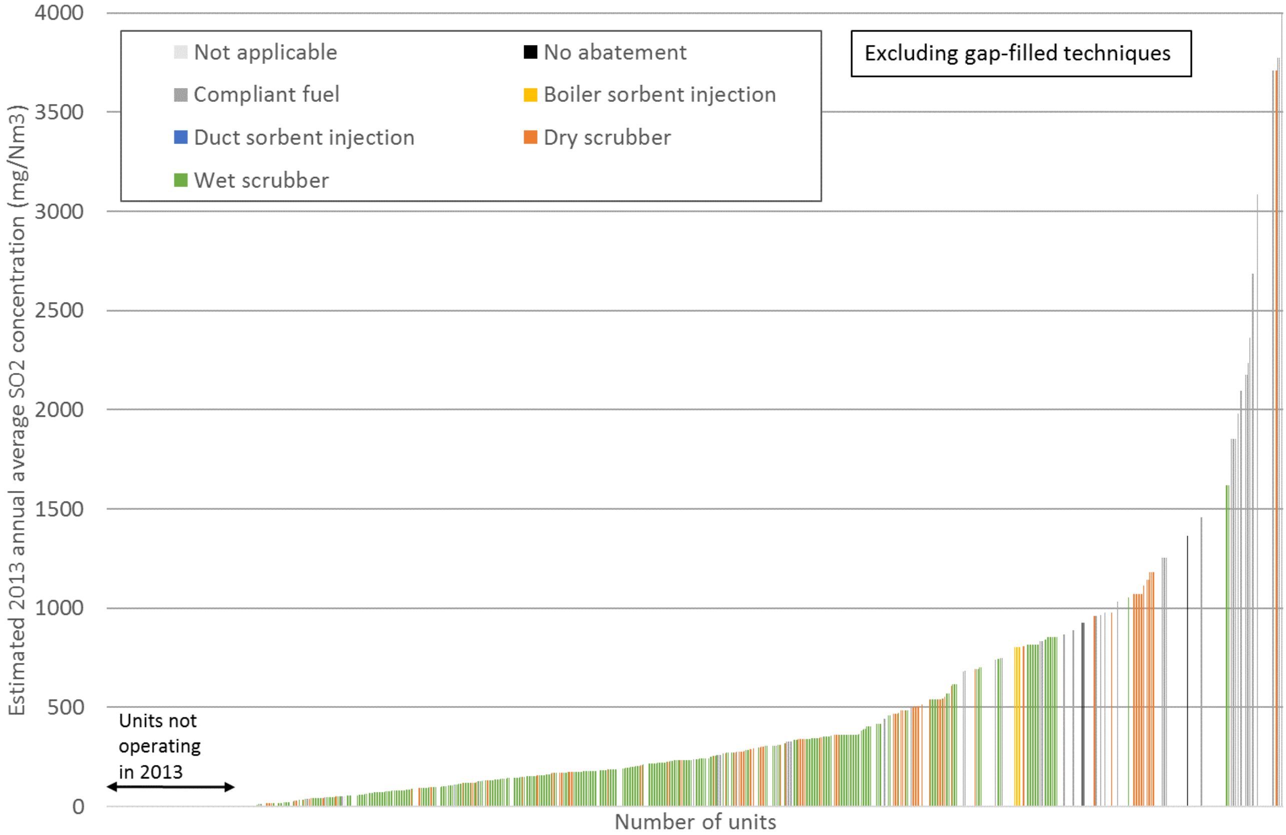
Pollutant	Abatement technique	Number of units	Installed capacity (MWe)	Share in capacity
SO_2	Not applicable (N/A) *Note 1*	35	6,292	3%
	No abatement (none)	19	2,130	1%
	Compliant fuel (CF)	74	19,758	10%
	Boiler sorbent injection (BSI)	26	2,257	1%
	Duct sorbent injection (DSI)	96	6,187	3%
	Dry scrubber (DSC)	188	18,483	9%
	Wet scrubber (WSC)	479	148,741	73%
NO_x	No abatement (none)	35	7,232	4%
	Primary measures (PMS)	624	125,251	61%
	Selective catalytic reduction (SCR) *Note 2*	138	48,596	24%
	Selective non catalytic reduction (SNCR)	8	758	0.4%
	Combi PMS & SCR (COMBI2)	107	21,040	10%
	Combi PMS & SNCR (COMBI3)	4	471	0.2%
	Combi SCR & SNCR (COMBI4)	1	500	0.2%
Dust	Not applicable (N/A) *Note 1*	35	6,292	3%
	No abatement (none)	14	714	0.4%
	Multicyclones (MULTI)	2	1,400	1%
	Electrostatic Precipitator (ESP)	107	18,750	9%
	Electrostatic Precipitator+ (ESP+)	394	91,050	45%
	Electrostatic Precipitator++ (ESP++)	253	75,703	37%
	Bag filter (BF)	104	8,837	4%
	Combi Electrostatic precipitator & Bag filter (COMBI1)	8	1,101	1%

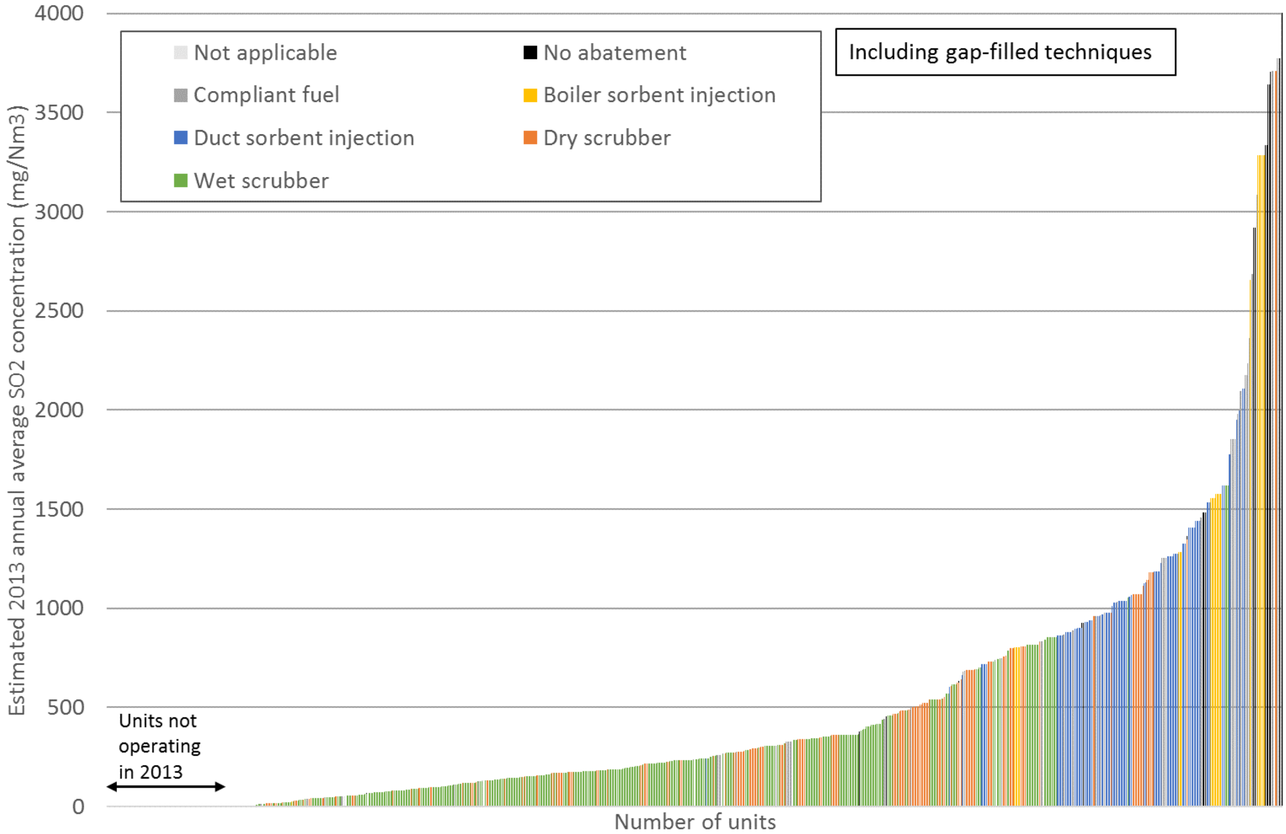
Note 1: N/A (Not applicable) for SO_2 and dust refers to gas-fired units at coal plants, where no relevant abatement techniques are applicable since emissions are generally negligible compared to other sources or pollutants. Note 2: The Platts WEPP database indicates in many cases that SCR is fitted but does not indicate that PMS are fitted. This perhaps should not be interpreted as SCR is fitted without PMS, but rather that the Platts WEPP database has not captured that PMS have been fitted.

Figure 23, Figure 24 and Figure 25 plot respectively the SO_2, NO_X and dust abatement techniques installed at the units against their pollutant concentrations in the baseline. In each figure, the top panel only shows those units where data on abatement techniques installed was identified (mostly from Platts-WEPP), whereas the bottom panel shows all units' techniques, i.e. also including the units for which assumptions have been made on their installed abatement techniques (as described in section 2.2.4). The figures show that the gap-filling approach has:

- Filled many of the higher than average SO_2 concentration gaps with duct sorbent injection and boiler sorbent injection.
- For NO_X, added a number of units with no abatement (at the top end of NO_X concentrations), listed PMS for most units with NO_X concentrations above ~ 200mg/Nm^3 and increased the number of SCR and combined PMS+SCR installed (at the lower range of NO_X concentrations).
- For dust, added mostly bag filters at lower concentrations and ESP at higher concentrations.

Figure 23 SO_2 concentrations and abatement techniques in the baseline





Note: two units with estimated SO_2 concentrations above 4000mg/Nm^3 in the baseline are not shown. They are not considered to have abatement techniques fitted.

Figure 24 NOx concentrations and abatement techniques in the baseline

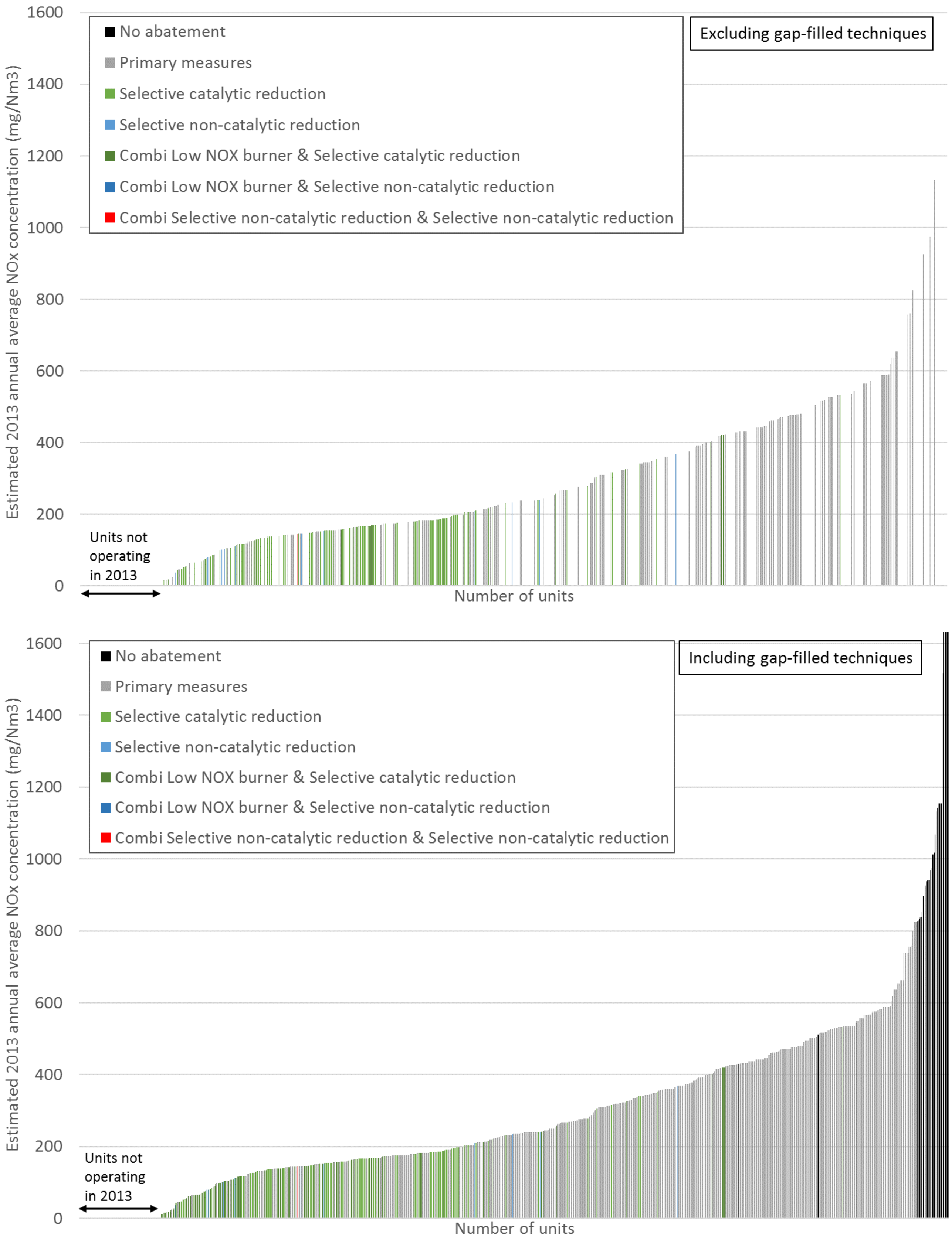
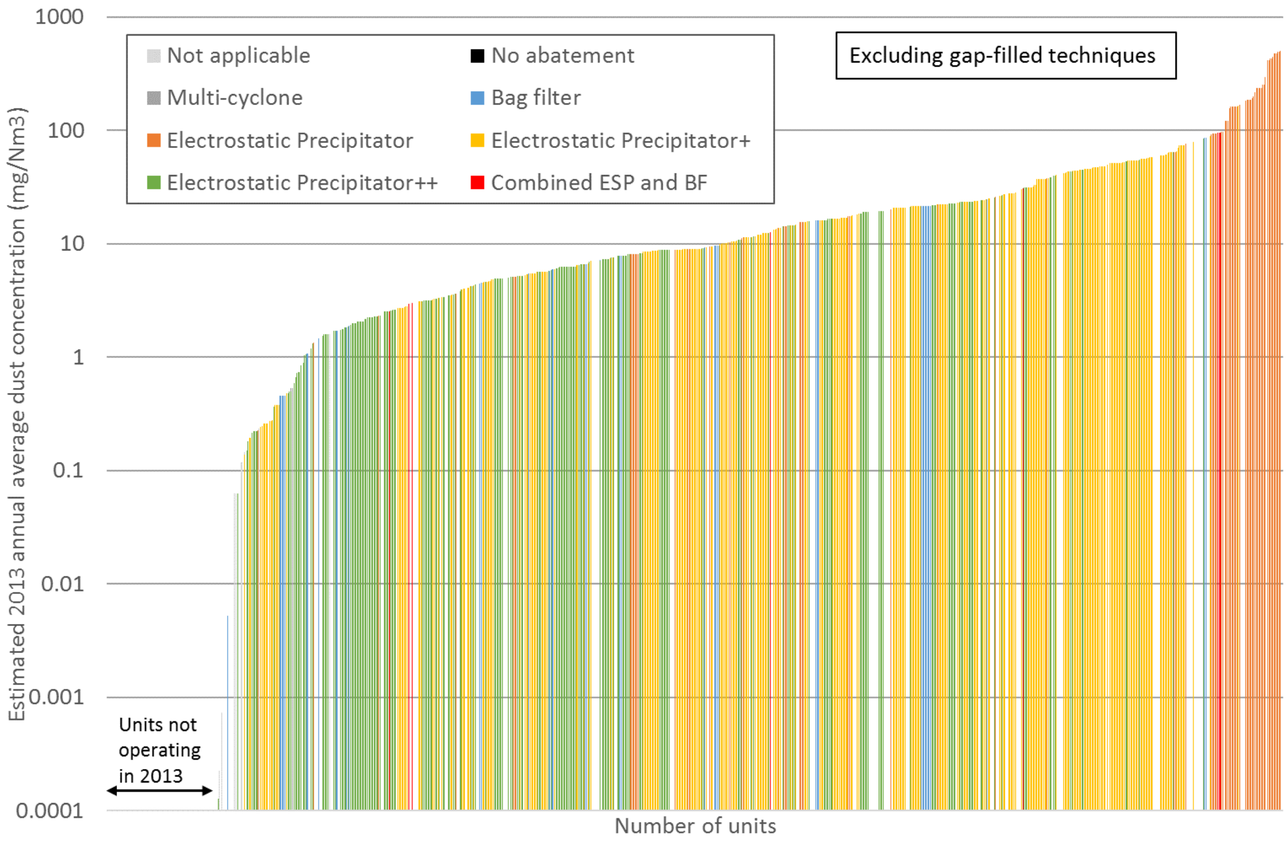
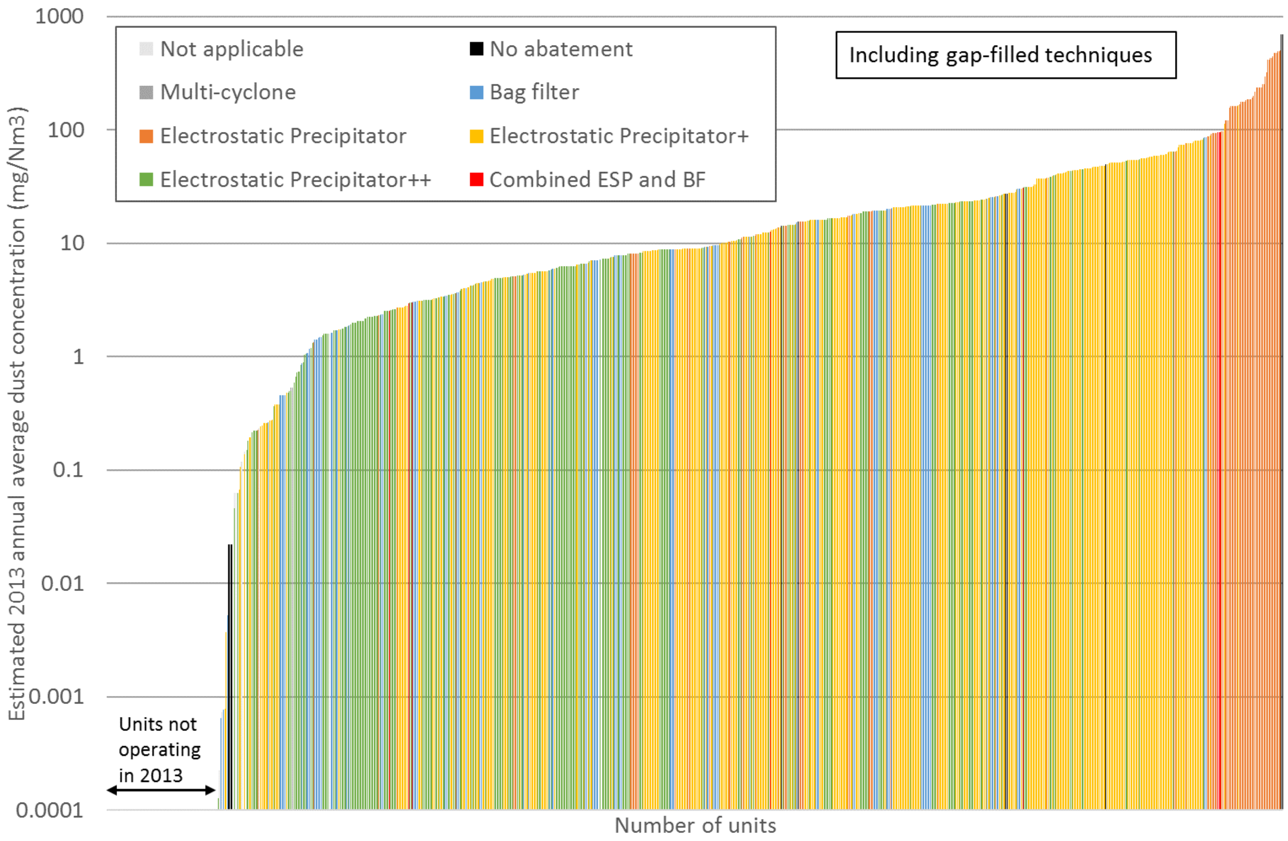


Figure 25 Dust concentrations and abatement techniques in the baseline (note logarithmic scale)





3.2 IED ELV and BAT-AEL Scenarios: Central estimate

3.2.1 Emissions

The EU-level SO_2, NOx, dust and Hg emissions from the LCPs in this study for the baseline, reference, IED, upper and lower BAT scenarios are shown in Table 22 and plotted in Figure 26. Member State level changes in emissions among the scenarios are shown in Figure 27 for year 2025.

The IED scenario, compared to the reference scenario, shows a substantial decline for SO_2, NO_X and dust emissions (45%, 32%, and 50% respectively as an average across all years). Although there are no IED ELVs for mercury, due to the implementation of other pollutant abatement techniques, an 8% reduction of mercury emissions is estimated to occur. Approximately 90% of the reductions in SO_2, NO_X and dust emissions, and 75% of mercury emissions, from the reference scenario in 2025 occur among six Member States (Bulgaria, Germany, Poland, Romania, Spain and the UK).

The Upper BAT-AEL scenario is estimated to bring about further declines for SO_2, NO_X, dust and Hg. Compared to the IED scenario, there are further reductions of 25% of SO_2 emissions, 8% of NO_X emissions, 31% of dust emissions, and 19% of Hg emissions (averages of all years; the proportional reductions are similar in 2020, 2025 and 2030). The smaller percentage reduction in NO_X than other pollutants is primarily because the upper BAT-AELs for NO_X (150/175 mg/Nm^3) are not significantly lower than the IED ELV (200mg/Nm^3, converted to 180 mg/Nm^3 as annual average).

The Lower BAT-AEL scenario is estimated to result in substantial further reductions in SO_2, NO_X, dust and Hg emissions relative to the upper BAT-AEL scenario: 81% lower SO_2, 56% lower NO_X, 78% lower dust and 71% lower Hg (averages of all years; the proportional reductions are similar in 2020, 2025 and 2030). The model could not identify abatement techniques that would achieve compliance with lower BAT-AELs for a small proportion of units (20 out of 970). This may be because for these plants switching to lower sulphur coal (which is not an option considered in the model) may be required as well as additional end of pipe techniques, and/or the analysis has overestimated their initial emission concentrations. This is described in the Box below Table 22.

Table 22. EU28 summary of emissions of the scenarios

Year	Scenario	SO_2 emissions (kt)	NOx emissions (kt)	Dust emissions (kt)	Hg emissions (t)
2013	Baseline	1,251	940	66.3	15.5
2020	Reference	736	689	34.1	11.7
	IED ELVs	402	466	17.5	10.8
	Upper BAT-AELs	303	431	12.1	8.8
	Lower BAT-AELs	61	198	2.7	2.5
2025	Reference	632	603	30.5	9.9
	IED ELVs	349	401	14.9	9.2
	Upper BAT-AELs	263	370	10.2	7.4
	Lower BAT-AELs	47	155	2.2	2.1
2030	Reference	475	429	24.0	7.0
	IED ELVs	261	300	11.5	6.6
	Upper BAT-AELs	193	276	8.2	5.3
	Lower BAT-AELs	40	117	1.7	1.6

	SO_2 emissions	NOx emissions	Dust emissions	Hg emissions
Average % reduction Reference → IED ELVs	**45%**	**32%**	**50%**	**8%**
Average % reduction IED ELVs → upper BAT	**25%**	**8%**	**31%**	**19%**
Average % reduction IED ELVs → lower BAT	**85%**	**60%**	**85%**	**77%**
Average % reduction upper BAT → lower BAT	**81%**	**56%**	**78%**	**71%**

Box 1 – Solution in cases the model cannot bring a plant into compliance

In the lower BAT-AEL scenario, for a small number of units, the model cannot identify techniques that sufficiently abate SO_2 and NO_X emissions in order to meet the lower BAT-AEL. This is an artefact of the methodology and assumptions. As the analysis covers only end-of-pipe technologies, within a relatively rigid framework, this does not mean that these plants/units will not be able to meet the limit values in reality, as it may be possible for example to shift completely or partly to the use of fuel(s) with lower sulphur content to meet the SO_2 BAT-AEL. For plants using hard coal this can be an option as hard coal is transported worldwide, but it may not be an option for plants/units using lignite. Equally, the operation of the plants in question in the baseline year may have been anomalous that year, giving rise to the erroneous estimate that they cannot meet the limit value. Table 23 sets out the number of units and fuel type per Member State that the modelling indicates cannot meet the lower BAT AELs in 2025.

To deal with this, an off-model solution has been implemented. For the units in question, it has been assumed that they implement the technique assumed to be installed in the Upper BAT scenario.

Table 23 Member States with units that modelling indicates cannot meet the lower BAT-AELs in 2025.

Member State	Fuel	Number of units with infeasible SO_2	Number of units with infeasible NO_X
BG	Lignite	2	0
CZ	Coal	3	0
ES	Lignite	3	0
IE	Coal	0	1
PL	Coal	1	0
RO	Coal	3	0
	Lignite	3	0
UK	Coal	0	4
Total		**15**	**5**

Figure 26. Change in emissions per annum of Reference, IED ELV, Upper BAT-AEL and Lower BAT-AEL scenarios to 2030 from 2013 baseline.

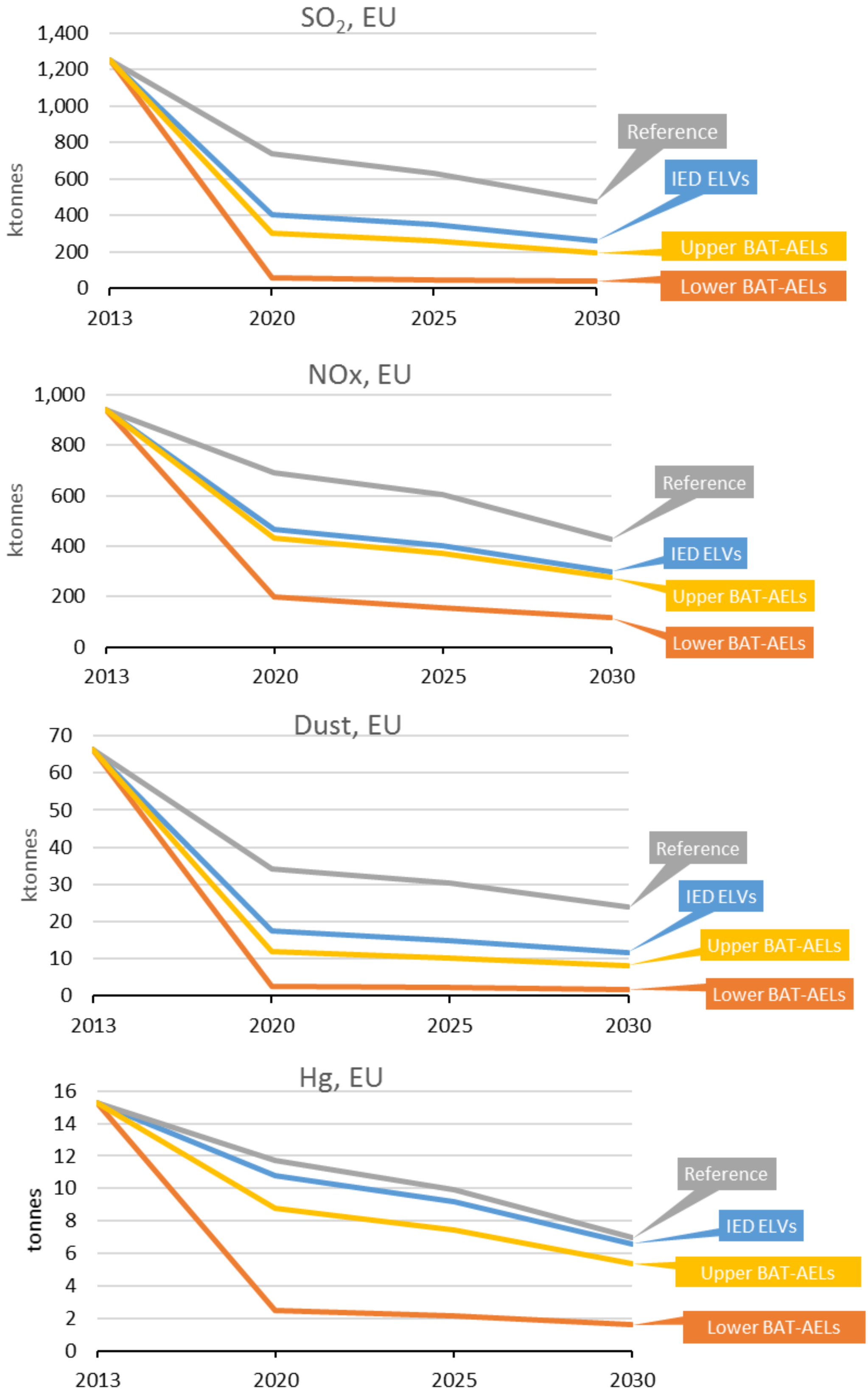
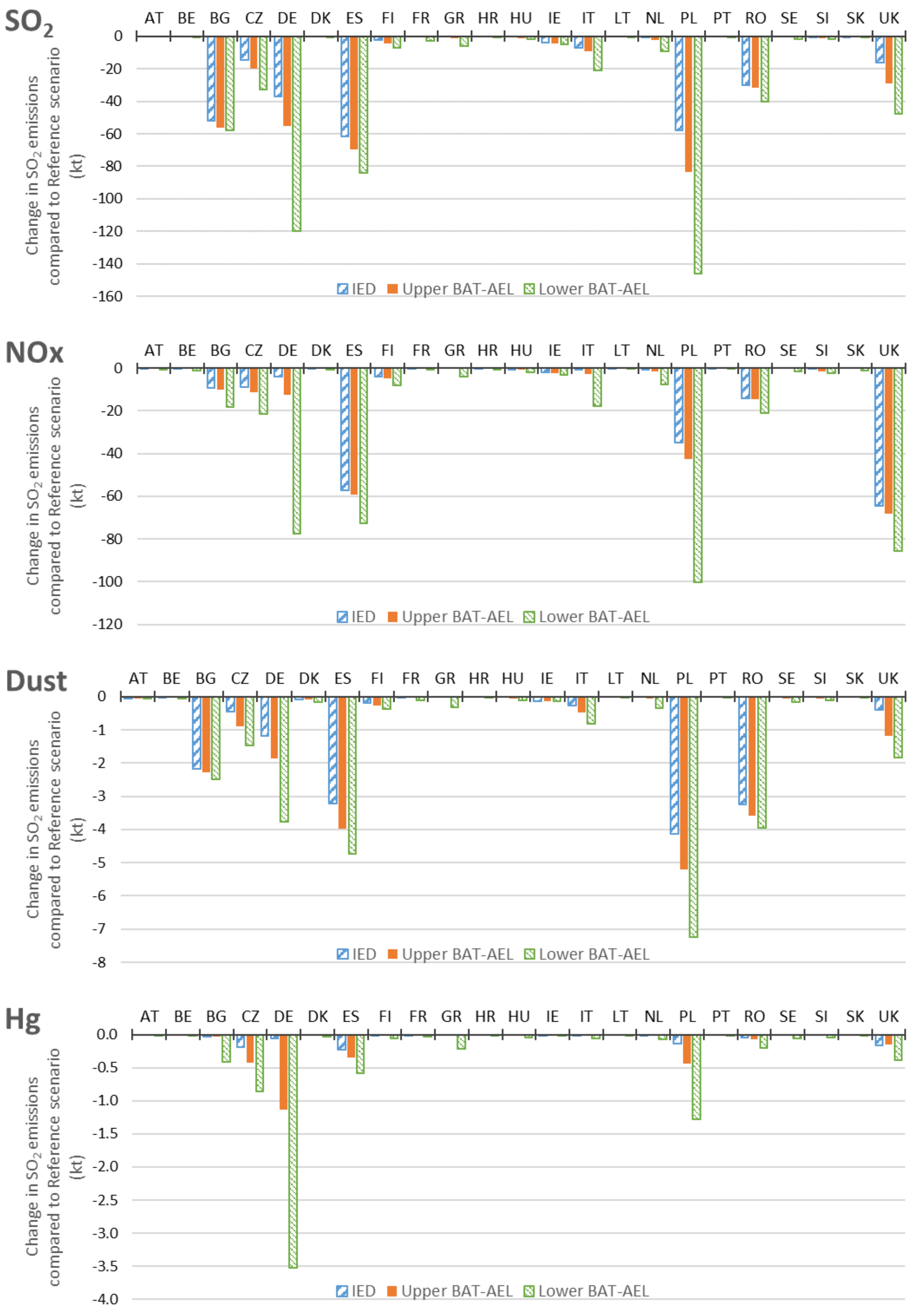


Figure 27. Summary of emission changes of the IED ELV, upper BAT-AEL and lower BAT-AEL scenarios compared to the Reference scenario in 2025 at Member State level



3.2.2 Health and environmental benefits of emission reductions

The quantified health and environmental benefits of the estimated emission reductions of each scenario in 2020, 2025 and 2030 at EU level are shown in Table 24 compared to the reference scenario and in Table 25 compared to the IED scenario. These results show the substantial benefits per year are dominated from reductions in SO_2 emissions. The monetised benefits of emissions reduction in the year 2025 per Member State are shown in Table 26, from which it can be seen that, in 2025, Germany and Poland receive 45% of total EU benefits of meeting the upper BAT-AEL. Five Member States (Germany, Poland, Spain, the UK and Romania) are estimated to receive 79% of total EU benefits.

Table 24 EU summary of monetised potential health and environmental benefits per year of meeting IED ELVs and BAT-AELs, compared to the reference scenario (EUR2015, using central damage costs)

Year	Scenario	Benefits from SO_2 emission reductions (€bn)	Benefits from NOx emission reductions (€bn)	Benefits from dust emission reductions (€bn)	Benefits from Hg emission reductions (€bn)	Total (€bn)
2020	IED ELVs	8.4	2.0	0.8	0.05	11.2
	Upper BAT-AELs	11.3	2.5	1.1	0.2	15.0
	Lower BAT-AELs	19.3	5.3	1.6	0.5	26.7
2025	IED ELVs	7.3	1.8	0.8	0.05	9.9
	Upper BAT-AELs	10.0	2.2	1.0	0.1	13.4
	Lower BAT-AELs	17.3	4.9	1.5	0.4	24.1
2030	IED ELVs	5.1	1.1	0.6	0.03	6.8
	Upper BAT-AELs	7.1	1.4	0.8	0.1	9.4
	Lower BAT-AELs	12.2	3.4	1.2	0.3	17.1

Table 25 EU summary of monetised potential health and environmental benefits per year of meeting BAT-AELs, compared to the IED scenario (EUR2015, using central damage costs)

Year	Scenario	Benefits from SO_2 emission reductions (€bn/yr)	Benefits from NO_X emission reductions (€bn/yr)	Benefits from dust emission reductions (€bn/yr)	Benefits from Hg emission reductions (€bn/yr)	Total €bn/yr
2020	Upper BAT-AELs	2.9	0.4	0.3	0.11	3.8
	Lower BAT-AELs	10.9	3.3	0.8	0.4	15.5
2025	Upper BAT-AELs	2.7	0.4	0.3	0.09	3.4
	Lower BAT-AELs	10.0	3.1	0.7	0.4	14.2
2030	Upper BAT-AELs	2.1	0.3	0.2	0.07	2.6
	Lower BAT-AELs	7.2	2.3	0.6	0.3	10.2

Table 26 Benefits arising from emission reductions from the reference scenario for year 2025 (EUR2015 €m/yr, using central damage costs)

Member State	IED ELV scenario					Upper BAT-AEL					Lower BAT-AEL				
	SO_2	NOx	Dust	Hg	Total	SO_2	NOx	Dust	Hg	Total	SO_2	NOx	Dust	Hg	Total
Austria	0	2	3	0.0	**5**	0	6	3	0.0	**9**	0	11	3	0.1	**14**
Belgium	0	3	2	0.0	**5**	3	3	3	0.0	**9**	11	12	6	1.4	**30**
Bulgaria	809	96	85	1.5	**992**	881	103	89	1.8	**1,074**	901	187	97	21.8	**1,207**
Czech Republic	430	128	27	10.3	**595**	583	166	51	22.8	**823**	957	311	84	46.0	**1,398**
Germany	1,696	59	85	3.3	**1,844**	2,544	193	135	60.1	**2,932**	5,510	1,208	272	187.4	**7,178**
Denmark	0	1	2	0.0	**3**	1	1	2	0.0	**5**	10	4	4	1.7	**20**
Spain	1,060	255	121	12.3	**1,448**	1,201	265	150	18.4	**1,634**	1,448	324	177	31.1	**1,981**
Finland	23	13	2	0.8	**39**	41	15	2	1.2	**59**	67	25	3	3.0	**98**
France	0	3	0	0.0	**3**	11	3	2	0.5	**16**	94	8	5	2.0	**108**
Greece	0	0	0	0.0	**0**	10	0	0	0.0	**10**	54	10	9	11.3	**85**
Croatia	0	1	0	0.0	**1**	0	3	0	0.0	**3**	6	8	0	0.4	**15**
Hungary	0	12	0	0.0	**12**	29	12	3	0.0	**45**	44	36	7	2.1	**88**
Ireland	104	17	3	0.3	**123**	109	20	3	0.3	**132**	125	25	3	1.0	**154**
Italy	251	17	21	0.2	**289**	335	54	35	0.5	**424**	765	327	61	2.8	**1,155**
Lithuania	0	2	0	0.0	**2**	1	2	0	0.0	**3**	2	3	0	0.6	**5**
Netherlands	31	7	0	0.4	**38**	124	16	4	0.2	**145**	552	88	27	3.5	**671**
Poland	1,583	400	245	7.3	**2,235**	2,288	484	308	23.0	**3,103**	3,991	1,148	429	68.2	**5,635**
Portugal	0	0	0	0.0	**0**	0	0	0	0.0	**0**	4	0	0	0.3	**5**
Romania	763	236	170	2.5	**1,170**	808	242	188	3.6	**1,241**	1,023	355	207	10.4	**1,595**
Sweden	0	0	0	0.0	**0**	5	0	1	0.0	**6**	22	7	2	3.0	**34**
Slovenia	26	5	0	0.0	**31**	34	33	3	0.2	**70**	74	53	6	2.7	**136**
Slovakia	4	0	0	0.0	**4**	7	4	0	0.0	**11**	17	17	2	1.3	**37**
United Kingdom	539	524	22	8.4	**1,093**	982	553	66	8.3	**1,609**	1,618	695	103	20.7	**2,437**
EU	**7,318**	**1,780**	**788**	**47**	**9,933**	**9,997**	**2,179**	**1,047**	**141**	**13,363**	**17,294**	**4,864**	**1,507**	**423**	**24,087**

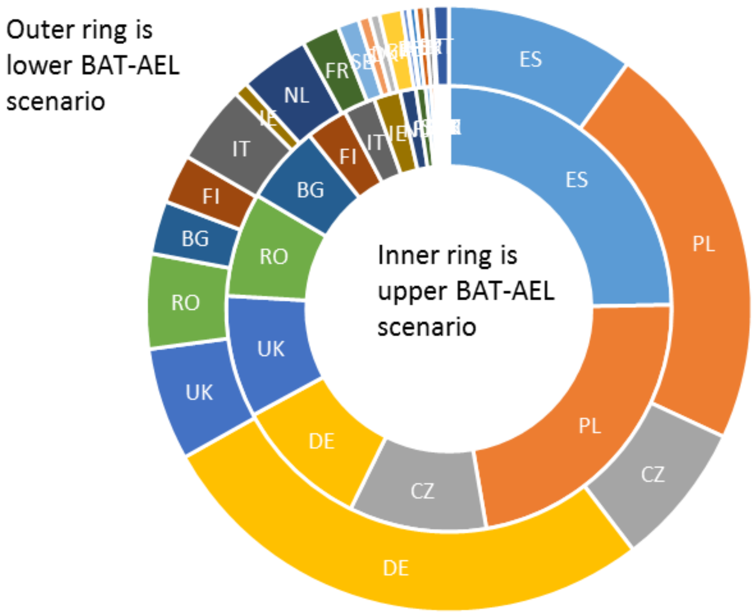
3.2.3 Costs of abatement techniques

Table 27 summarises the EU-level total annualised (annualised capital costs and annual operating cost) for the IED and BAT scenarios in comparison to the reference scenario in 2020, 2025 and 2030.

Table 27 EU level total annualised costs of the scenarios beyond the reference scenario (EUR2015)

Year	Scenario	Meeting SO_2 limits (€m/yr)	Meeting NOx limits (€m/yr)	Meeting dust limits (€m/yr)	Meeting Hg limits (€m/yr)	Total (€m/yr)
2020	IED ELVs	460	466	93	-	1,019
	Upper BAT-AELs	707	565	238	55	1,565
	Lower BAT-AELs	5,047	1,564	423	383	7,417
2025	IED ELVs	275	412	62	-	749
	Upper BAT-AELs	436	512	186	45	1,179
	Lower BAT-AELs	3,947	1,359	326	338	5,969
2030	IED ELVs	162	329	51	-	542
	Upper BAT-AELs	280	416	131	36	862
	Lower BAT-AELs	3,001	1,137	255	294	4,687

Figure 28. Distribution (share) of costs among Member States in 2025 compared to the reference scenario



The distribution of estimated costs among the Member States for the IED, upper and lower BAT-AEL scenarios in 2025 is shown in Figure 28 and Table 28. Appendix 8 includes MS level costs for years 2020 and 2030. The graphic illustrates that Spain and Poland are estimated to bear nearly half the costs for compliance with the upper BAT-AELs, and together with the UK, the Czech Republic and Germany, three quarters of the cost of the upper BAT-AEL scenario compared to the reference scenario.

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Table 28 Total costs for year 2025 beyond the reference scenario (2015 EUR €m/yr).

Member State	IED ELV scenario					Upper BAT-AEL					Lower BAT-AEL				
	SO_2	NOx	Dust	Hg	Total	SO_2	NOx	Dust	Hg	Total	SO_2	NOx	Dust	Hg	Total
Austria	0	0	1	0	**1**	0	1	1	0	**2**	0	1	3	0	**4**
Belgium	0	0	1	0	**1**	0	0	1	0	**2**	4	7	7	2	**20**
Bulgaria	23	21	5	0	**50**	30	23	15	0	**67**	64	55	34	16	**169**
Czech Republic	26	32	3	0	**60**	43	44	27	3	**118**	304	107	18	28	**458**
Germany	22	7	3	0	**32**	39	37	10	30	**116**	1,173	303	9	142	**1,627**
Denmark	0	0	2	0	**2**	0	0	2	0	**3**	12	5	9	5	**31**
Spain	71	123	13	0	**207**	115	131	42	3	**291**	312	174	91	21	**599**
Finland	5	14	5	0	**24**	14	17	4	0	**36**	102	40	9	6	**156**
France	0	4	1	0	**6**	2	4	1	1	**8**	100	10	3	7	**120**
Greece	0	0	0	0	**0**	2	0	0	0	**2**	59	6	0	7	**72**
Croatia	0	0	0	0	**0**	0	1	0	0	**1**	21	4	0	2	**27**
Hungary	0	1	0	0	**1**	0	1	0	0	**1**	6	8	5	2	**20**
Ireland	11	6	0	0	**18**	16	7	0	0	**23**	36	8	0	0	**45**
Italy	9	1	0	0	**10**	13	7	8	0	**27**	207	43	0	0	**250**
Lithuania	0	0	0	0	**0**	0	0	0	0	**0**	1	2	3	1	**6**
Netherlands	1	4	0	0	**5**	6	7	1	0	**14**	182	28	0	12	**221**
Poland	68	95	18	0	**181**	93	125	41	8	**266**	850	332	77	49	**1,307**
Portugal	0	0	0	0	**0**	0	0	0	0	**0**	45	0	0	5	**51**
Romania	28	37	9	0	**74**	33	37	18	1	**89**	182	73	35	10	**302**
Sweden	0	0	0	0	**0**	1	0	3	0	**4**	45	14	4	5	**68**
Slovenia	1	0	0	0	**1**	2	1	1	0	**4**	26	8	0	2	**36**
Slovakia	0	0	0	0	**0**	1	0	0	0	**1**	6	13	0	2	**21**
United Kingdom	8	65	0	0	**73**	26	68	11	0	**104**	209	120	17	13	**359**
EU	**275**	**412**	**62**	**0**	**749**	**436**	**512**	**186**	**45**	**1,179**	**3,947**	**1,359**	**326**	**338**	**5,969**

The results in Table 27 indicate that the costs of abatement techniques needed to meet the **IED ELVs** is estimated to be €0.75bn/yr in 2025, comprising predominantly NO_X compliance costs (55%) and SO_2 costs (37%). The cost arises from an estimated 393 techniques estimated to be implemented at unit level, 5% of which are upgrades, and 95% are new techniques (replacement or additional techniques). The upgrades are estimated to be cheaper, making up only 2% of the costs. The total costs decrease in future years due to the lower number of plants forecast to be operating, and the proportion made up of NO_X compliance costs increases.

Table 27 suggests that the cost of the **upper BAT-AEL** scenario, when compared to the reference scenario, is estimated to be €1.6bn/year in 2020, falling to €1.2bn/year in 2025. These costs are predominantly from SO_2 and NO_X compliance, with a greater contribution of SO_2 costs in 2020 compared to greater contribution of NO_X costs in 2025. The costs in 2025 arise from an estimated 567 SO_2/NOx/dust techniques assumed to be implemented at unit level, 12% of these techniques are upgrades and 88% are new techniques (replacement or additional techniques). The upgrades are cheaper, making up only 4% of the costs. In addition, 55 units are estimated to fit dedicated Hg abatement techniques.

However, the incremental cost of the upper BAT-AEL scenario beyond the IED scenario is not simply the difference between the costs quoted in Table 27. Compared to the IED scenario, the higher cost of the upper BAT-AEL scenario comprises three categories of plants:

a. Plants whose techniques installed to meet the IED ELVs also enables them to meet the upper BAT-AELs. These plants incur no additional costs to meet the upper BAT-AEL.

b. Plants that already met the IED ELVs without incurring costs, but which are estimated to need to fit <u>additional</u> techniques to meet the upper BAT-AELs.

c. Plants that are estimated to fit certain techniques to meet the IED ELVs but which are estimated to need to fit <u>different</u> techniques (including no upgrades of techniques) to meet the upper BAT-AELs. Accounting for the full cost of these techniques is an upper bound of the compliance cost impacts of the upper BAT-AEL scenario. These plants may be expected to incur stranded costs due to the short time frame between incurring costs to meet IED ELVs (2016) and to meet BAT-AELs (assumed 2020), for example if the techniques needed to be installed to meet the upper BAT-AELs implies the need to remove the techniques that were needed to meet the IED ELVs. The marginal cost increment of the different techniques above those needed to meet the IED ELVs could be considered a lower bound of the compliance costs.

The two costs b and c, from the above list, for the upper BAT-AEL scenario, beyond the IED scenario, are shown in Table 29. The table shows the full cost of different techniques, as well as the marginal cost and the possible stranded costs. In practice, what is classed as a “different technique” could be an incremental technique. For example, if ESP is foreseen as needed to meet the IED ELVs but ESP+ is needed to meet the upper BAT-AELs. In such situations the stranded costs would be much lower.

It is also important to recognise that in theory a plant operator would be expected to make the most economically favourable decision on which pollution abatement techniques to implement at the plant if the level of the revised upper BAT-AELs had been known at the time that the investment decisions to meet the IED ELVs were made. What is marked in this model as an “additional technique” to meet the upper BAT-AEL over and above the IED ELV may or may not be the most economically advantageous way of meeting the BAT-AEL if the technique used to meet IED ELVs does not also achieve compliance with the upper BAT-AEL.

The 2025 results indicate, out of 264 plants, 136 unique plants are estimated to need to fit <u>additional</u> techniques to those already fitted to meet the IED ELVs, and in doing so are estimated to incur costs of €0.32bn/yr to reduce one or more of SO_2, NO_X, dust or Hg. These figures comprise 69 plants incurring €104m/yr for SO_2 abatement techniques; 30 plants paying €54m/yr for NO_X, 42 plants incurring €119m/yr for dust, and 44 plants paying €45m/yr to meet Hg upper BAT-AELs.

On top of this €0.32bn, there are a further 53 plants (14 plants for SO_2, 41 for NOx and 1 for dust) estimated to incur €0.11bn/yr more than the costs already incurred in the IED scenario as <u>different</u> techniques are estimated to be needed to meet the upper BAT-AELs. However, for these plants, the full costs of the techniques to meet the upper BAT-AELs would be €0.27bn/yr, i.e. there could be up to

€0.16bn/yr of stranded costs. The €0.16bn/yr would be an upper bound of the stranded costs because plants would have several years of operation of techniques fitted to meet the IED ELVs before BAT-AELs applied. Furthermore, depending on the techniques fitted, the full cost of €0.27bn/yr may not be incurred if there is no need to remove existing abatement techniques (e.g. if ESP was needed for meeting IED ELVs and ESP+ for meeting upper BAT-AELs). These plants could potentially be candidates for applications for time-limited derogations under IED Article 15(4).

Table 29 Upper BAT-AEL scenario costs compared to the IED scenario (2015EUR)

Year	Upper BAT-AEL scenario cost component	Meeting SO_2 limits (€m/yr)	Meeting NOx limits (€m/yr)	Meeting dust limits (€m/yr)	Meeting Hg limits (€m/yr)	Total (€m/yr)
2020	b. Additional technique to IED	132	51	141	55	378
	c. Different technique to IED (full cost)	191	187	29	-	407
	d. Different technique to IED (marginal cost beyond IED)	118	50	21	-	189
	Minimum total (b+d)	**250**	**101**	**162**	**55**	**567**
	Maximum total (b+c)	**323**	**238**	**169**	**55**	**785**
	Possible stranded cost (c-d)	*73*	*137*	*7*	-	*218*
2025	b. Additional technique to IED	104	54	119	45	322
	c. Different technique to IED (full cost)	91	170	10	-	270
	d. Different technique to IED (marginal cost beyond IED)	57	47	6	-	109
	Minimum total (b+d)	**161**	**101**	**125**	**45**	**431**
	Maximum total (b+c)	**196**	**224**	**128**	**45**	**592**
	Possible stranded cost (c-d)	*34*	*123*	*4*	-	*161*
2030	b. Additional technique to IED	66	44	77	36	223
	c. Different technique to IED (full cost)	76	101	10	-	186
	d. Different technique to IED (marginal cost beyond IED)	54	42	6	-	101
	Minimum total (b+d)	**120**	**86**	**83**	**36**	**324**
	Maximum total (b+c)	**141**	**145**	**87**	**36**	**409**
	Possible stranded cost (c-d)	*22*	*59*	*4*	-	*85*

The incremental costs of the lower BAT-AEL scenario from IED ELVs are similarly shown in Table 30.

Table 30 Lower BAT-AEL scenario costs compared to the IED scenario (2015EUR)

Year	Lower BAT-AEL scenario cost component	Meeting SO_2 limits (€m/yr)	Meeting NOx limits (€m/yr)	Meeting dust limits (€m/yr)	Meeting Hg limits (€m/yr)	Total (€m/yr)
2025	b. Additional technique to IED	2,509	633	246	338	3,726
	c. Different technique to IED (full cost)	1,373	575	53	0	2,001
	d. Different technique to IED (marginal cost beyond IED)	1,161	312	30	0	1,502
	Minimum total (b+d)	**3,669**	**945**	**275**	**338**	**5,228**
	Maximum total (b+c)	**3,882**	**1,208**	**299**	**338**	**5,727**
	Possible stranded cost (c-d)	*213*	*262*	*24*	-	*499*

3.2.4 Techniques selected by the modelling for meeting pollutant limits

The following 4 tables (Table 31, Table 32, Table 33 and Table 34) summarise the modelled selection of SO_2, NO_X, dust and Hg abatement techniques respectively in 2025 to meet the IED ELVs and the upper and lower BAT-AELs at unit level. The total annualised cost (sum of annualised capital costs and yearly operating cost) per technique is presented, as well as the cost per tonne abated. Similar tables for the years 2020 and 2030 can be found in Appendix 8.

SO_2

Depending on the scenario the selected abatement techniques differ. In 2025, wet scrubbers are the primary technique taken up in the IED ELV and upper BAT-AEL scenarios. The lower BAT-AEL scenario leads to the high efficiency scrubber WSC++ being preferentially selected to achieve the lower emission levels (at high cost). The costs per tonne abated for WSC++ and WSC+ are higher than for WSC as expected. Dry scrubbing (DSC) techniques are selected in roughly the same number of units in all scenarios, with increasing cost per tonne abated with the more stringent scenarios, reflecting their use on units with smaller emissions in later scenario years. The WSC upgrade technique is selected more in the upper BAT case than the IED ELV, but not at all in the lower BAT-AEL scenario, reflecting the fact that the WSC upgrade would not achieve sufficiently high reductions compared to WSC++.

Table 31 SO_2 abatement techniques estimated to be taken up in each scenario in 2025 (costs expressed as beyond the reference scenario)

Technique	IED ELV			Upper BAT-AEL			Lower BAT-AEL		
	No. units	Cost €m/yr	Cost per tonne abated (€/t)	No. units	Cost €m/yr	Cost per tonne abated (€/t)	No. units	Cost €m/yr	Cost per tonne abated (€/t)
Replacement / new DSC	15	34	2,852	20	37	3,011	15	12	4,639
Replacement / new WSC	158	198	767	202	259	871	76	179	1,925
Replacement / new WSC+	1	6	4,031	15	85	2,014	42	253	6,571
Replacement /new WSC++	3	24	4,436	3	24	4,182	297	3,503	7,769
WSC upgrade	8	9	2,006	19	19	2,335	0	-	-
WSC+ upgrade	3	3	2,688	17	12	3,215	0	-	-

Note: the lower BAT scenario includes a small number of model-infeasible SO_2 and NO_X cases. These cases have been assumed to apply the upper BAT technique.

NOx

Replacement SCR and SNCR techniques have similar costs per tonne abated across the three scenarios. SNCR as a standalone technique is selected by the model for roughly the same number of units in all three scenarios, in contrast to SCR which is selected for many more units in the more stringent scenarios.

The costs per tonne abated are lower for the SCR++ than for SCR. Although this result may be a limitation of the modelling, this could be due to the significantly larger quantities being abated by the SCR++ technique compared to the additional cost of SCR++ relative to SCR.

Despite the low cost per tonne abated of the upgrade SCR techniques, they are rarely selected by the model, which could be indicative that if secondary techniques are already fitted, no further improvements would be needed for the IED and upper BAT scenarios, but complete overhauls may be needed to reach the lower BAT-AELs, as suggested by the large number of replaced COMBI 2 compared to other scenarios.

Negative costs for individual units can occur in the model due to the plant-optimising algorithm. If the algorithm identifies, based on the costs of techniques, it is cheaper to replace one technique on one unit with a cheaper, less efficient one, but fit a more advanced technique on one or more other units of the same plant, then the model will select such a combination. Due to the model assumption of using the marginal cost of the new technique over the existing technique, this will result in a negative cost for the unit for which the model selects a cheaper technique. This appears to be the case for the selection of COMBI3 in the lower BAT-AEL scenario. In reality this outcome is considered unlikely to occur, and it occurs very rarely in the modelling. In the modelling for 2025, this situation occurs for two units out of 393 that fit techniques in the IED scenario, no units in the upper BAT scenario and two units out of 938 that fit techniques in the lower BAT-AEL scenario.

Table 32 NOx abatement techniques estimated to be taken up in each scenario in 2025 (costs beyond the reference scenario, EUR2015)

Technique	IED ELV			Upper BAT-AEL			Lower BAT-AEL		
	No. units	Cost €m/yr	Cost per tonne abated (€/t)	No. units	Cost €m/yr	Cost per tonne abated (€/t)	No. units	Cost €m/yr	Cost per tonne abated (€/t)
replacement / new COMBI2 (SCR+PMS)	2	21	742	4	24	808	76	278	2,585
replacement / new COMBI3 (SNCR+PMS)	6	6	551	5	6	568	4	-3	-
replacement / new SCR	58	151	2,454	69	198	2,384	91	345	3,607
replacement / new SCR+	21	73	2,703	32	102	3,006	47	154	4,023
replacement / new SCR++	17	65	2,005	20	60	2,263	111	430	2,714
replacement / new SNCR	86	96	2,405	87	122	2,639	79	149	4,070
upgrade COMBI2 (SCR+PMS)	9	0.2	124	9	0.2	96	10	0.8	150
upgrade COMBI3 (SNCR+PMS)	0	-	-	1	0.4	15,424	0	-	-
upgrade SCR	1	0.1	121	2	0.2	86	4	0.3	191
upgrade SNCR	0	-	-	0	-	-	0	-	-

Note: the lower BAT scenario includes a small number of model-infeasible SO_2 and NO_X cases. These cases have been assumed to apply the upper BAT technique.

Dust

As expected, the uptake of more efficient versions of the ESP increases with the more stringent scenarios – compared to the 3 ESP++ techniques selected in the IED scenario, there are 12 units selected to fit ESP++ in the upper BAT-AEL case and 64 in the lower BAT-AEL scenario.

The cost per tonne abated of the more efficient ESP++ and ESP+ (including of the upgrade technique) are lower than the cost per tonne abated of the ESP technique. This reflects the larger tonnes of dust reduced by the more efficient techniques compared to their smaller incremental cost.

Very few upgrade techniques are selected by the model in the upper BAT-AEL scenario, and none in the IED or lower BAT-AEL scenarios.

Table 33 Dust abatement techniques estimated to be taken up in each scenario in 2025 (costs beyond the reference scenario)

Technique	IED ELVs			Upper BAT-AELs			Lower BAT-AELs		
	No. units	Cost €m/yr	Cost per tonne abated (€/t)	No. units	Cost €m/yr	Cost per tonne abated (€/t)	No. units	Cost €m/yr	Cost per tonne abated (€/t)
replacement / new ESP	1	3	35,475	4	8	50,711	4	7	40,204
replacement / new ESP+	29	50	12,683	62	135	20,929	42	80	34,524
replacement / new ESP++	3	9	3,772	12	32	7,345	64	238	24,574
upgrade ESP	0	-	-	6	4	26,202	0	-	-
upgrade ESP+	0	-	-	9	5	20,960	0	-	-
upgrade ESP++	0	-	-	4	2	15,640	1	0.04	30,879

Note: cost per tonne abated for dust includes the emissions reduced as co-benefit of SO_2 techniques.

Mercury

No specific techniques for mercury abatement are selected by the model in the IED scenario, as there are no Hg limit values. The most prominent technique selected in the Upper BAT and Lower BAT scenarios is active carbon injection (ACI), with 54 units installing it in the Upper BAT scenario at a cost of €45m, and 206 units applying it in the Lower BAT scenario at a cost of €227m. The Lower BAT scenario also makes extensive use of the more efficient Bromide addition to active carbon injection (BACI) technique, with 78 units applying it at a cost of €111m.

The cost per tonne abated of ACI in the upper BAT scenario increases by around a factor of four in the lower BAT scenario when applied to a far larger number of units. In the lower BAT scenario, BACI has a substantially lower cost per tonne abated than ACI. Note that these costs per tonne abated consider only emissions reductions from Hg reduction techniques, and not co-benefits from other abatement techniques. The higher cost per tonne abated of BACI compared to ACI in the upper BAT scenario is expected for this more costly technique, although it is only taken up at one unit. The combination of high mercury reduction and a moderate cost, results in this low BACI cost per tonne mercury abated in the lower BAT-AEL scenario. That the costs per tonne abated for ACI are higher in the lower BAT-AEL scenario is because some plant concentrations are close to the AEL level, but not under it, so they still need Hg abatement at full investment costs, but with little further absolute emission reduction. The emissions reduced by ACI in the lower BAT-AEL scenario is only 1.2 times that of the upper BAT-AEL scenario, while costs are 5 times higher.

Table 34 Hg abatement techniques estimated to be taken up in each scenario in 2025 (costs beyond the reference scenario)

Technique	Upper BAT-AEL			Lower BAT-AEL		
	No. units	Cost €m/yr	Cost per kg abated (€/kg)	No. units	Cost €m/yr	Cost per kg abated (€/kg)
Active carbon injection (ACI)	54	45	29,989	206	227	121,887
Bromide addition to active carbon injection (BACI)	1	0.6	76,226	78	111	31,114

Note: cost per tonne abated for Hg is just in relation to the emissions reduced by the Hg techniques, i.e. excluding the emissions reduced as co-benefit of SO_2/NOx/dust techniques.

3.2.5 Costs compared to benefits

The net annualised costs for 2020, 2025 and 2030 at EU level are less than the benefits in all of the scenarios assessed when considering costs compared to the reference scenario or to the IED scenario. This is shown for the year 2025 in Table 35. The IED scenario compared to the reference scenario is estimated to have a benefit-cost ratio of 13:1 in 2025. The upper and lower BAT-AEL scenarios compared to the IED scenario have benefit-cost ratios of 5.8:1 and 2.5:1 respectively.

Most MS have benefits far outweighing costs, as shown in Figure 29 and Figure 30 for the upper BAT-AEL scenario and Figure 31 for the lower BAT-AEL. However, not all MS are estimated to have net benefits when considering costs compared to the reference scenario (primarily in the lower AEL scenario). Table 36 on the following pages shows the net benefit-cost position across each MS for each scenario in 2025, with the costs compared to the reference scenario. The shading used is: net benefits in green shading, net costs in red shading; and in both colours darker shades mean higher absolute values.

Although no sensitivity analysis has been carried out on the assumed costs of techniques, the high benefit-cost ratios suggest that even if costs were 50% higher than as modelled, the estimated benefits would still far outweigh the costs of compliance at an EU level.

Table 35. EU-level costs compared to benefits in 2025 show all scenarios are net beneficial

Scenario	Component	SO_2 (€bn/yr)	NO_X (€bn/yr)	Dust (€bn/yr)	Hg (€bn/yr)	Total (€bn)
IED ELV scenario compared to Reference scenario	Emission reduction benefits	7.3	1.8	0.8	0.05	9.9
	Compliance costs	0.28	0.41	0.06	-	0.75
	Total net benefits					**9.1**
	Benefit-cost ratio					**13**
Upper BAT-AEL scenario compared to Reference scenario	Emission reduction benefits	10.0	2.2	1.0	0.1	13.4
	Compliance costs	0.44	0.51	0.19	0.05	1.2
	Total net benefits					**12.2**
	Benefit-cost ratio					**11**
Upper BAT-AEL scenario compared to IED scenario	Emission reduction benefits	2.7	0.4	0.3	0.1	3.4
	Compliance costs (maximum)	0.20	0.22	0.13	0.05	0.59
	Total net benefits					**2.8**
	Benefit-cost ratio					**5.8**
Lower BAT-AEL scenario compared to Reference scenario	Emission reduction benefits	17.3	4.9	1.5	0.4	24.1
	Compliance costs	3.9	1.4	0.3	0.3	6.0
	Total net benefits					**18.1**
	Benefit-cost ratio					**4.0**
Lower BAT-AEL scenario compared to IED scenario	Emission reduction benefits	10.0	3.1	0.7	0.4	14.2
	Compliance costs (maximum)	3.9	1.2	0.3	0.3	5.7
	Total net benefits					**8.4**
	Benefit-cost ratio					**2.5**

Figure 29 Annual costs and benefits per MS of meeting the upper BAT-AEL from the IED ELVs (2015EUR). Inset shows share of the costs.

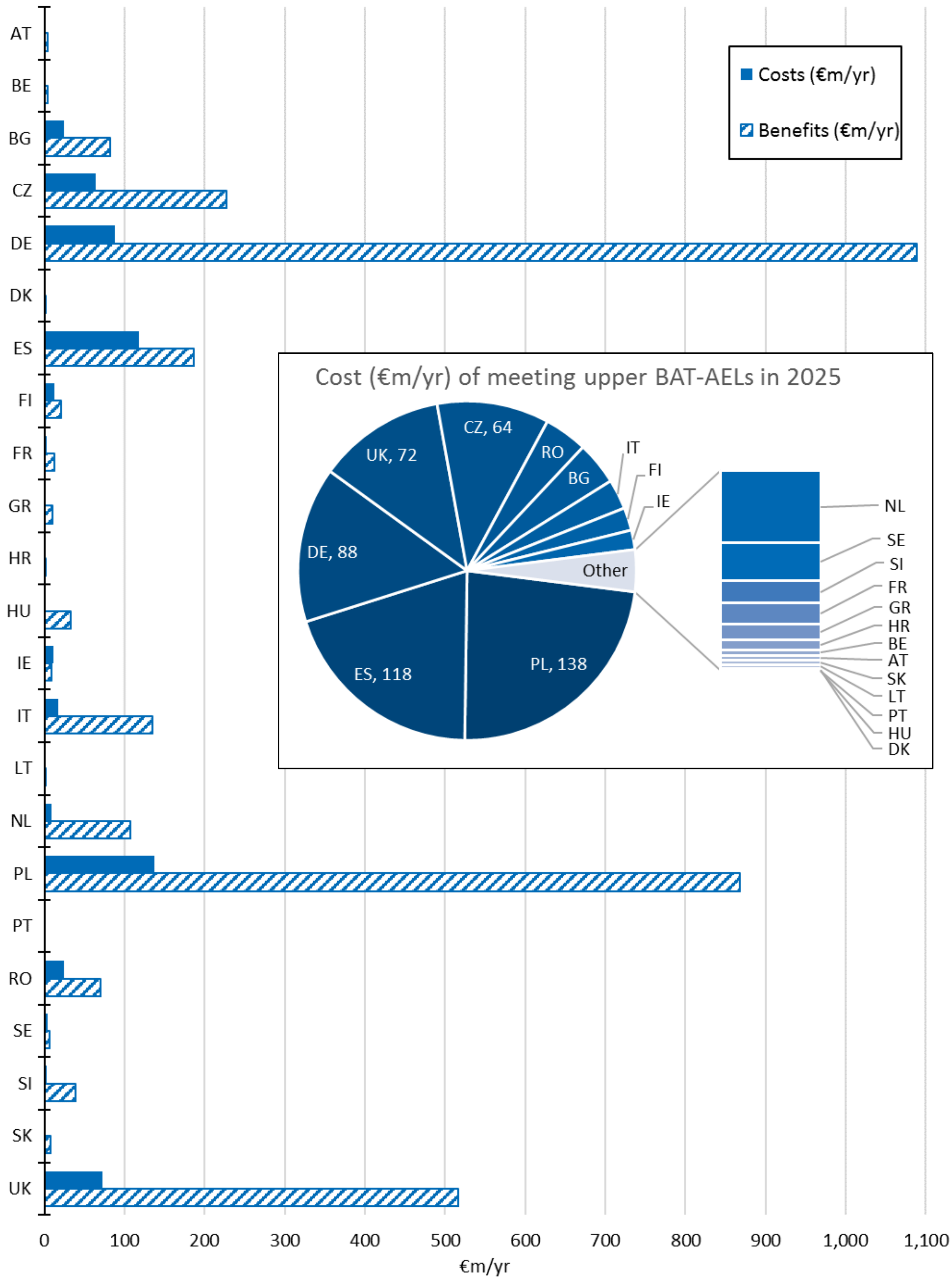


Figure 30 Net incremental benefits in 2025 per ranked Member State of meeting upper BAT-AELs from IED ELVs, split by pollutant. One Member State is indicated to incur net costs.

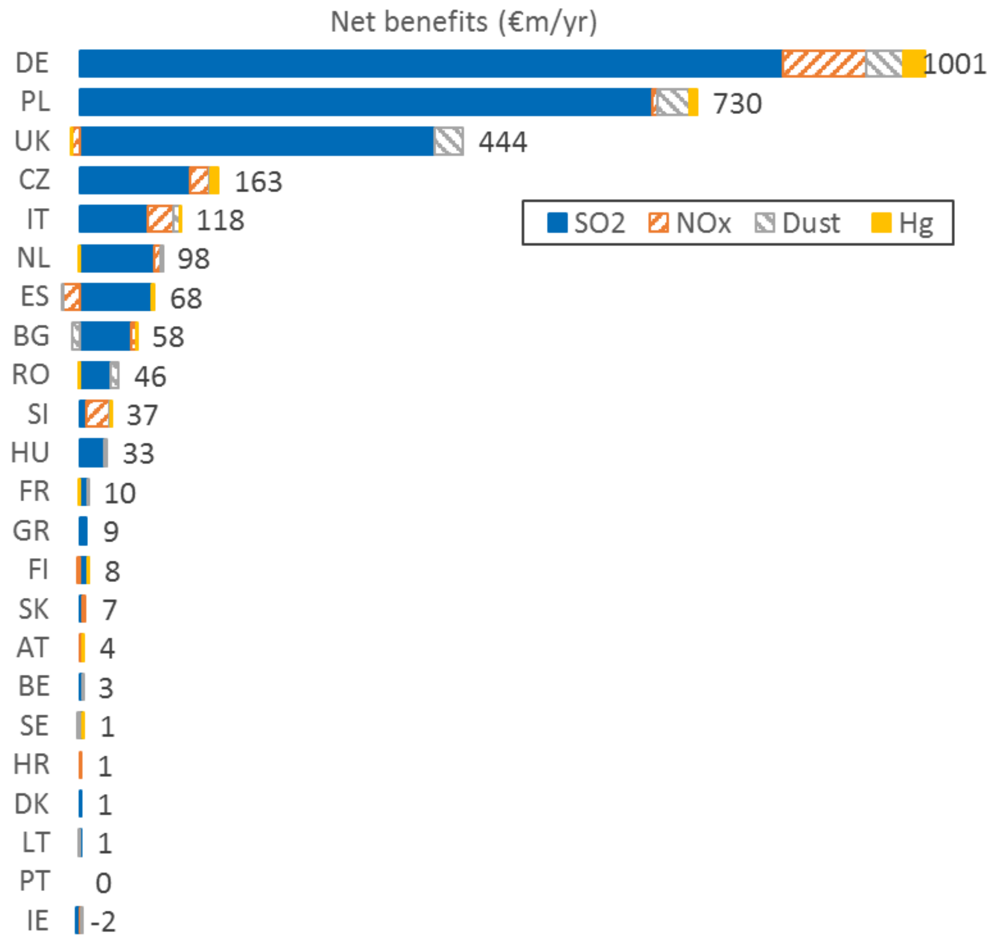


Figure 31 Net incremental benefits in 2025 per ranked Member State of meeting lower BAT-AELs from IED ELVs, split by pollutant. Eight Member States are indicated to incur net costs.

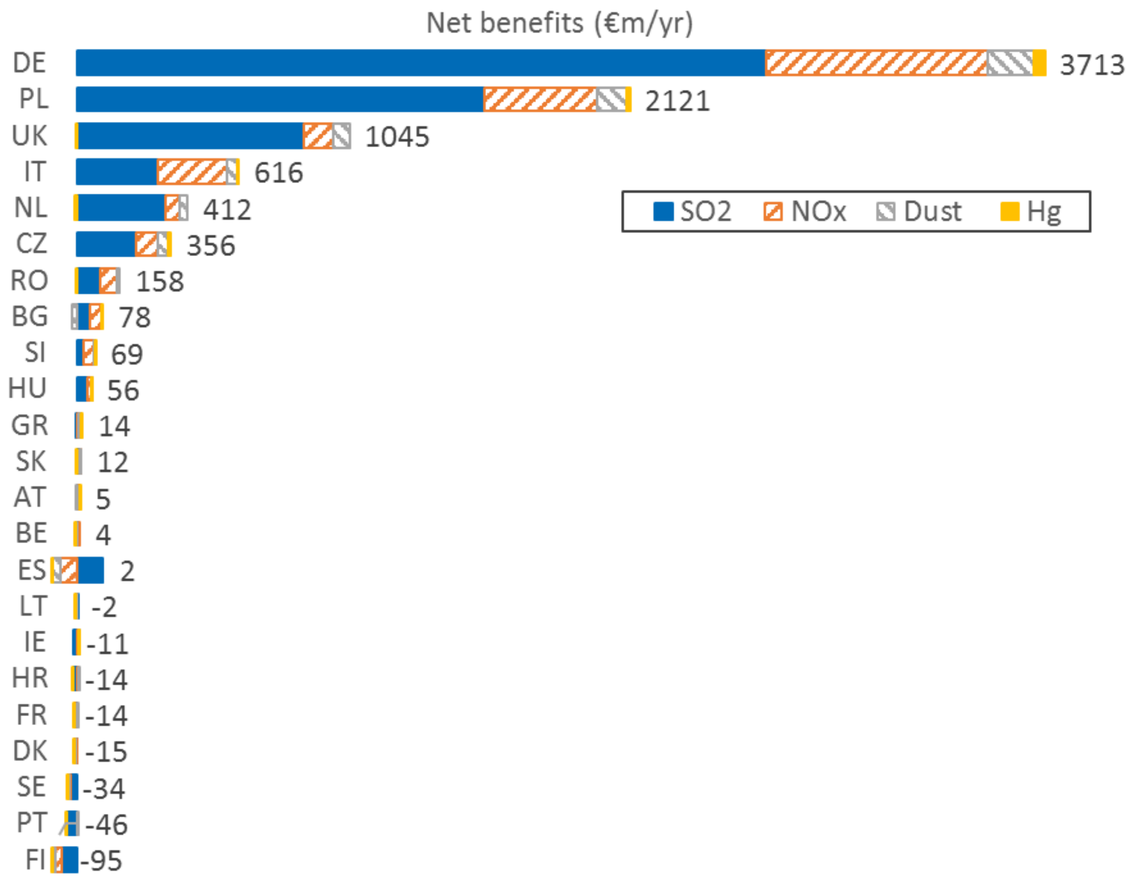


Table 36 Total benefits minus costs for year 2025 (2015EUR €m/yr). Net benefits in green shading, net costs in red. Darker shades mean higher absolute values.

Member State	IED ELV scenario from reference scenario					Upper BAT-AEL from reference scenario					Lower BAT-AEL from reference scenario				
	SO_2	NOx	Dust	Hg	Total	SO_2	NOx	Dust	Hg	Total	SO_2	NOx	Dust	Hg	Total
Austria	0	2.1	1.8	0	**4.0**	0	5.8	1.8	0.04	**7.7**	0	9.8	0.5	0.1	**10**
Belgium	0	2.8	1.3	0	**4.1**	2.7	2.8	1.7	0	**7.2**	6.3	5.3	-1.6	-0.3	**9.7**
Bulgaria	786	74	80	2	**942**	851	80	74	1.8	**1,006**	837	133	63	5.4	**1,038**
Czech Republic	405	96	24	10	**535**	539	122	24	20	**705**	653	204	66	18	**940**
Germany	1,674	52	83	3	**1,812**	2,506	155	125	30	**2,816**	4,337	905	263	45	**5,550**
Denmark	0	1.4	-0.3	0	**1.1**	0.8	1.4	-0.3	0	**1.9**	-2.1	-0.8	-5.3	-3.5	**-12**
Spain	988	132	108	12	**1,241**	1,086	134	108	15	**1,343**	1,136	151	86	10	**1,383**
Finland	18	-1.1	-3.1	0.8	**15**	27	-2.5	-2.2	1.2	**24**	-35	-15	-5.7	-2.5	**-58**
France	0	-1.7	-1.0	0.01	**-2.6**	8.8	-1.7	0.6	-0.2	**7.6**	-5.9	-1.7	1.6	-5.2	**-11**
Greece	0	0	0	0	**0**	8.5	0	0	0	**8.5**	-4.3	4.4	9.2	4.1	**14**
Croatia	0	1.4	0	0	**1.4**	0	2.3	0	0	**2.3**	-15	4.0	0.3	-1.4	**-12**
Hungary	0	11	0	0	**11**	29	11	3.1	0	**44**	38	28	1.7	0.3	**68**
Ireland	92	10	2.5	0.3	**106**	93	13	2.6	0.3	**109**	90	17	3.0	0.5	**110**
Italy	242	15	21	0.2	**278**	322	47	28	0.5	**397**	558	283	61	2.8	**905**
Lithuania	0	1.6	0	0	**1.6**	0.7	1.6	-0.04	0	**2.2**	1.2	0.8	-2.7	-0.2	**-0.9**
Netherlands	30	2.3	0	0.4	**32**	118	10	2.9	0.2	**131**	370	61	27	-8.1	**450**
Poland	1,515	305	227	7	**2,054**	2,195	360	267	15	**2,837**	3,141	816	352	20	**4,328**
Portugal	0	0.1	0	0	**0.1**	0	0.05	0	0	**0.05**	-41	0.1	0.2	-4.9	**-46**
Romania	734	199	161	2	**1,096**	775	204	170	2.4	**1,152**	840	282	171	0.1	**1,293**
Sweden	0	0	0	0	**0**	3.8	-0.3	-2.1	0.01	**1.5**	-24	-6.3	-2.5	-1.8	**-34**
Slovenia	25	4.5	0	0	**29**	32	32	2.0	0.2	**66**	48	46	5.8	0.3	**99**
Slovakia	3.7	0	0	0	**3.7**	6.4	4.1	0	0	**10**	11	3.9	1.9	-0.7	**16**
United Kingdom	531	459	22	8	**1,020**	956	485	55	8.3	**1,505**	1,409	576	86	7.6	**2,078**
EU	**7,044**	**1,368**	**726**	**47**	**9,184**	**9,561**	**1,667**	**861**	**95**	**12,184**	**13,347**	**3,506**	**1,181**	**85**	**18,118**

3.3 Impacts on electricity prices

In this task we compare the incremental costs to comply with the upper BAT limit values from the IED ELVs in 2025 per member state for solid fuel fired power plants with the levelised cost of electricity (LCOE) and the carbon costs. The LCOE is the lifetime cost of building and operating an electricity generating plant, amortised and discounted to present day values. The costs for electricity generation by power plant operators includes the following cost factors:

- Fuel costs
- Operation & Maintenance costs
- Capital expenditure costs
- Net electricity production
- Discount rate
- Carbon price

The LCOE is often used to compare the cost of different technologies over a certain period of time, taking into account the initial investments and the lifetime of the production asset. However, the LCOE may vary from year to year, due to variations in e.g. fuel costs and electricity prices, which are dependent on external market factors.

In the previous tasks of this project, the abatement costs were calculated for solid fuelled power plants in the EU, specifically for emissions of SO_2, NO_x, Hg and dust. This was done not only nationally, but also at plant/unit level. The goal of this assessment was to assess the wider financial impacts of the estimated compliance costs (abatement technique costs) for power plant operators.

Exact data for the LCOE at plant or Member State level are not readily available, due to the variable nature of the LCOE. However, one of the major cost factors is the fuel cost, which is similar (excluding biomass and lignite) for most of the power plants. The International Energy Agency assesses the LCOE of coal-fired power plants to be between €64.3/MWh and €74.9/MWh (at a 4% discount rate) (IEA, 2015). In addition, data on electricity production costs have also been identified for specific Member States including Belgium, Germany, the Netherlands and Portugal. However, in a similar study in 2010, more data are given for Belgium, Czech Republic, Germany, and Slovakia (IEA, 2010). In addition, an average number for Eurelectric (the European trade association of the electricity industry) is given. This number is taken as an average for the countries where no specific information is available. In summary, the following numbers are adopted for the levelised cost of electricity in the European countries:

- For Belgium, Germany, the Netherlands and Portugal the most recent reference IEA (2015) is taken.
- For the UK, DECC (2012) is used.
- For the Czech Republic and Slovakia the IEA (2010) data are taken.
- For the other countries for which no direct LCOE information is available, the Eurelectric data are taken as an average approximation (IEA, 2010).

A comparison between the different IEA sources is given below:

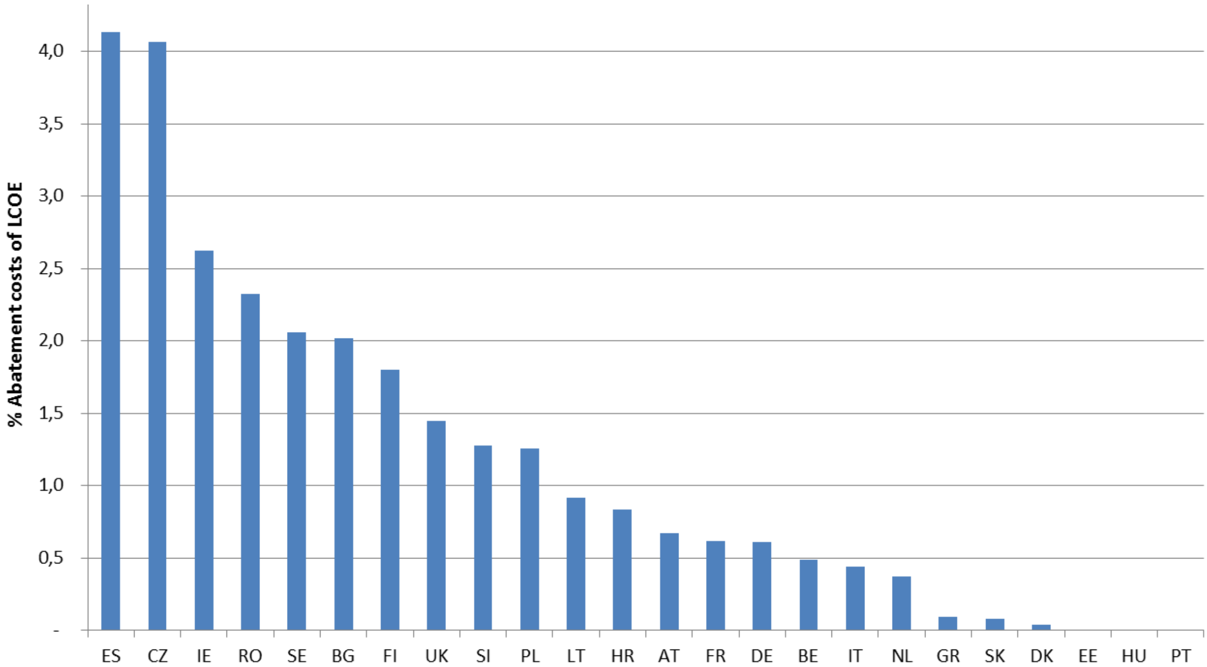
Table 37 Comparison LCOE data from IEA (2010) and IEA (2015) with a 4% discount rate. (Values with * are converted from USD 2010 to EUR2015)

	Fuel	LCOE 2010 (€/MWh)	LCOE 2015 (€/MWh)
BE	coal	59.2	70.1
DE	coal	57.5	64.3
DE	lignite	50.4	64.4
NL	Coal	52.6	74.9
Eurelectric	Coal	53.8	64.3*
Eurelectric	Lignite	44.8	53.6*

LCOE costs may vary year-to-year, depending on the operating time and the electricity prices in the specific country. Overall, the data are consistent between the sources within a 10% error range. Therefore, we expect an error of 10% due to the LCOE approximation.

In Figure 32, the incremental annual total abatement costs to meet the upper BAT limit values to meeting the IED ELVs in 2025 for coal and lignite plants are divided by the total LCOE of all the plants per member state. Both LCOE and abatement technique costs are annualised yearly cost factors for power plant operators. The share of the abatement costs in the LCOE ranges between 0% and 4.1% for the Member States, dependent on the age, type and fuel of the LCP mix.

Figure 32 Average 2025 incremental upper BAT-AEL compliance costs divided by LCOE (%), weighted by electricity production per plant

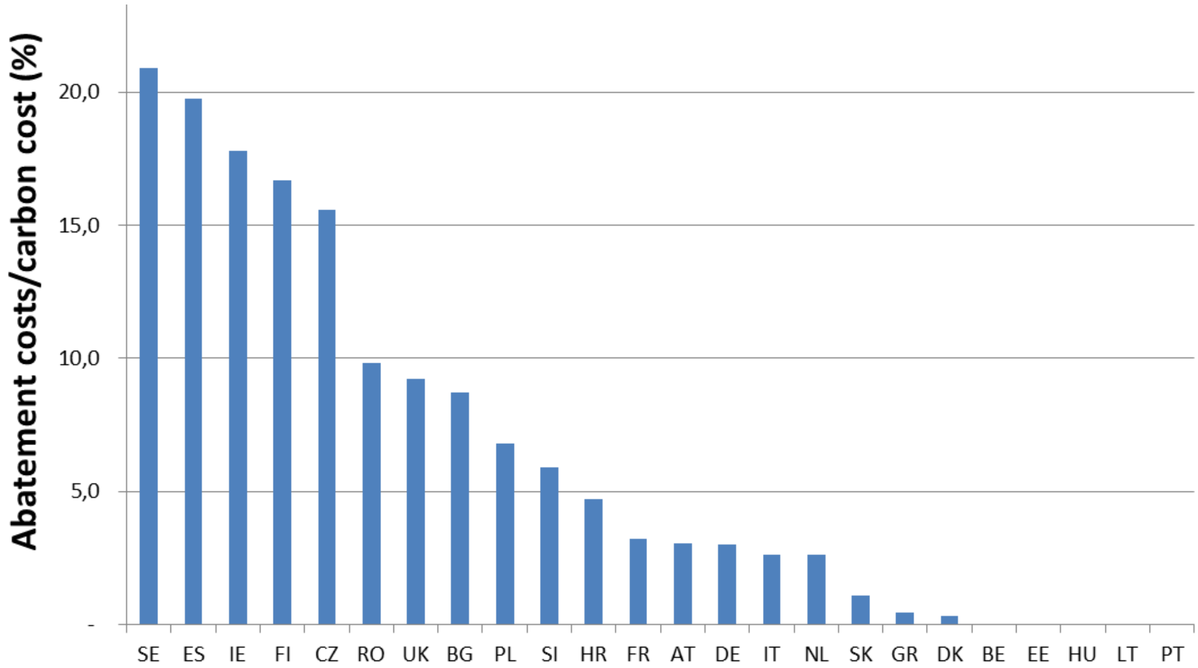


In addition, to compare against the policy-induced cost of carbon, the incremental compliance costs of the upper BAT-AELs in 2025 have been compared with the estimated carbon cost in Figure 33. Within the EU Emission Trading Scheme (EU ETS), the carbon cost is variable. In recent years, the cost for an emission allowance (equivalent to a tonne of CO_2) has been around €5/t (EEX, 2016; EC, 2015b). Given the needed acceleration of the decrease in emission allowances from 1.74%/year to 2.2%/year in 2022, an increase of this price could be possible (EEA, 2015d).

$$Carbon\ cost \approx carbon\ emission(tonne\ CO2eq) * carbon\ price(€/tonne\ CO2eq)$$

The estimated ETS carbon price of the PRIMES 'reference scenario 2013' for the year 2025, which amounts to €14/tonne CO_2, was used (EC, 2013). Additional carbon taxes of individual Member States are not taken into account. The CO_2 emission per LCP is determined from the fuel consumption, which is already estimated in the study, together with IPCC emission factors per fuel (IPCC, 2006).

Figure 33 Compliance costs of meeting SO_2, Hg, NOx and dust upper BAT-AELs as a proportion of carbon costs



4 Uncertainty, limitations and sensitivity analysis

4.1 Introduction and summary

Modelling work that tries to estimate future impacts is always uncertain. This study is no exception. Whilst a substantial amount of bottom-up data has been used very effectively in this study, there remain several assumptions that had to be made in order to complete the analysis. These limitations lead to uncertainty in the results and have implications for interpretation of the results. This chapter summarises the assessment of the uncertainty in the results, their limitations and implications.

The parameters leading to uncertainty in each part of the modelling are summarised in Table 38 and described in sections 4.2, 4.3 and 4.4. Quantitative sensitivity of the results to variation in key assumptions is reported in section 4.5. Not all the assumptions or key variables that are part of the methodology have been subject to sensitivity analysis.

Table 38 Summary of parameters affecting the results, whether they have been assessed through sensitivity analysis and whether they may affect estimated costs and/or benefits

Model part	Parameter	May affect		Preliminary testing indicated model not sensitive to parameter	Sensitivity results to parameter in section 4.5
		Costs	Benefits		
Baseline	Issues linking plants correctly across data sources	✓	✓		
	LCP emission inventory data quality	✓	✓		
	Accounting for heat-producing units	✓	✓		
	Estimating unit level emissions and fuel consumption	✓	✓		
	Estimating flue gas concentrations	✓			✓
	Incomplete data on installed abatement	✓	✓		
	Completeness of other data fields in Platts-WEPP	✓	✓		
	Correct identification of LCPD opt outs, and plants in IED LLD / TNP regimes	✓	✓		
Reference scenario	Projecting the amount of plant capacity that will close or remain open in a MS	✓	✓		
	Projecting the amount of plant capacity that will be replaced in each MS	✓			
	Projecting which units at plants will close	✓	✓		
	Projecting future fuel consumption	✓	✓	✓	
	Determining which plants follow the desulphurisation approach	✓	✓	✓	
IED ELV and BAT-AEL scenarios	Optimisation methodology	✓			
	Techniques available	✓	✓		✓ off model
	Technique costs and abatement efficiencies	✓	✓		
	Economic life of techniques	✓			✓
	Monetary valuation of emission reductions		✓		✓

4.2 Parameters affecting the uncertainty of the 2013 baseline

4.2.1 Issues linking plants correctly across data sources

The link between the LCP and E-PRTR databases was already integrated in the 2013 LCP dataset by the EEA. The plant identification link between LCP EI and E-PRTR[15] was reviewed, resulting in the identification of links where we believe the linked E-PRTR facility was incorrect. These erroneous links were communicated to DG ENV and EEA after which an updated LCP EI (v1.1) was published by the EEA. In this updated dataset there remained some erroneous links to E-PRTR. We have made further corrections to these links in obvious cases, which has been documented within the baseline database. In cases where it was not clear, no changes were made, and hence there is a risk that an LCP from the LCP EI is linking to the incorrect data on Hg emissions from E-PRTR.

All LCPs were linked to an E-PRTR facility except for one Croatian plant. E-PRTR is used primarily to add emissions of mercury. For 155 LCPs, the corresponding E-PRTR facility did not contain information on facility level emissions of mercury.

A manual one-to-many link has been established between the LCP EI (plant level) and the Platts-WEPP database (unit level). In most cases, linking by plant name, operator and location was sufficient to identify the correct units. In a number of cases however, it was not clear which units belonged to which LCP when there were multiple LCPs in one larger complex. In some cases, the link was only based on one common characteristic and is relatively uncertain. Approximately 20 links are relatively uncertain and these have been marked as such in the database. There is therefore uncertainty for these 20 links that the data from WEPP match the data from the LCP EI.

Other data sources have been used, including BATIS (EC, 2015a), TNPs, Enipedia (2016), Global Energy Observatory (GEO, 2016), and in some cases information from the website of the operator of a specific power plant. These data have been used only for gap-filling where the LCP EI, Platts-WEPP and E-PRTR did not hold any information. This process brings potential additional issues around linking the plants, since plants are referred to using different names or identifiers. Information has only been included in those cases where the correct plant/unit in the LCP EI and Platts-WEPP datasets could be confidently identified.

4.2.2 LCP emission inventory data quality

This study in principle assumed that the LCP emission inventories that formed an input to the analysis contained accurate and correct data. However, some quality checks were made for the LCP entries that were selected for this project, resulting in the identification of some errors in the databases that needed to be dealt with.

- For some LCPs, 2012 rather than 2013 data were used because the plant reported zero fuel input and zero emissions in 2013 (inclusion of the plant in the LCP EI suggested these plants were not closed). Two of the originally identified ten plants with 2012 data (one plant in Italy, one in Romania) was identified as having reported in 2013 under a different identifier. The 2012 instances of these plants were subsequently excluded from the baseline to avoid double counting these plants.
- For 6 plants, the total reported fuel input (in TJ) exceeded the theoretical maximum fuel input based on the thermal capacity of the plant. This was an issue that needed correction, since the fuel input is used to estimate emission concentrations, the ELV (as fuel mix) and operating hours. The 6 entries concerned were reviewed case-by-case and corrections applied and documented in the baseline database. In most of these cases, it was found that the value listed as rated thermal input (MW_{th}) was likely representing the electric output capacity of the plant (MW_e) based on comparison with WEPP, therefore the actual reported thermal input (MW_{th}) should have been higher. In other cases, the fuel input appeared to be too high compared to the rated thermal input and were adjusted downwards.

Apart from the above points, more data quality issues may exist in the LCP EI. However, it was not in the scope of this study to quality assure the LCP EI, and therefore corrections were only made to those data points that were considered to otherwise significantly affect the results of this project.

[15] This is the mapping which associates a plant in the LCP EI with the correctly matched facility in E-PRTR.

4.2.3 Accounting for heat-producing units

Since the Platts-WEPP dataset only contains electricity generating units (including those which generate electricity and heat in combined cycles), for some LCPs no corresponding unit(s) could be found in Platts-WEPP, likely because these LCPs are heat generation only. This occurred for 9 LCPs. These plants have been treated as comprising a single unit and have been assigned generic fuel types in order to calculate flue gas concentrations and determine ELVs and BAT-AELs at plant and unit level. The properties of the generic fuel types (generic biomass, generic other solid fuel etc.) are based on the IPCC (2006) fuel types: Other solid biomass for biomass, an average of bituminous coal, sub-bituminous coal, lignite and anthracite for other solid fuels, residual fuel oil for liquid fuels, and coke oven/gas works gas for other gases.

Apart from the plants with no information in Platts-WEPP, there are several plants which produce both electricity and heat, where information on the capacity for heat generation is missing. That missing heat capacity could either be additional heat-only boilers (not listed in Platts-WEPP) or in units that are already in the Platts-WEPP database and which generate both heat and electricity (but for which only electrical capacity is known in Platts-WEPP). Such manual adjustments if they were carried out would in any case come with high uncertainty as to the correct number and capacity of heat units.

However, since the LCP EI data source which includes heat plants provides the capacity data needed to multiply the unit cost data (expressed in €/MW_{th}), and that these capacity data are complete, it is not considered important that heat only units may not be identified in Platts.

As a quality control measure, and to identify outstanding issues, the rated thermal input (MW_{th}) at plant level (from LCP EI) has been compared to the sum of the MW_e electric output from the underlying units (from Platts-WEPP). The results are shown in Figure 34.

Figure 34 Observed MW_e/MW_{th} ratio for each of the LCPs considered in this study, after corrections and gap-filling processes

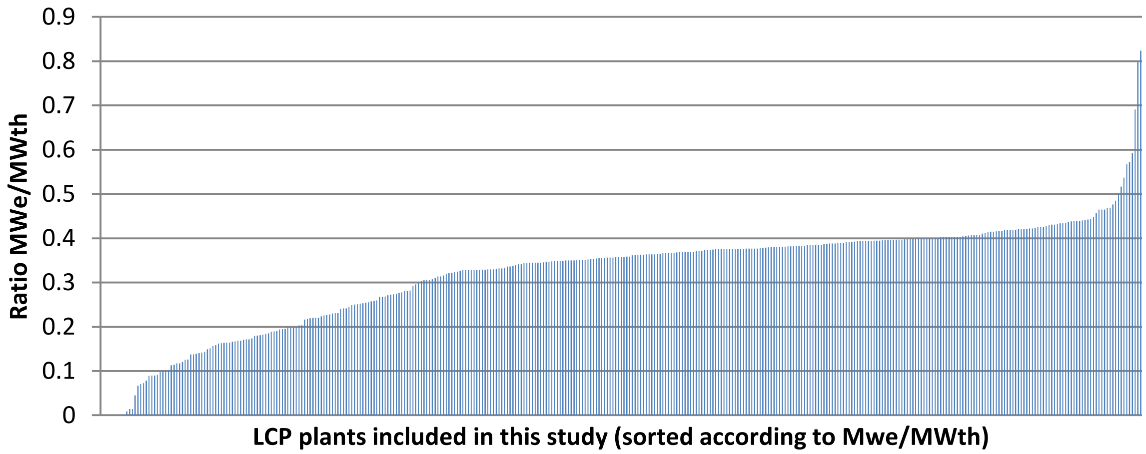


Figure 34 shows for most cases MW_e/MW_{th} ratios between 0.3 and 0.5, which is what we would expect based on the typical electrical efficiency of electricity producing plants. However, we do see some specific plants with very high ratios (e.g. >60% for around 15 plants) which are likely to be errors in either MW_{th} or MW_e, or mistakes in selecting the correct units for each LCP. On the other hand, there are a large number of lower MW_e/MW_{th} ratios (below 0.3). These low values are assumed to be attributed to heat production plants, as the thermal output (in the form of heat) from CHP or purely heat producing plants is not taken into account in this analysis (since heat production is not accounted for in Platts-WEPP).

When comparing the cases with MW_e/MW_{th} ratio > 0.6 with the cases where the fuel input exceeds the thermal input power MW_{th} (see Section 4.2.2), it is observed that in many cases these are the same LCP entries. In these cases, both discrepancies can be explained by a thermal input capacity that has been reported too low. By checking individual plants for these cases, we have identified in many cases the LCP dataset reported MWe as being MW_{th}. This has been corrected where possible by searching for the actual MW_{th} in alternative datasets. However, this appears to be a parameter not found easily. For 6 plants, no data on thermal capacity could be found. In these cases 35% efficiency has been assumed (rounded average ratio) and the MW_{th} has been calculated based on the sum of the MW_e from the corresponding units.

4.2.4 Estimating unit level emissions and fuel consumption

The modelling includes assumptions made on how emissions and fuel consumption, which have been reported at plant level, should be allocated to the units that combine to make the plant. Various uncertainties arise from this process, including:

- Whether all the units in the plant have been listed in the database, and their relative capacities correctly known;
- How many hours in the base year each unit was operational;
- What fuels are combusted in each unit if the fuel mix is not the same across all units;
- What techniques for pollution abatement are installed at each unit and whether these are specific to each unit or common to the plant;
- Whether any units had operational characteristics in the base year that led to e.g. particularly high emissions, such as abatement technique failure, or other accidents.

Assumptions for all of the above points have been made, as no data are readily available at EU level to answer these questions. It is suspected that MS also would be unlikely to hold information to answer the above questions, such that the questions would need to be posed to each plant operator, which was not within the scope of this study.

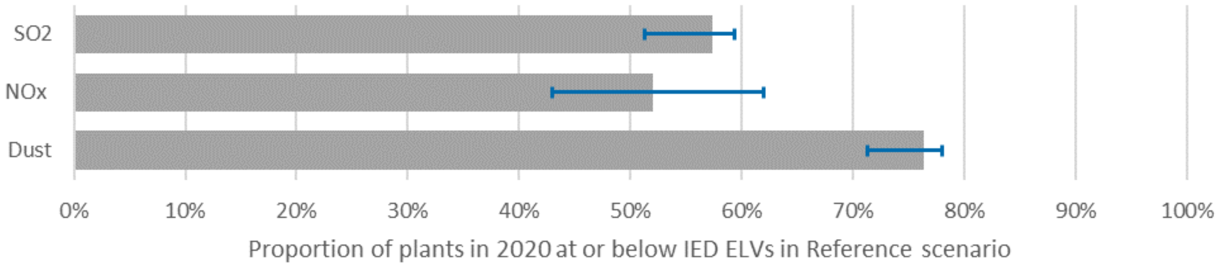
4.2.5 Estimating flue gas concentrations

Although monitoring takes place at installations to establish emission concentrations of pollutants in flue gases, the *reported* data that have been drawn upon are fuel consumption and mass emissions. From these reported data, flue gas concentrations have been estimated. Flue gas concentrations can be calculated from the mass emissions using different methodologies. In this project, the method that has been followed is the empirical method suggested by the EEA (EEA, 2016). In EEA (2008), the same method was used to estimate flue gas volumes, and the sensitivity of results to the flue gas calculation method was analysed. The flue gas volumes as estimated with this method were found to be generally higher than when estimated using a theoretical relationship. For low NCV fuels, the difference may be significant (~20%), while for hard coal the difference is smaller (approximately 6%).[16] Higher estimates of flue gas volume leads to a lower estimated pollutant concentration. This means that the concentrations estimated in the current study are likely to be at the low end. To reflect the uncertainty of the results to a higher or lower flue gas volume, we have used an estimate for all units and plants of 10% uncertainty above the calculated value and 5% below. This interval was chosen to account for the fact that EEA (2008) suggests that alternative methods would lead to 6% lower flue gas volumes and thus higher concentrations. Figure 35 shows the percentage of plants[17] estimated to have emission levels at or below the IED ELVs for SO_2, NOx and dust, where the error bars represent uncertainty in the calculation of the flue gas concentration (10% above, 5% below central value), as described in this paragraph. The higher variation for NO_X than for SO_2 and dust is expected to reflect a larger proportion of plants with emission concentrations close to the IED ELVs than for SO_2 and dust, and hence these plants are more affected by small variations in the estimation of emission concentrations. A consequence of the uncertainty in the emission level is an uncertainty in the reduction required to achieve compliance, and hence potentially the costs of compliance.

This range only takes into account the uncertainty in the estimate of flue gas concentration, which is not the only uncertainty. Other uncertainties include errors or inconsistencies in the LCP inventory, Platts-WEPP, E-PRTR or other datasets, uncertainties in linking the datasets, missing information in E-PRTR, gap-filled estimates but also measurement uncertainties in the emission measurements in individual stacks. Therefore, the overall uncertainty will be higher than 10%.

[16] For high NCV fuels (e.g. liquids and natural gas), the empirical approach may actually give a slightly lower estimate of the flue gas volume.
[17] I.e. similar to Table 20, except presented as numbers not capacity of plants.

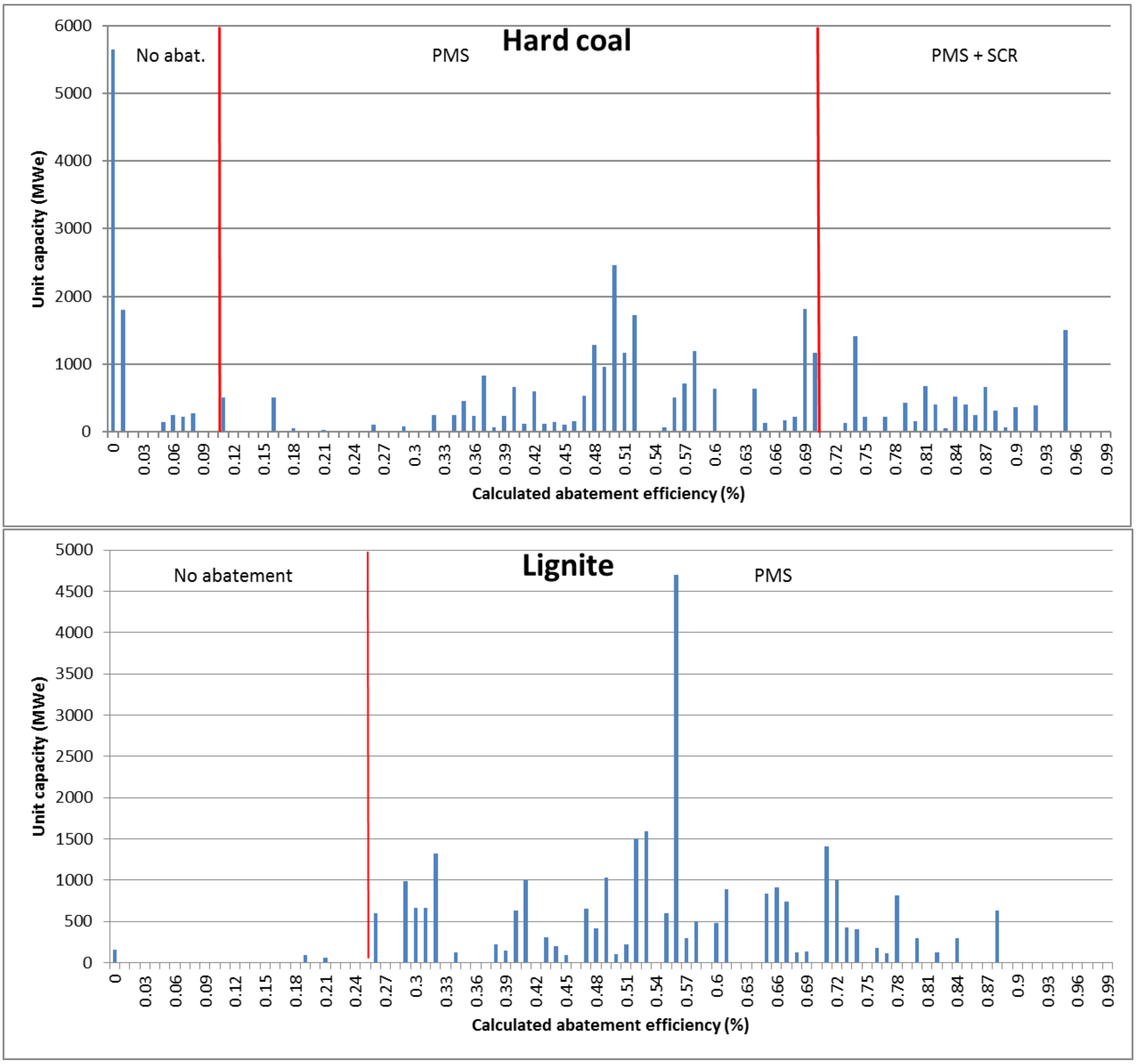
Figure 35 Uncertainty in the percentage of number of plants with concentrations at or below the IED ELV in 2020 based on the uncertainty in calculating flue gas volumes



4.2.6 Incomplete data on installed abatement techniques

No information on installed NOx abatement techniques was available for around one third of installed capacity, and therefore assumptions were made to fill this gap using calculated abatement efficiencies at plant level (method described in section 2.2.4). To look at the sensitivity of the assigned abatement technique to the assumed ranges for each of the techniques, in Figure 36 the calculated abatement efficiency rounded to two decimal places is plotted on the x-axis against the sum of the installed capacity (MWe) of these units on the y-axis (separately for hard coal and lignite plants). It should be noted that this graph only includes the units for which the abatement technique was unknown and hence gap-filled. The graph shows a number of units burning hard coal having zero abatement efficiency, these were in fact calculated to have higher emissions than when using unabated emission factors assumed in this study.

Figure 36 Illustration of the gap-filled abatement techniques for NOx for coal and lignite based on the assumed abatement ranges for efficiencies



The borders between different abatement techniques that were assigned (i.e. from Table 3) are indicated by the red lines, and at the top it is indicated which abatement technique was assumed. For efficiencies < 10%, no abatement was assumed for hard coal, while for lignite this cut-off value is 25%. Since very limited capacity is installed with around 10% calculated abatement efficiency for hard coal, the border between no abatement and PMS is not particularly sensitive to changes to the 10% value. For lignite this sensitivity is somewhat larger, but still relatively small. For hard coal, the boundary between PMS and the combination of PMS and SCR (70% efficiency assumed) is more sensitive since a larger share of the capacity is installed around this value.

- A decrease of the assumption value from 70% to 65% would mean an additional 3.4 GWe capacity would be assumed to have the combination of PMS and SCR instead of just PMS.
- An increase of the assumption value from 70% to 75% would mean an additional 1.8 GWe capacity would be assumed to have PMS instead of the combination of PMS and SCR.

4.2.7 Completeness of other data fields in Platts-WEPP

Several fields of the Platts-WEPP database were incomplete. The example of air pollution abatement techniques was already described in section 4.2.6. Other important fields where information was incomplete in Platts-WEPP included boiler type, and commissioning year.

The boiler type field, had it been more fully populated, could have been used more extensively to distinguish applicability of abatement techniques to certain plant (boiler) types, including differentiating the abatement efficiency of techniques. A more populated boiler type field would have reduced the need for gap-filling installed abatement techniques and therefore reduced the uncertainty regarding costs and efficiency of abatement techniques. Using the boiler type field could have enabled the model algorithm to apply limitations of applicability of specific techniques. For example, the type of SO_2 control, whether in-boiler techniques of sorbent injection are applicable or not.

Commissioning year was used to determine the age of the units and determining the appropriate ELVs. Examples are the turbine and generator type, air pollution control techniques, retirement years and for some cases even the commissioning year of the unit. Given the importance of some of these parameters for the outcome of this study, the control techniques have been gap-filled (see section 2.2.4) as well as the retirement year (for retired units), or expected retirement year (based on inclusion in TNP/LLD or using technical lifetime assumptions). Gap-filling the retirement year was done by visiting the operator website or looking for other available sources online (see below). The missing commissioning years, turbine and generator types have not been gap-filled. For units where the starting year is not available, no estimate could be made on the expected decommissioning year.

4.2.8 Correct identification of LCPD opt outs, and plants in IED LLD / TNP regimes

In the master database, available information has been integrated on plants that have applied for a limited lifetime derogation under the IED, are part of a TNP or opted out of the LCPD. Since some of these lists are provided by Member States independently (e.g. the TNPs) in different formats, it involved a lot of manual linking of the plant names. In some cases, this manual linking proved to be difficult since plant names and/or operators are different compared to the names used in the LCP EI or Platts-WEPP. An additional important issue is that most of the information is typically only available at plant level, and the information on which units are concerned is not always available. If specific units are mentioned, it is sometimes challenging to link them to units in Platts-WEPP since names might be different.

For **LCPD opt outs**, the LCP EI is published listing which LCPs are opted out. However, in some MS, only certain units, not whole plants, are opted out. A separate dataset is provided by EEA on their website, listing the specific units opted out per plant. However, a manual linking between the units in this dataset and Platts-WEPP was found to be ambiguous in some cases, including in some cases some of the units listed as being opted out were found not to be part of the Platts-WEPP database. Best reasonable efforts have been made to try to exclude the units that are truly opted out from the Reference and policy scenarios, but some errors in identifying the right units may remain. It was found that for specific plants, one unit may have been opted out of LCPD, while other units had applied for LLD. In these cases, at plant level there is an opt-out as well as an application for LLD.

The information on **LLDs** and **TNPs** is available in separate files per country, generally at plant level. For some countries the unit level information is included, for others not. For example, for Poland, this is a major issue as there is no information at all on which units are considered. In cases where this information was missing, a best guess estimate was made on which units are concerned based on age of the units, capacity (if some information was available on the amount of capacity for LLD/TNP). Additional uncertainties come from the fact that we have to link these lists per country (all in different formats) to the plant names as we have them, which proved difficult. And then we also have assumed that Unit 1 in such a TNP/LLD document was the same Unit 1 as in the Platts-WEPP. Where possible we have verified this, but it needs to be stressed here that this assignment brings significant uncertainties.

4.3 Parameters affecting the uncertainty of the reference scenario

4.3.1 Projecting the amount of plant capacity that will close or remain open in a MS

Projecting future plant capacity is by its nature highly uncertain. The factors that affect whether LCPs in liberalised markets remain operational are market conditions, which are only to a minor extent affected by environmental legislation such as the IED.

The modelling used in this study does not assess total power demands in each MS nor develop a supply model from the LCPs available. Instead the approach taken has been to match the capacity and fuel consumption projections at MS level of modelling that does consider the wider power market demand/supply drivers. Projections of plant capacity from the PRIMES model outputs and the trends implied in those projections have been matched.

The PRIMES model projection that has been used is the “2013 reference scenario” which accounts for the prevailing climate and energy policies affecting the power sector at that time, and so which should also affect the LCP sector.[18] Whilst the documentation for the PRIMES model outputs mentions that the IED was “included in the reference scenario”, it is not explained what aspects of the IED have been taken into account. Certainly it was not known at the time that the 2013 reference scenario was put together which plants were opting for the TNP or LLD regimes under the IED for example, and hence by extension which plants have to meet the ELVs. It is certainly also the case that the revised LCP BREF was not accounted for. Therefore it has been assumed that compliance with IED limit values at plant level should be imposed on top of the PRIMES projections.

The cost estimates in this study are related principally to two aspects: the rated thermal input (MW_{th}) of the units assumed to make the investment, and the emission level of those units. The approach to capacity projections in this study does not consider emission levels of units when considering which units to project to remain open or to close. Therefore the projection of plant capacity does affect the costs estimates in the study.

4.3.2 Projecting the amount of plant capacity that will be replaced in each MS

The approach taken in this study is to take account of known new plants that are listed in the Platts-WEPP database as being the entire representation of new plants. Given the capacity of these new plants are included within the process of matching PRIMES capacity trends, this means that these new plants may represent plant replacements. However, as the latest plants projected to open in Platts-WEPP database are projected to open by 2020 (not by definition), no further new plant that could potentially open in the 2020s is taken into account. Any further new plant would not add to the capacity, but would otherwise replace old capacity. New plant would be assumed to meet environmental requirements of prevailing policies. Therefore if additional replacement plant capacity into the 2020s were assumed (which is not the case), then costs would fall.

Due to the design of the methodology in using PRIMES to project the capacity and fuel consumption changes in the reference scenario, and due to no further consideration of plant closures or load factor changes as a response to IED compliance, the risk of double counting the effects of the IED is considered to be low.

4.3.3 Projecting which units at plants will close

The selection of which units will close and hence which will remain open in a MS is uncertain. In reality the main factors affecting operators’ decisions will be operational costs, profit margins, and other market conditions, rather than the primarily age-based approach taken. The future emissions and fuel consumption of existing plants has been based on data from the baseline year, although the process to scale to match PRIMES fuel consumption projections should mitigate the issue of selecting plants based on capacity without considering load factor. This uncertainty also has an implication for costs of scenarios as the algorithm for selection of units does not account for emission levels – i.e. implicitly it

[18] As noted in section 2.3.4, there is very little change between the PRIMES version used for this model (2013 Reference Scenario) and the more recently released EC energy modelling (2016 Reference Scenario) in relation to the forecast capacity of coal- and lignite-fired power generation.

assumes that the costs of compliance with scenario limits are small compared with the existing plant operational costs.

4.3.4 Projecting future fuel consumption

The amount of future fuel consumption, and the particular fuel mix, is uncertain. The modelling has taken the fuel consumption and fuel mix of units in the baseline that are projected to remain open, and scaled these collectively within each MS, until the trends in MS total consumption of each of coal, lignite and biomass match the trends in consumption projected by PRIMES and GAINS modelling. The uncertainty in the reality of these fuel consumption amounts, and the fuel type mix, affects the projected total future emissions, as well as affecting some operating costs of compliance techniques. Related to this is the resulting impact on load factor of the fuel consumption scaling, as a different set of plants are assumed to have load factors less than 1500 hours per year in the future scenarios compared to the baseline. This affects which limit values are applied to them.

Early analysis of this parameter indicated that overall results were not sensitive (<4%) to the assumptions made on whether plants' load factors were adjusted to match PRIMES or not.

The PRIMES scenario used in the modelling was the 2013 Reference Scenario. A more recent 2016 Reference Scenario has since been published which assumed (at EU level) similar projections of coal/lignite-fired capacity but higher coal/lignite consumption, implying higher load factors. It has not been assessed if there were significant distributional effects among the Member States. Had the more recent PRIMES scenario been used, then costs would have remained similar, as the cost modelling is largely dependent on capacity, whilst the increased fuel consumption would have led to increased emissions and so larger emission reductions and hence higher benefits.

However, the 2016 Reference Scenario does not include the effects of the 2030 climate and energy framework which corresponds with the most recent developments including the Paris Agreement. The most recent EU climate change commitments could be expected to lead to a further shift away from coal and lignite consumption from the assumptions used in this modelling study. That further shift could be commensurate with higher carbon costs, which – if the current accounting for CO_2 emissions from biomass burning remain – could lead to further replacement of coal/lignite capacity with biomass. This could significantly alter the estimated compliance costs for 2025/2030.

4.3.5 Determining which plants follow the desulphurisation approach

In the LCP EI, MS report on which plants adopted the desulphurisation approach allowed for in the LCPD. The IED retains an option for indigenous solid fuel-fired plants to apply a minimum rate of desulphurisation rather than meeting an ELV – and the modelling assumes that those plants which adopted the approach under LCPD continue to do so under IED. The revised LCP BREF also provides maximum BAT AEL calculated based on the abatement efficiency of the FGD for a LCP with a total rated thermal input of more than 300 MW, which is specifically designed to fire indigenous lignite and which can demonstrate that it cannot achieve the BAT-AELs for techno-economic reasons. In the reference scenario five plants are identified as taking the above mentioned approaches.

Early analysis of this parameter indicated that overall results were not sensitive (<2%) to the assumptions made for these five plants (e.g. switching between a ceiling of 320mg/Nm^3, the upper SO_2 BAT-AEL, and the IED desulphurisation requirement of 96%).

4.4 Parameters affecting the uncertainty of the IED and BAT scenarios

4.4.1 Optimisation methodology

The model algorithm selects the cost-optimal solution among all the units at a plant; the algorithm does not select the cost-optimal solution for the environment or society. The modelling considers first the techniques needed for compliance with SO_2 limits, then considers compliance with NO_X limits, then considers compliance with dust limits (having taken dust co-benefits of SO_2 techniques into account), and then finally considers techniques needed for compliance with Hg limit (taking Hg co-benefits of SO_2, NO_X and dust techniques into account). This order of pollutants means that the plant and its compliance is not considered holistically across all four pollutants. The impacts of pollutants other than SO_2, NO_X, dust and Hg are not taken into account (e.g. HCl).

4.4.2 Techniques available

In general, the options the model assesses as applicable to a unit in the cost-optimisation algorithm is limited (by design) to a specific list of techniques. In reality, a wider range of techniques than considered in this study may be considered and fitted by installation operators to bring their plants into compliance with pollutant limit values and this possibility could lead to lower costs.

Two specific cases of adjusting techniques selected by the model have been tested for sensitivity:

1. No data were identified on which specific PMS for NO_X abatement are in place at each LCP. Therefore the modelling has focussed on secondary abatement techniques. However, it is considered that lignite-fired plants ought to be able to meet the IED ELV for NO_X without secondary abatement techniques. As such sensitivity of the central case results of the IED scenario was undertaken. In the sensitivity analysis, PMS rather than SNCR is assumed.
2. Applicability limitations have been identified in the final draft of the LCP BREF for SNCR applied to large (>700MW_{th}) lignite boilers. As such, in the upper BAT scenario, consideration has been given to how sensitive the results are to switching any modelled uptake of SNCR to SCR for such boilers.

Further information on these two cases is described in section 4.5.1.

4.4.3 Technique costs and abatement efficiencies

The assumptions on costs and reduction percentages of abatement techniques are a general, or central, case. In reality, costs of techniques and their effectiveness will be specific to the plant. Cost data in the study have mainly drawn on TFTEI as a source; this source is recent and detailed.

The costs per tonne abated results shown in section 3.2.4, indicate some unintuitive results. For example, the costs per tonne abated for SCR++ are indicated to be lower than for SCR. This result may be due to some inconsistency in the parametrisation of the techniques and/or larger emission reductions, and could be refined in future modelling.

Whether an abatement technique can be applied on a plant/unit also depends on other characteristics of the plant, such as the available area. Abatement techniques on large power plants can require a lot of space. In particular, the SO_2 techniques (scrubbers) creating gypsum as a 'waste product' need a large space to store the gypsum. Furthermore, the choice to implement a new abatement technique on top of one already in use to meet limit values depends on flue gas characteristics (volume, temperature etc.) after the existing technique.

4.4.4 Economic life of techniques

Capital costs have been annualised in order to present costs on a comparable basis with annual emission impacts. Two variables affect the annualisation: the discount (interest) rate, and the number of years over which the capital costs are assumed to be spread (economic lifetime).

The central results assumed techniques have an economic lifetime of 20 years, and assumed that plant operators would be willing to upgrade existing plant abatement techniques if those techniques had at least 6 years remaining economic lifetime.

The sensitivity of the modelling to the economic lifetime has been carried out. In the sensitivity analysis, the economic lifetime was reduced from 20 years to 15 years, and the threshold of years remaining for operators considering upgrades to existing abatement techniques was reduced from 6 years to 5 years. No change was made to the assumed 4% discount rate used as the public appraisal of private investment. Given these are investments by private firms, a higher rate representing private cost of capital could be more appropriate. It is not possible to anticipate how firms would choose to finance investments in new techniques, i.e. whether costs would be incurred upfront or spread over time.

4.4.5 Monetary valuation of emission reductions

The limitations of the approach for valuing benefits and their implications are listed in Table 39.

Table 39 – Limitations of approach for valuing benefits

Limitation	Implication
Impacts have been estimated only for changes in emissions of air pollutants SO_2, NOx, dust and Hg. There may be additional impacts arising from changes in emissions of other pollutants which have not been captured in this analysis. Additional impacts may be either impacts of the abatement techniques considered for SO_2, NOx, dust, Hg compliance on other pollutants, or may be additional techniques that plant operators would need to take to meet other BATC requirements (e.g. BAT-AELs for other air pollutants or for pollutants in waste water). Other air pollutants relevant for solid fuel fired large combustion plants include carbon monoxide, heavy metals, hydrogen chloride, hydrogen fluoride, unburnt hydrocarbons, non-methane volatile organic compounds, nitrogen monoxide, ammonia, and dioxins.	Estimated benefits are underestimates.
The damage costs do not account for all the health and environmental impacts arising from the pollutant emissions.	Estimated benefits are underestimates.
No account is made of the potential for increased wealth over time leading to possible increases in willingness to pay.	Estimated benefits may be underestimates.
Potential emissions of ammonia (and hence damage) resulting from the use of ammonia (especially in SNCR when a wet abatement system for SOx is not in place) for NOx abatement have not been quantified.	Estimated benefits are overestimates. This is expected to be a small effect, though.
The damage costs are assumed constant for all scenario years. The real (actual) damage costs should change over time as pollutant loads from different sources change in magnitude and location.	There is greater uncertainty in the benefits for later scenario years (2025, 2030) than earlier years (2020).
The damage costs are fixed factors per country, and are not specific to the installations in question. The real (actual) damage costs ought to account for variations in stack parameters (release height, flue gas temperature and flow rate) and location in the country (i.e. to account for different meteorology and proximity to populations).	Estimated benefits are uncertain.

4.5 Sensitivity analysis

4.5.1 List of parameters tested for sensitivity

The parameters that have been subject to sensitivity analysis are below. The list of sensitivity runs are specified in Table 40, indicating the selection for each variable.

A. **Emission concentrations** (uncertainty generated in baseline method of flue gas volume calculation for estimating concentrations from mass emissions).
   - <u>Low</u> = flue gas volumes 10% higher, leading to emission concentrations 9.1% lower than central
   - <u>Central</u>
   - <u>High</u> = flue gas volumes 5% lower, leading to emission concentrations 5.3% higher than central.

B. **Economic lifetime of abatement technique**
   - <u>Central</u>: economic lifetime of 20 years used to annualise capital costs, and upgrades possible with at least 6 years economic lifetime remaining.

- Alternative: shorter lifetime of 15 years used to annualise capital costs, upgrades possible with at least 5 years economic lifetime remaining.

C. Damage costs.

- Low – Valuation of Life years lost (VOLY) approach
- Central (average of VOLY and VSL)
- High – Valuation of statistical life (VSL) approach

D. Choice of abatement techniques (off model)

- Central – no adjustments to model
- Alternative 1 - Restrict lignite-fired plants modelled as selecting SNCR to achieve IED NO_X ELV to instead rely solely on PMS to meet the IED ELV.
- Alternative 2 - Restrict lignite-fired plants > 500MW$_{th}$ modelled as selecting SNCR to achieve upper NO_X BAT-AEL as instead fitting SCR

Table 40 List of sensitivities

Sensitivity	Parameter			
	A	B	C	D
1 (Central)	*Central*	*Central*	*Central*	*Central*
2a (low emission concentration)	**Low**	Central	Central	Central
2b (high emission concentration)	**High**	Central	Central	Central
7 (shorter technique lifetime)	Central	**Alternative**	Central	Central
8a (low damage costs)	Central	Central	**Low**	Central
8b (high damage costs)	Central	Central	**High**	Central
9a (lignite plants use PMS not SNCR to meet IED ELV)	Central	Central	Central	**Alternative 1**
9b (lignite plants >500MW$_{th}$ use SCR not SNCR to meet upper BAT-AEL)	Central	Central	Central	**Alternative 2**

Off-model sensitivity #9 on abatement techniques

For **scenario 9a**, all units which the model had selected SNCR or COMBI3 techniques for compliance with the IED NO_X ELV were identified. For these units, which number 29 in 2025 and are located in Bulgaria, Czech Republic, Hungary, Poland, Romania and Spain, the estimated impact of if these units had only needed PMS to reach the IED NO_X ELV were assessed. As no firm information was available on the existing installed PMS at units in the baseline, it was assumed that further primary techniques could be implemented at the units. The manual off-model adjustment back-calculated the emissions without the SNCR/COMBI3 and removed the costs of these techniques and instead used the abatement efficiency and costs of PMS. Two data sources for PMS were used. The first, Table 17, which is based on TFTEI, as one data source indicates PMS with NO_X abatement efficiency of 39%, with capital costs of €6,070/MW$_{th}$ and operating costs of €178/MW$_{th}$/yr which gives a total annualised cost of €625/MW$_{th}$/yr using the same annualisation assumptions as in the central case. The second source was data in the draft BREF on Flue Gas Recirculation (FGR), which indicated NO_X abatement efficiency of 20%, capital costs of €2,500/MW$_{th}$ and indicated no operating costs, giving total annualised cost of €184/MW$_{th}$.

For **scenario 9b**, all units greater than 500MW$_{th}$ which the model had selected SNCR or COMBI3 techniques for compliance with the upper BAT-AEL were identified. In 2025 this was 21 units located across Bulgaria, Czech Republic, Germany, Hungary, Poland, Romania and Spain, and all of these fitted SNCR not COMBI3. For these units the estimated impact of if these units had used SCR rather than SNCR to reach the upper NO_X BAT-AEL were assessed. The manual off-model adjustment back-calculated the emissions without the SNCR and removed the cost of this technique and instead used the abatement efficiency and costs of SCR+ from Table 16 and Table 17.

4.5.2 Results of sensitivity analysis

The results for sensitivity 9a, which affects the IED scenario, is shown in Table 41. The results for the remaining sensitivities are shown in Table 42 and Figure 37.

Of the parameters assessed for sensitivity, the results show there is uncertainty in the cost estimates due to : the emission concentration calculation, the period over which capital costs are annualised and the assumed possible techniques. These uncertainties could be additive. In addition, although not modelled for sensitivity, there is uncertainty in the unitised technique costs assumed in the model.

The benefits are most affected by the uncertainty in valuation of emission reductions (i.e. in the damage costs), and to a lesser degree the emission concentration calculation. These uncertainties could be additive.

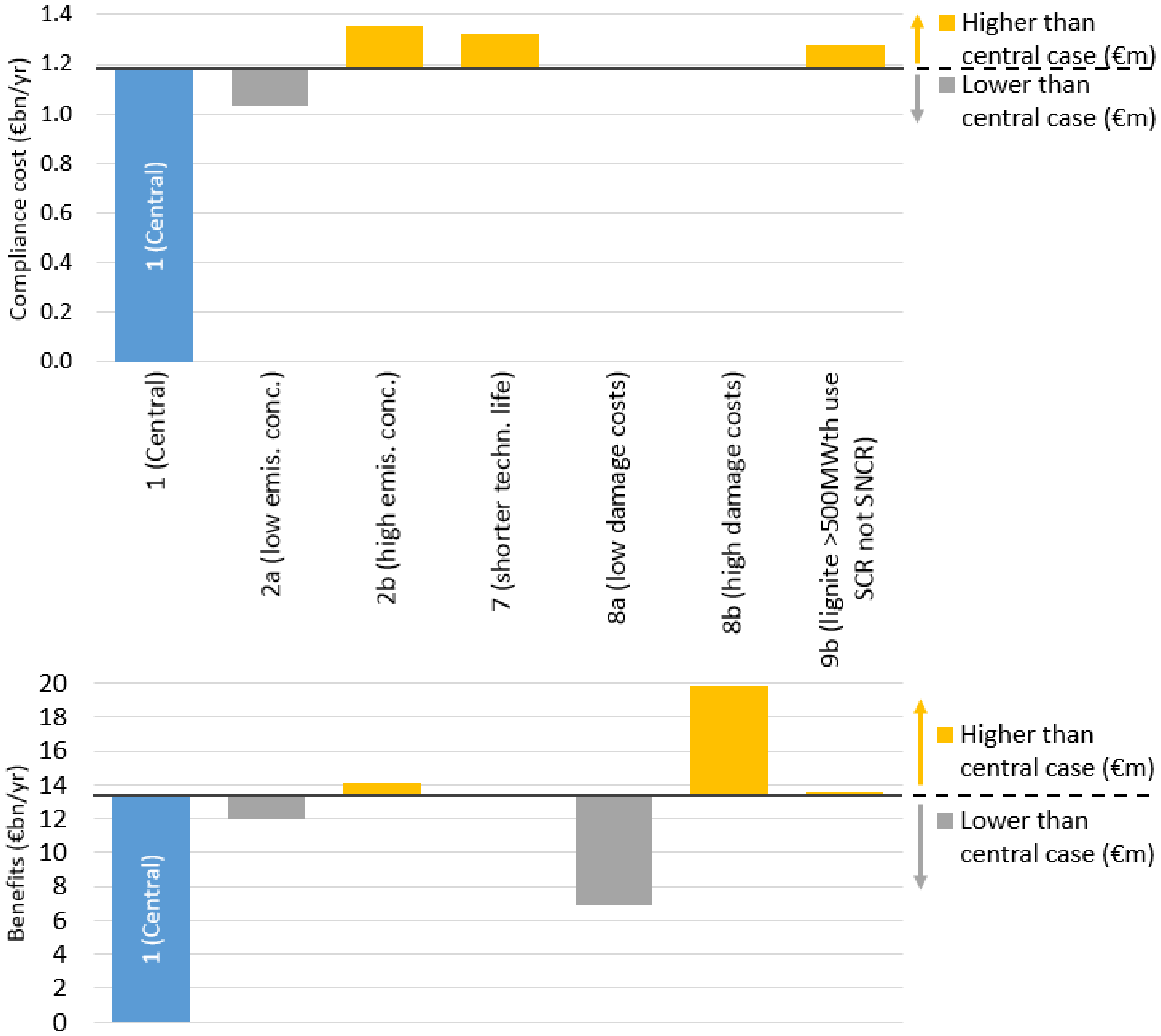
Table 41 Sensitivity analysis of costs and benefits of meeting the IED ELV in 2025 compared to the reference scenario

Sensitivity	Costs (€m/yr)	Costs (% change from Central)	Benefits (€m/yr)	Benefits (% change from Central)
1 (Central)	749	-	9,933	-
9a (lignite plants use PMS not SNCR to meet IED ELV)	715 to 723	-3.4% to -4.5%	9,841 to 9,927	-0.06% to -0.9%

Table 42 Sensitivity analysis of costs and benefits of meeting the upper BAT-AELs in 2025 compared to the reference scenario.

Sensitivity	Costs (€m/yr)	Costs (% change from Central)	Benefits (€m/yr)	Benefits (% change from Central)
1 (Central)	1,179	-	13,363	-
2a (low emission concentration)	1,031	-12%	11,963	-10%
2b (high emission concentration)	1,354	+15%	14,139	+5.8%
7 (shorter technique lifetime)	1,322	+12%	13,372	+0.1%
8a (low damage costs)	1,179	-	6,849	-49%
8b (high damage costs)	1,179	-	19,877	+49%
9b (lignite plants >500MW_{th} use SCR not SNCR to meet upper BAT-AEL)	1,281	+8.6%	13,608	+1.8%

Figure 37 Sensitivity of costs and benefits from the central case for the upper BAT-AEL scenario in 2025



The combined impacts of sensitivities 9a and 9b have also been modelled. Combining the two sensitivities 9a and 9b models from the reference scenario to the IED scenario and then to the upper BAT-AEL scenario. These two sensitivities include many of the same units. For the purposes of combining the sensitivities the mid-point value between the two sources of costs and benefits of PMS has been assumed.

Sensitivity 9a is concerned with the IED scenario and effectively makes an off-model correction from a model-selected SNCR technique to a chosen technique of PMS for compliance with IED ELVs. Assuming that PMS is insufficient to meet the upper-BAT scenario (in sensitivity 9b), then a further technique for all these units is needed. Therefore, the costs of sensitivities 9a and 9b are additive.

Sensitivity 9b makes an off-model correction for model-selected SNCR technique replaced with the manually chosen technique of SCR to meet the upper BAT-AEL from the reference scenario. Accounting for sensitivity 9a yields an estimate of the IED scenario emissions for the affected plants. From the emission levels in this IED scenario sensitivity 9a, the upper BAT scenario in sensitivity 9b can be identified by applying the SCR abatement efficiency. Therefore, the benefits of sensitivities 9a and 9b have been combined by specifying them as increments from the reference scenario to IED scenario and then from the IED scenario to the upper BAT-AEL scenario.

Figure 38 shows the estimated NO_x emissions in 2025 of the IED scenario in both the central case and with sensitivity 9a, and also shows the upper BAT scenario for both the central case and the combined upper BAT sensitivity 9a+9b. The figure illustrates that the gap between the IED scenario and the upper

BAT scenario widens from a marginal benefit of 31kt NO_X in the central case to 54kt NO_X in the combined 9a and 9b sensitivity. There is little difference between the IED scenario and sensitivity 9a due to the similar assumed NO_X abatement efficiencies of primary measures and SNCR.

Figure 39 and Figure 40 show the estimated costs and benefits respectively compared to the reference scenario in 2025 of the IED scenario and upper BAT-AEL scenario for both the central case, sensitivity 9a and the combined sensitivity 9a and 9b. In particular, Figure 39 illustrates the cost reduction in sensitivity 9a – of using primary measures only rather than SNCR – and highlights the increased additional cost of the upper BAT scenario if assuming lignite plants >500MW_{th} require SCR rather than SNCR.

Figure 38 Total EU NO_X emissions in 2025 in the IED scenario and upper BAT-AEL scenario for both the central case and the combined sensitivity 9a and 9b

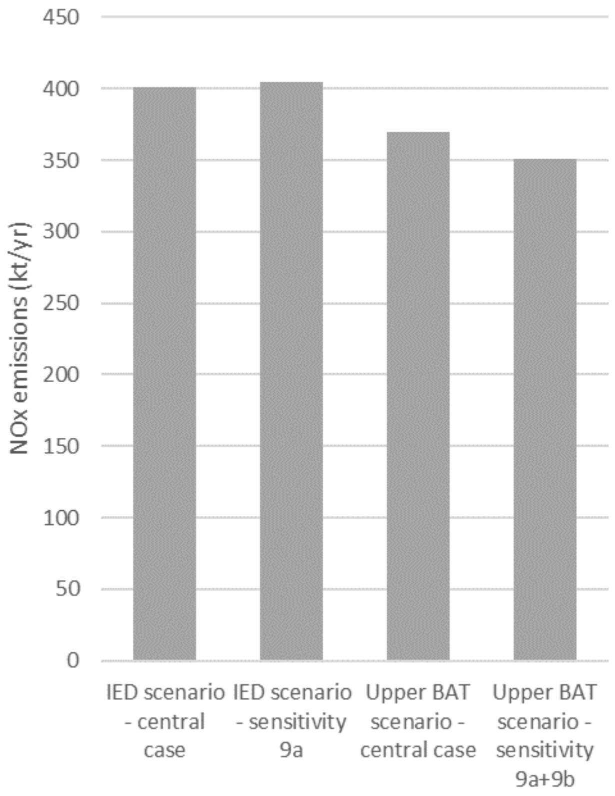


Figure 39 Total EU costs compared to the reference scenario in 2025 of the IED scenario and upper BAT-AEL scenario for both the central case, sensitivity 9a and the combined sensitivity 9a and 9b

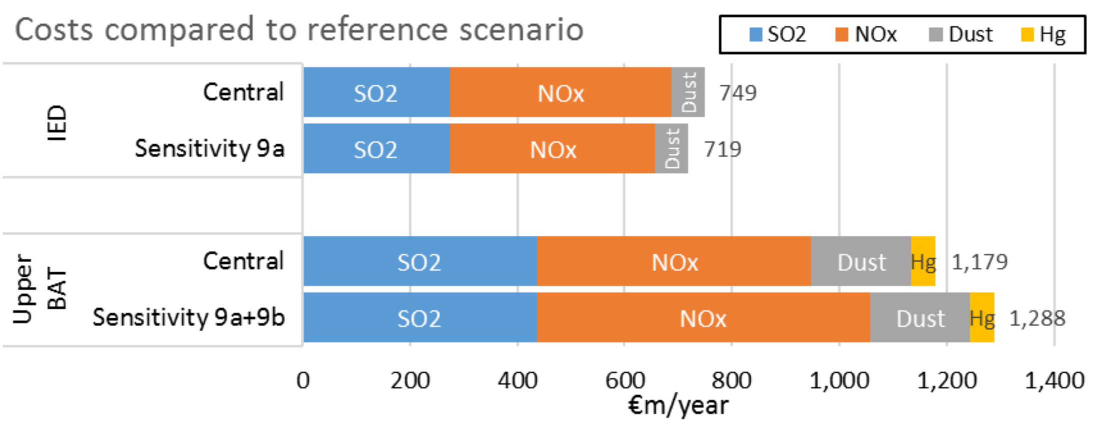
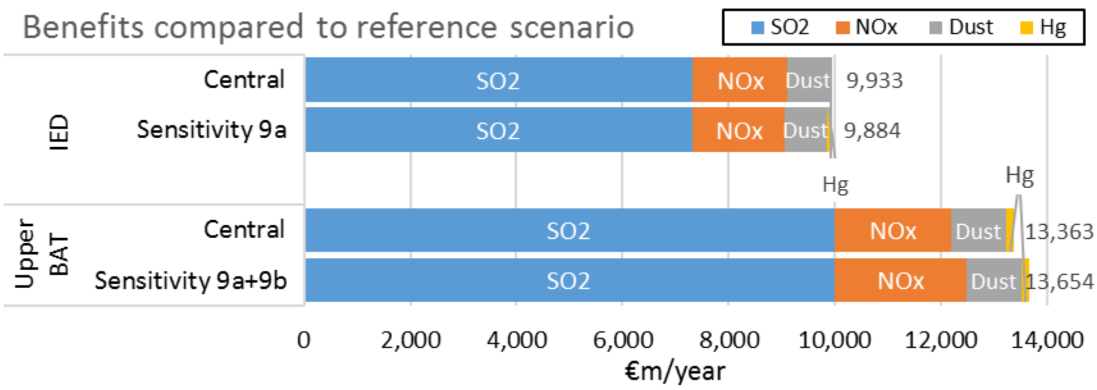


Figure 40 Total EU benefits compared to the reference scenario in 2025 of the IED scenario and upper BAT-AEL scenario for both the central case, sensitivity 9a and the combined sensitivity 9a and 9b



5 Conclusions

5.1 Assessment of the costs and benefits

The results of the assessment show the following:

1. The impacts of legacy policies (closures of LCPD opt outs, expiry of Accession Treaty LCPD derogation) and other transitionary changes (closures of plants in a declining coal industry, including IED LLD plants) without imposition of the IED ELVs is expected to have led to substantial emission reductions by 2020 in the reference scenario: reducing 2013 baseline annual SO_2 emissions by 41%, NOx by 27%, dust by 49% and Hg by 24%. These emission reductions represent monetised benefits of €19bn/year in 2020.

2. The costs of abatement techniques to meet the **IED ELVs** from the reference scenario is estimated to be €1.0bn/yr in 2020 (declining to €0.75bn/yr by 2025 and €0.54bn/yr by 2030), comprising predominantly NO_X and SO_2 compliance costs. The costs are estimated to arise mostly from new, additional or replacement techniques rather than upgrades of techniques. Meeting the IED limit values is estimated to lead to further substantial emission reductions of the sector in scope of this study of around 45% reductions in SO_2, 32% NOx and 49% dust, as well as co-beneficial Hg reductions of 8% compared to a reference scenario in 2020. The estimated benefits of these emission reductions (dominated by the valuation of SO_2 emission reductions) sum to €11.2bn/yr in 2020, declining to €9.9bn/yr in 2025 (i.e. a benefit-cost ratio of around 13:1 in 2025) and declining to €6.8bn/yr in 2030. All Member States in scope of this study (apart from Portugal and Sweden) are estimated to need to fit techniques to meet the IED ELVs. In 2025, for all Member States bar one (France), the benefits of emission reductions due to these investments are estimated to outweigh the costs of the techniques. The estimated costs are shown against the benefits for meeting the IED ELVs in Figure 41.

3. Meeting the **upper BAT-AELs**, as measured beyond the IED ELV scenario, comprises three categories of plants:

    - Plants whose techniques installed to meet the IED ELVs also enables them to meet the upper BAT-AELs. These plants incur no additional technique compliance costs to meet the upper BAT-AELs.
    - Plants that already met the IED ELVs without incurring compliance costs, but which are estimated to need to fit <u>additional</u> techniques to meet the upper BAT-AELs.
    - Plants that are estimated to fit certain techniques to meet the IED ELVs but which are estimated to need to fit <u>different</u> techniques to meet the upper BAT-AELs. Accounting for the full cost of these techniques is an upper bound of the compliance cost impacts of the upper BAT-AEL scenario. These plants may be expected to incur stranded costs due to the short time frame between incurring costs to meet IED ELVs (2016 at the latest except in cases of derogations) and to meet BAT-AELs, for example if the techniques needed to be installed to meet the upper BAT-AELs implies the need to remove the techniques that were needed to meet the IED ELVs. The marginal cost increment of the different techniques above those needed to meet the IED ELVs could be considered a lower bound of the compliance costs.

    Out of 264 plants estimated to be operational in 2025, 136 plants are estimated to need to fit <u>additional</u> techniques to those already fitted to meet the IED ELVs, and in doing so are estimated to incur costs of €0.32bn/yr to reduce one or more of SO_2, NO_X, dust or Hg.

    On top of this €0.32bn, there are a further 53 plants in 2025 estimated to incur €0.11bn/yr more than the costs already incurred in the IED scenario as <u>different</u> techniques are estimated to be needed to meet the upper BAT-AELs. However, for these plants, the full costs of the techniques to meet the upper BAT-AELs would be €0.27bn/yr, i.e. there could be up to €0.16bn/yr of stranded costs. Furthermore, depending on the techniques fitted, the full cost of €0.27bn/yr may not be incurred if there is no need to remove existing abatement equipment. These plants could potentially be candidates for applications for time-limited derogations under IED Article 15(4).

Figure 41 Estimated annual (in 2025) EU compliance costs and benefits of emissions reductions of meeting IED ELVs, upper and lower BAT-AELs from the reference scenario (€bn/yr)

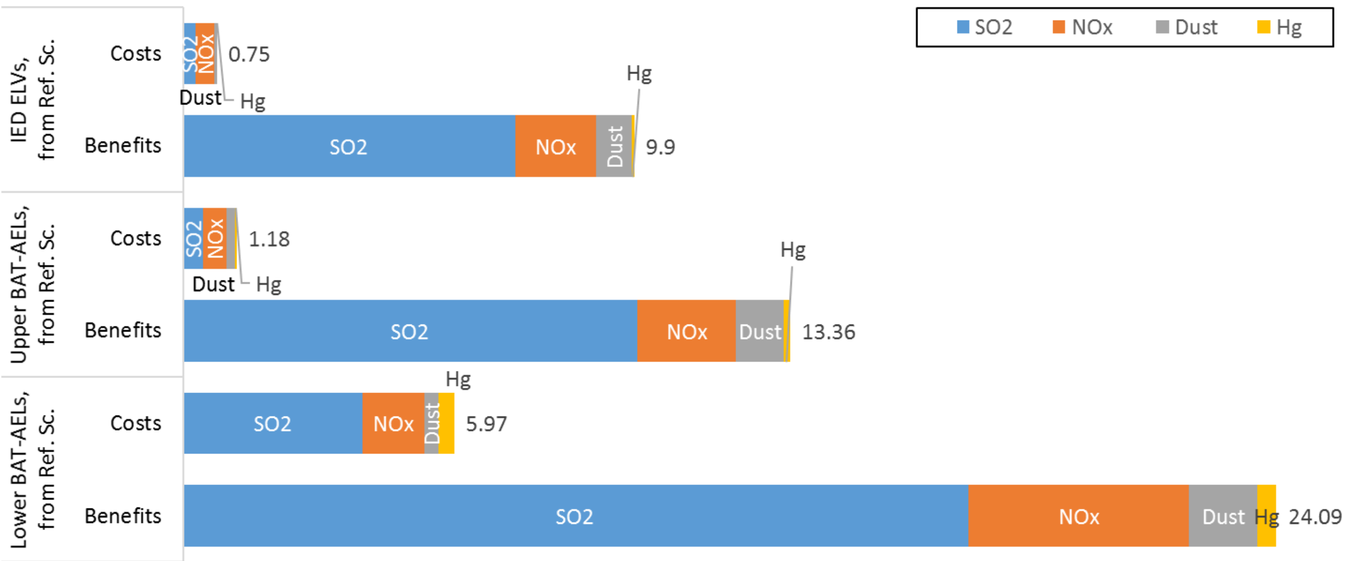
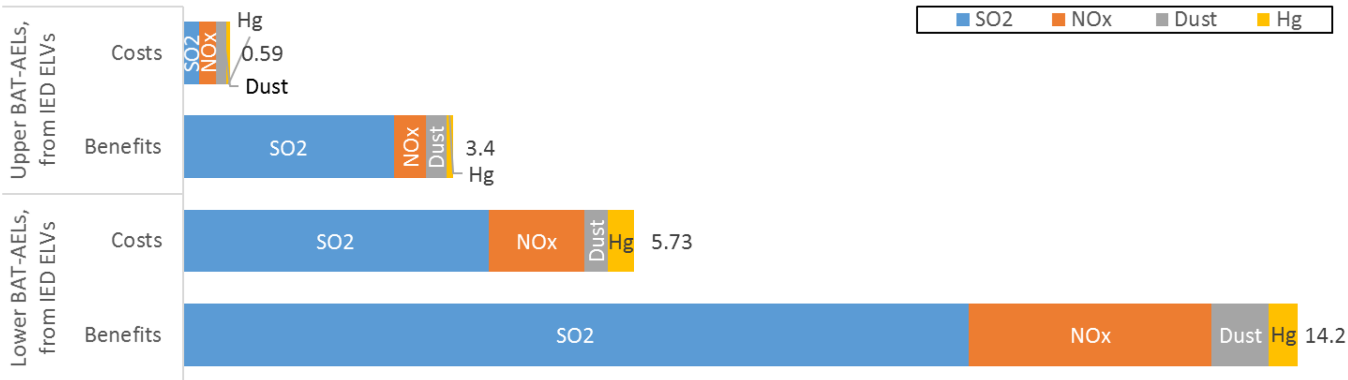


Figure 42 Estimated annual (in 2025) EU compliance costs and benefits of emissions reductions of meeting the upper and lower BAT-AELs from the IED scenario (€bn/yr)



As a best case, the total compliance cost of meeting the upper BAT-AELs taking into account the plants fitting additional techniques and the marginal additional cost of those plants fitting different techniques to the IED is estimated to be €0.55bn/yr in 2020 falling to €0.43bn/yr in 2025 and €0.32bn/yr in 2030. However, the total compliance costs of meeting the upper BAT-AELs, after accounting for the full cost of those plants fitting different techniques to the IED, could be higher at €0.79bn/yr in 2020 falling to €0.59bn/yr in 2025 and €0.41bn/yr in 2030. The higher total costs in 2025 are shown in Figure 42.

The majority of the LCPs in scope of the study are electricity generating plants. The incremental compliance costs of meeting the upper BAT-AELs, when considered as a proportion of estimated Member State average levelised cost of electricity generation, is estimated to vary substantially between Member States. The proportion varies between 0% and 4.1%, depending on the Member State. The upper BAT-AEL compliance costs have been estimated to be smaller than the costs of their CO_2 emissions priced from the EU ETS, typically varying between 2% and 20% of the carbon costs among Member States.

The benefits of the emission reductions of meeting the upper BAT-AELs, estimated based on existing compliance with the IED ELVs, is estimated to be €3.8bn/yr in 2020, declining to €3.4bn/yr in 2025 and to €2.8bn/yr in 2030. As such, the benefits at EU level of reducing emissions to meet the upper BAT-AELs are estimated to outweigh the costs by a factor of more than 5 to 1. In 2025, for all Member States bar one (Ireland), the benefits of emission reductions are estimated to outweigh the costs of the techniques needed to reduce emission levels to upper BAT-AELs. The benefits in 2025 are shown in Figure 42 compared to the IED scenario.

4. Meeting the **lower BAT-AELs** is estimated to lead to large SO_2, NO_X, dust and Hg emission reductions from the Reference and IED scenarios. In particular, SO_2 emissions are reduced substantially. The benefits of the emission reductions of meeting the lower BAT-AELs, compared to compliance with the IED ELVs, is projected to be €15.5bn/yr in 2020, declining to €14.2bn/yr in 2025 and to €10.2bn/yr in 2030. The costs of this scenario are estimated to be much higher than the other scenarios: €5.7bn/yr more than the IED ELV scenario in 2025, and compliance costs dominated by SO_2 technique costs followed by NOx technique costs. The lower BAT-AEL scenario would appear to require high efficiency versions of abatement techniques of wet flue gas scrubbers (WSC), selective catalytic reduction (SCR) and electrostatic precipitators (ESP), as well as dedicated Hg abatement techniques. The total EU benefit-cost ratio of 2.5:1 is lower than for the other scenarios but still with benefits exceeding costs. The benefit-cost ratios vary among the Member States from 4.5:1 for the UK to 0.1:1 (i.e. costs 10 times benefits) for Portugal.

5. Despite the large amount of data available for the LCP sector, the data itself remains a limitation of the modelling. Specifically, although some errors in the source data on emissions were identified and resolved, further errors may persist. In addition, errors may have been inadvertently introduced through incorrect manual linking of datasets covering individual plants and their units. Furthermore, where there were gaps in the data, in-filling techniques were drawn upon, leading to increased uncertainty in the outcomes. For example, of all the pollutants, least information was available on the existing installed NO_X abatement techniques at plants particularly related to the extent and type of primary techniques used for NO_X reduction. This meant that, compared to SO_2 and dust, there is more uncertainty in the model-selected techniques and thus costs for reducing NO_X.

   Estimating future impacts is inherently uncertain. This work is no different; a number of assumptions have been necessary to make in the modelling, and in cases the methodology itself introduces uncertainties. The cost results are most sensitive (-12% to +15%) to the uncertainty in the assumed techniques for compliance, the annualisation of capital costs and the estimation of plant emission concentrations. In addition, the assumed cost of abatement techniques may introduce further uncertainties. The benefits results are most sensitive (-50% to +50%) to the uncertainty in valuing health and environmental impacts, in particular damage costs for SO_2 emissions. However, for the lower BAT-AEL scenario which has the lowest estimated benefit-cost ratio at EU level, even with the most pessimistic assumptions (e.g. benefits lowest valued 50% lower) the benefits are estimated to still outweigh the costs.

   In addition, the forecast reference scenario coal and lignite consumption may be over-estimated as the PRIMES scenario used does not include the effects of the 2030 climate and energy framework which could be expected to lead to a further shift away from coal and lignite consumption from the assumptions used in this modelling study. That further shift could be commensurate with higher carbon costs, which – if the current accounting for CO_2 emissions from biomass burning remain – could lead to further replacement of coal/lignite capacity with biomass. This could significantly alter the estimated compliance costs and benefits, particularly in 2025 and 2030.

   A description of each uncertainty and limitation has been made in the report. A number of the key assumptions have been included in sensitivity analysis in section 4.

5.2 Comparison with other sources

5.2.1 Impact assessment for the Clean Air Policy Package, including NECD

The impacts of the revised NECD were considered in the impact assessment for the Clean Air Policy Package adopted December 2013.[19] The policy options for the post-2020 period considered in the impact assessment included, for the power generation sector, option 6C covering low sulphur coal, stricter NO_X and SO_2 control in medium-sized plants and stricter PM controls in biomass plants, and option 6D that included ‘all technically feasible measures irrespective of cost’ (all options were considered on top of a baseline that assumed full implementation of the IED minimum ELVs for LCPs).

The specific measures for the power sector considered in the NECD impact assessment therefore do not correspond exactly with the upper or lower BAT-AEL scenarios in this study e.g. the modelling in this study did not include low sulphur coal as an option for operators for compliance. No specific quantification of impacts was made in the impact assessment of updated BAT conclusions for LCPs as the review of the LCP BREF was at the time at an early stage of development. Comparison with this study is further limited due to scope differences, even though both this study and the impact assessment rely on PRIMES 2013 Reference Scenario.

The SO_2 and NO_X impacts of the BATC estimated in this study have been compared to the reductions required from reported 2013 emissions data at EU level in Table 43. The comparison separates the impact of the IED from a 2013 baseline (shown to contribute a large proportion of the reductions required to meet 2030 NECD ceilings) from the estimated additional impact of the LCP BATC. The contribution of the LCP BATC to meeting NECD 2030 ceilings is estimated at 3.9% of SO_2 and 0.6% of NO_X for the upper BAT scenario. $PM_{2.5}$ ceilings are not compared because of the difficulty in robustly estimating the $PM_{2.5}$ size fraction from total dust emissions estimated in this study.

Selected costs and benefits from the Clean Air Policy Package impact assessment are extracted in Table 44, with metrics from this study shown alongside.[20]

Table 43 Estimated impact of BATC on SO_2 and NO_X emissions in 2030 compared to reduction commitments under NECD to 2030

	Parameter and units	SO_2	NO_X
EU totals	(A) 2013 reported EU28 emissions (kt)[1]	3,352	8,055
	(B) 2030 EU28 ceiling (kt)[2]	1,619	4,187
	(C) (= A – B) Reduction from 2013 to 2030 ceiling (kt)	1,733	3,868
This study	Reduction from baseline in 2013 to IED scenario 2030		
	kt	990	640
	expressed as a proportion of (C)	57%	17%
	Reduction from IED scenario in 2030 to upper BAT-AEL scenario in 2030		
	kt	67	24
	expressed as a proportion of (C)	3.9%	0.6%
	Reduction from IED scenario in 2030 to lower BAT-AEL scenario in 2030		
	kt	221	183
	expressed as a proportion of (C)	13%	4.7%

[1] EU28 sum of Member State national totals for compliance assessment, year 2013, from EEA NEC data viewer http://www.eea.europa.eu/data-and-maps/data/data-viewers/emissions-nec-directive-viewer

[2] 2030 ceiling calculated from EU28 % reduction commitments in Annex II of Directive (EU) 2016/2284 and 2005 emissions for EU28 reported in IIASA (2015) http://ec.europa.eu/environment/air/pdf/review/TSAP_16a.pdf

[19] http://ec.europa.eu/environment/archives/air/pdf/Impact_assessment_en.pdf

[20] Cost per tonne abated results have not been added to the table because insufficient information is available in the impact assessment, i.e. data are not split by pollutant for both costs and benefits.

Table 44 Selected costs and benefits from the Clean Air Policy Package impact assessment compared to results from this study

Parameter	NECD impact assessment		This study	
	Option 6C compared to the baseline [1]	Option 6D compared to the baseline	Upper BAT-AEL compared to IED scenario	Lower BAT-AEL compared to IED scenario
Compliance costs (€m/yr in 2030)	+€0.44bn for the power generation sector	+€3.7bn for the power generation sector	+€0.41bn	+€4.5bn
Benefit-cost ratio (in 2030; central damage costs)	22 total for all sectors (€94bn benefits, €4.2bn costs)	2.6 total for all sectors (€134bn benefits, €51bn costs)	6.3	2.3

[1] *Baseline includes the effect of the IED.*

5.2.2 IED impact assessment

The IED impact assessment[21] carried out by the Commission and supported by various studies estimated the cost and benefit impacts of a scenario in which ELVs applicable to LCPs covered by the then LCPD would be tightened to be in-line with the (then) LCP BREF upper BAT-AELs. This scenario can be compared to the IED scenario in this study with the following caveats:

- This study covers combustion plants larger than 300MW$_{th}$ fired with biomass, coal and lignite only. The IED impact assessment scenario considered all LCPs of at least 50MW$_{th}$ firing all relevant fuels. Hence the costs and benefits in the IED impact assessment would be expected to be higher than in this study, primarily because of the NO_X compliance costs of gas-fired plants, but also the cost-benefit ratios would be different for smaller plants.
- The values that ended up as the published IED ELVs (and so are taken into account in this study) are not necessarily the same as the values that were assumed in the IED impact assessment due to the subsequent rounds of negotiations and exceptions that were agreed.
- The valuation of benefits – the damage costs – have changed since the IED impact assessment.
- The IED impact assessment is dated 2007, and so is likely to be quoting costs and benefits in 2005 or 2006 prices. The year of pricing data was not identified in the impact assessment. Due to inflation, prices in EUR have increased by around 8% between 2005/6 prices and 2015 prices.
- The IED impact assessment was carried out against an earlier baseline which is expected to have projected greater coal and lignite consumption due to then less ambitious climate and energy policy commitments.
- This study has much clearer certainty than the IED impact assessment on which LCPs adopted each compliance route for the IED, and also the timing of LCPs closures that opted out under Article 4(4) of the LCPD.

The IED impact assessment considered the total benefits in 2020 of the IED for all LCPs to be between €9bn/yr to €30bn/yr. Despite the above caveats, this appears to be consistent with the estimates in this study of €11.2bn/year (2015 prices), which relate to one part of the total LCPs in the EU, albeit a subsector of the very largest plants in the EU. The IED impact assessment considered total costs in 2020 of the IED for all LCPs to be around €2.1bn/yr (for the then upper BAT-AELs). This compares to €1.0bn/yr in this study. The benefit-cost ratio is high in both the IED impact assessment and in this study.

[21] http://ec.europa.eu/environment/archives/air/stationary/ippc/ippc_revision.htm

5.2.3 Greenpeace and European Environmental Bureau study

Greenpeace and EEB (2015) have assessed the possible monetised health and environmental benefits of adopting the proposed lower BAT-AELs (from the April 2015 draft LCP BREF) for coal and lignite power plants rather than the upper BAT-AELs. They quantified this benefit across an EU28 total of 281 coal and lignite plants at around €6.4bn annually. This compares with the additional benefit of the lower BAT-AEL scenario compared to the upper BAT-AEL scenario estimated in this study of €10.7bn/yr in 2020 for a slightly larger number of plants (300 in 2020). The reasons for the differences could include:

- This study quantified the benefits of applying specific techniques, which reduce emission levels to below the lower BAT-AEL (over-compliance), rather than quantifying the benefits just to the lower BAT-AEL which is understood to be the method in the Greenpeace and EEB study.
- This work covers 300 plants open in 2020 compared to 281 in the Greenpeace and EEB study (7% more plants).
- The valuation of damage costs of mercury in this study (€52,129/kg, 2013 prices) is much higher than in the Greenpeace and EEB study (€2,860/kg). The mercury benefits of the lower BAT-AEL scenario in this study were €0.4bn in 2020.

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Appendices

Appendix 1: Baseline database, baseline fiche and scenario outputs

Appendix 2: Baseline: master database user manual

Appendix 3: Unabated emission factors used to estimate abatement techniques in the baseline

Appendix 4: Specific flue gas volumes

Appendix 5: Link between WEPP and BREF abatement technique

Appendix 6: Member State level assumptions used in projecting future capacity and fuel consumption in the Reference scenario

Appendix 7: SO_2, NO_X and PM_{10} Damage costs

Appendix 8: Modelling Results

Appendix 1 – Baseline database, baseline fiche and scenario outputs

Available as separate files.

Note CONFIDENTIAL and subject to license conditions of Platts database.

Appendix 2 – Baseline database user manual

The baseline database consists of 3 main data sources, a number of link tables, parameters and manual inputs. The three main data sources are:

- Platts WEPP dataset, ver. Europe September 2015
- LCP dataset, v.1.1
- E-PRTR dataset, v.8. While the other 2 datasets have been included in their entirety, for the E-PRTR data 2 extracts have been created from the E-PRTR dataset with facility information and emission data only for those facilities included in this study.

The following link tables are included:

- LCP – WEPP: a one-to-many link of the LCP *Unique_Plant_ID* and WEPP *UnitID* for all LCPs that have been selected for this project. Included in this table is an indication of how the plants and units have been linked:
  - N: similarities in the name of plant and unit;
  - O: similarities in the operator of plant and unit;
  - L: similarities in the location of plant and unit;
  - F: similarities in the fuel type of plant and unit;
  - Y: similarities in the starting year of plant and unit;
  - C: corresponding capacities of plant and unit;
  - S: similarities in the status of plant and unit.
- An additional comment field has also been included.
- LCP – E-PRTR: a many-to-one link of the LCP *Unique_Plant_ID* and *MemberState* code, and the E-PRTR *NationalID* and *CountryCode*. Since the E-PRTR NationalID's are not necessarily unique, this double link is required. The link was already included in the LCP dataset, but in some cases the link was corrected when found to be incorrect.
- LCP selection for SR18: a selection of the LCPs that have been selected for this project.
- WEPP – BREF abatement: a link between the abatement technologies as specified in WEPP and the corresponding technologies from the BREF.

The following parameters are included:

- Specific flue gas volume: the specific flue gas volume (in m^3/MJ) per fuel type and turbine type (steam turbine or gas turbine) as calculated with the Rosin and Fehling relationship.
- CO_2 emission factors: fuel specific CO2 emission factors based on the 2006 IPCC guidelines.
- Pollutant (unabated) emission factors: unabated emission factors for SO_2, NOx and dust for the different fuel types and turbine types specified. The emission factors for SO_2 and dust are based on the GAINS no-control emission factors and are country specific. The NOx unabated emission factors are from the EMEP/EEA 2009 guidebook on air pollution emission inventories.
- Abatement efficiencies: typical average abatement efficiencies for several types of NOx, SO_2 and dust abatement techniques.
- Expected technical lifetime: typical technical lifetimes for plants with a certain fuel type. Based on the lifetimes used in a previous project for the EEA.

The (manual) inputs exist of tables with data to improve or complete the data gathered from the 3 main data sources. Furthermore, these table also include data gained through manual analysis of existing sources. These tables typically include the source of improved or gap-filled data for every record. The following input tables are included:

- Abatement technologies: Data on installed SO_2, NOx and dust abatement from WEPP, gap-filled through additional sources (mainly BATIS).
- Decommissioning year: Data on decommissioning year when this could be found in any of the consulted sources (LLD, TNP, WEPP, consultation results EEA project, LCPD opt out).
- LLD ELV: the emission limit values from the limited lifetime derogation when specified.
- TNP and LLD: the status of the plant/unit regarding inclusion in the Transitional National Plan and the LLD.
- Fuel distribution: manually performed distribution of LCP fuel input over the linked WEPP units (which were assumed operational in 2013).
- Fuel specification: manually performed specification of the LCP fuel types based on unit fuel data in the WEPP dataset.
- Data correction: Additional manual corrections to data in the LCP and WEPP datasets (e.g. corrected plant capacities, emissions, and fuel inputs).

The database follows these steps in generating the final results:

1. Combining relevant data from 3 data sources by using the link tables.
2. Overwriting data fields with data fields that were manually corrected (with specification of data source).
3. Importing data on fuel specification and distribution.
4. Using the fuel data to estimate plant operating hours and check the ratio of MWth vs MWe.
5. Estimating decommissioning years based on manually gap-filled data and a calculation using the ear of start of operation and the typical technical lifetime.
6. Estimating thermal capacity (MWth) per unit.
7. Estimating CO_2 emission per plant and unit based on fuel input and CO_2 emission factors.
8. Estimating the abatement efficiency on plant level by calculating unabated emissions (fuel input x unabated emission factors) and comparing these with LCP reported emissions.
9. Gap-filling data on unit installed abatement technologies by assigning certain abatement technologies based on estimated abatement efficiency.
10. Distributing plant emissions over the corresponding units by taking into account the fuel type, capacity and installed abatement of the different units.
11. Estimating the annual flue gas volume per unit based on fuel inputs and specific flue gas volumes.
12. Estimating pollutant concentration in the flue gas based on the reported and distributed emissions and estimated annual flue gas volumes.
13. Selecting the applicable ELV per unit and plant.
14. Selecting the applicable BAT-AEL per unit and plant.
15. Combining all data on both the (LCP) plant level and (WEPP) unit level for export to the excel fiche format. To update the information contained in the fiche, the results of queries Q99a and Q99b need to be hard copied into the Excel file in the sheets “Database_plant_level” and “Database_unit_level”, respectively.

Checks are included in the database to make sure that:

- The distributed emission on the unit level add up to the emissions at plant level.
- The distributed fuel inputs on the unit level add up to the fuel inputs at plant level.
- No relevant WEPP units have been excluded from the dataset.

If it is required to change certain parameters or input data in the database, this can be done directly in the parameter or input tables in the dataset. When data has been changed, all ‘make table’ queries have to be run again in the correct order.

Appendix 3 – Unabated emission factors used to estimate abatement techniques in the baseline

Available as separate file.

Appendix 4 – Specific flue gas volumes

The default specific flue gas volumes are available as separate file. This appendix also includes the plant specific lignite NCVs provided by the Commission and the resulting specific flue gas volumes applied to lignite use in these plants.

Appendix 5 – Link between WEPP and BREF abatement technique

Platts abbreviation	Platts description	Assigned BREF technique
BH	Baghouse (fabric filter)	BF
CSE	Cold side ESP (downstream of air preheater)	ESP
CSE/BH	Cold-side electrostatic precipitator (electrofilter) (ESP)/baghouse (fabric filter)	COMBI1
ESP	Unspecified type of electrostatic precipitator (electrofilter)	ESP
ESP/BH	Unspecified type of electrostatic precipitator (electrofilter) (ESP)/baghouse (fabric filter)	COMBI1
HSE	Hot side ESP (upstream of air preheater)	ESP
MULTI	Multicyclone particulate collector	MULTI
ACFB	Atmospheric circulating fluidized bed boiler, also used to code for SO2CTL for ACFB units	DSC
BFB	Bubbling fluidized bed	DSC
CBFGD	Circulating-bed FGD scrubber	DSC
CFBS	Semi-dry circulating fluidized-bed FGD scrubber (aka Turbosorp)	DSC
DL	Dry lime FGD scrubber	DSC
DRYPAC	Wet/dry lime spray FGD system	DSC
FGD	FGD scrubber (unspecified)	WSC
LMSTIJ	Limestone injection	DSC
NID	Novel integrated desulphurisation scrubber (dry lime)	DSC
PFBC	Pressurized fluidized-bed combustor	DSC
SD	Spray dry lime FGD scrubber	DSC
SEMIDRY	Semi-dry lime FGD or other semidry gas cleaning system	DSC
SORBENT	Dry sorbent injection (typically lime or limestone) for acid gas or mercury control	DSC
SWFGD	Seawater FGD scrubber	WSC
WCAL	Wet calcium carbonate FGD scrubber	WSC
WELL	Wellman-Lord FGD scrubber	WSC
WFGD	Wet FGD (unspecified)	WSC

Platts abbreviation	Platts description	Assigned BREF technique
WL	Wet lime FGD scrubber	WSC
WL/LMS	Wet lime/limestone FGD scrubber	WSC
WLMG	Wet lime/magnesium FGD scrubber	WSC
WLST	Wet limestone FGD scrubber	WSC
BOFA	Boosted overfire air	PMS
DLE	GE dry low-NOX combustor system	PMS
DLNC	Dry low-NOX combustors	PMS
EVB	EV burners (dry low-NOX burners)	PMS
FGR	Flue gas recirculation (particulate and NOX control)	PMS
HYBRID	Hybrid low-NOX burners	PMS
LNB	Low-NOX burners	PMS
LNB/OFA	Low-NOX burners/overfire air	PMS
LNB/SCR	Low-NOX burners/selective catalytic reduction (SCR)	COMBI2
LNB/SCRC	Low NOX burners/selective catalytic reduction (SCR) low dust	COMBI2
LNB/ST	Low-NOX burners/staged combustion	PMS
OFA	Overfire air (NOX control methodology)	PMS
ROFA	Rotating overfire air system for NOx control	PMS
ROFA/RM	Rotating overfire air system and Rotamix SNCR system	COMBI3
SCR	Selective catalytic reduction	SCR
SCR/SN	Selective catalytic reduction (SCR)/selective non-catalytic reduction	COMBI4
SCRC	SCR cold/high dust (after FGD system)	SCR
SCRH	SCR hot/low dust (between economizer and air preheater)	SCR
SNCR	Selective non-catalytic reduction	SNCR
SOFA	Separated overfire air (NOX control method)	PMS
ST/SNR	Staged combustion/SNCR	COMBI3
STAGED	Staged combustion	PMS
STM IJ	Steam injection	STA

Appendix 6 – Member State level assumptions used in projecting future capacity and fuel consumption in the Reference scenario

The tables in this section are referred to in section 2.3.4 of the report.

Note MS without LCPs in the baseline (i.e. not in the scope of this study) are not mentioned

Table 45 Capacity scaling factors calculated from PRIMES net generation capacity of solids-fired thermal power, based to year 2013. The further the factors are from 1, the darker they are shaded (Source: derived from PRIMES – EC, 2013)

Member State	2013	2020	2025	2030
Austria	1	0.99	0.23	0.22
Belgium	1	0.4	0.4	0.4
Bulgaria	1	0.98	0.97	1.2
Croatia	1	0.64	0.64	0.59
Czech Republic	1	0.9	0.7	0.63
Denmark	1	0.71	0.44	0.27
Estonia	1	0.62	0.62	0.62
Finland	1	0.92	0.73	0.73
France	1	0.58	0.4	0
Germany	1	0.95	0.85	0.71
Greece	1	0.94	0.41	0.29
Hungary	1	0.29	0.28	0.28
Ireland	1	0.93	0.9	0.26
Italy	1	0.98	0.8	0.87
Netherlands	1	1.26	1.26	1.17
Poland	1	0.94	0.86	0.77
Portugal	1	1	0.79	0.32
Romania	1	0.95	0.75	0.57
Slovakia	1	0.4	0.39	0.45
Slovenia	1	0.83	0.79	0.79
Spain	1	0.97	0.92	0.86
Sweden	1	1	0.99	0.99
United Kingdom	1	0.33	0.26	0.19
EU28	**1**	**0.84**	**0.72**	**0.62**

Table 46 Hard coal as a proportion of total hard coal and brown coal (lignite, peat) – source: GAINS (scenario WPE_2014_CLE)

Member State	2013	2020	2025	2030
Austria	100%	100%	100%	100%
Belgium	96%	95%	95%	96%
Bulgaria	24%	20%	18%	22%
Croatia	96%	96%	94%	99%
Czech Republic	22%	37%	38%	49%
Denmark	100%	100%	100%	100%
Estonia	3%	2%	2%	3%
Finland	62%	62%	63%	68%
France	100%	100%	100%	100%
Germany	47%	47%	45%	63%
Greece	77%	68%	51%	35%
Hungary	22%	45%	47%	47%
Ireland	74%	77%	76%	64%
Italy	100%	100%	100%	100%
Netherlands	100%	100%	100%	100%
Poland	76%	74%	70%	73%
Portugal	100%	100%	100%	100%
Romania	8%	9%	11%	14%
Slovakia	59%	60%	61%	63%
Slovenia	15%	22%	14%	15%
Spain	100%	100%	100%	100%
Sweden	80%	82%	79%	79%
United Kingdom	100%	100%	100%	100%
EU28	**67%**	**68%**	**66%**	**71%**

Table 47 Fuel consumption scaling factors calculated from PRIMES projections of biomass & waste fired power generation, and PRIMES projections of solids fired fuel consumption split into coal and lignite using GAINS

	Biomass				Coal				Lignite			
Member State	**2013**	**2020**	**2025**	**2030**	**2013**	**2020**	**2025**	**2030**	**2013**	**2020**	**2025**	**2030**
Austria	1	1.01	1.01	1	1	0.32	0.09	0.07	1	0.13	0.05	0.07
Belgium	1	1.07	1.18	1.15	1	0.66	0.66	0.67	1	0.81	0.74	0.65
Bulgaria	1	1.7	1.63	2.17	1	0.74	0.69	0.73	1	0.93	0.99	0.82
Croatia	1	0.94	3.19	5.55	1	0.79	0.45	0.32	1	0.87	0.73	0.09
Czech Republic	1	1.38	1.51	1.66	1	1.26	1.25	1.15	1	0.61	0.58	0.34
Denmark	1	1.18	1.18	1.01	1	0.51	0.26	0.03	N/A			
Estonia	1	0.96	0.95	1.12	1	0.51	0.5	0.46	1	0.74	0.63	0.47
Finland	1	1.21	1.13	1.02	1	0.72	0.7	0.69	1	0.73	0.69	0.52
France	1	1.38	1.59	1.68	1	0.27	0.17	0	1	0.37	0	0
Germany	1	0.97	0.96	1.02	1	0.82	0.71	0.71	1	0.81	0.75	0.36
Greece	1	1.7	1.59	1.54	1	0.7	0.33	0.09	1	1.1	1.04	0.54
Hungary	1	1.24	1.3	1.15	1	0.78	0.8	0.57	1	0.27	0.25	0.18
Ireland	1	1.98	2.17	3.43	1	1.15	0.66	0.1	1	0.93	0.6	0.17
Italy	1	1.24	1.24	1.39	1	1.14	1.06	1.09	1	0.91	0.91	0.86
Netherlands	1	1.14	1.19	1.22	1	1.14	1.12	0.92	1	0.68	0.59	0.56
Poland	1	1.14	1.22	1.44	1	1.01	0.93	0.72	1	1.14	1.23	0.85
Portugal	1	1.3	1.52	1.82	1	0.7	0.07	0.03	N/A			
Romania	1	2.63	4.44	5.29	1	1.02	1.08	1.16	1	0.88	0.74	0.64
Slovakia	1	1.55	1.13	1.84	1	0.87	0.92	0.81	1	0.83	0.84	0.68
Slovenia	1	2.13	2	1.94	1	0.91	0.57	0.54	1	0.56	0.59	0.52
Spain	1	1.6	1.29	1.17	1	1.11	1.18	1.1	N/A			
Sweden	1	1.42	1.36	1.22	1	1.11	1.08	1.06	1	0.96	1.09	1.11
United Kingdom	1	1.17	1.25	1.17	1	0.52	0.41	0.08	1	0.93	0.92	0.51
EU28	**1**	**1.18**	**1.2**	**1.23**	**1**	**0.84**	**0.73**	**0.59**	**1**	**0.83**	**0.79**	**0.48**

Appendix 7 – SO_2, NOx and PM_{10} Damage costs

Table 48 Damage costsused for monetising benefits from reductions in SO_2, NOx and particulate emissions (2015 prices).

Country	SO_2 (EUR/tonne)			NOx (EUR/tonne)			PM_{10} (EUR/tonne)		
	Low	Central	High	Low	Central	High	Low	Central	High
Austria	23,663	47,049	70,436	10,453	19,943	29,432	29,947	59,403	88,859
Belgium	27,203	53,649	80,095	5,000	9,861	14,723	44,826	89,150	133,474
Bulgaria	7,511	15,614	23,717	5,525	10,337	15,149	18,911	41,048	63,184
Croatia	12,461	25,104	37,748	8,191	15,193	22,196	16,697	33,892	51,087
Czech Republic	15,031	29,486	43,941	7,731	14,500	21,269	31,184	60,609	90,034
Denmark	13,497	26,738	39,978	3,723	6,988	10,253	12,569	25,070	37,571
Finland	4,957	9,624	14,290	1,783	3,168	4,552	4,646	9,023	13,401
France	19,116	37,199	55,281	6,578	11,689	16,799	26,391	51,086	75,781
Germany	22,826	46,047	69,268	8,209	15,579	22,950	36,993	76,184	115,375
Greece	4,817	9,435	14,054	1,674	2,729	3,783	14,598	29,538	44,478
Hungary	14,234	28,478	42,722	9,034	16,771	24,509	30,051	61,290	92,528
Ireland	13,259	26,123	38,988	4,499	8,141	11,783	10,525	21,024	31,522
Italy	17,736	36,654	55,572	9,390	18,560	27,730	37,757	79,199	120,640
Lithuania	12,169	23,995	35,821	4,549	8,256	11,963	12,494	24,799	37,104
Netherlands	30,428	60,017	89,606	5,845	11,815	17,785	42,643	81,623	120,603
Poland	14,211	27,343	40,475	6,179	11,422	16,665	32,960	62,357	91,754
Portugal	6,281	12,141	18,001	2,173	3,716	5,259	16,521	32,688	48,856
Romania	12,846	25,352	37,857	9,040	16,779	24,518	27,888	55,034	82,180
Slovakia	12,536	24,386	36,237	8,103	14,850	21,598	25,415	48,792	72,170
Slovenia	18,994	38,246	57,497	10,990	21,144	31,298	26,456	53,039	79,621
Spain	9,055	17,243	25,432	2,699	4,470	6,241	20,794	39,506	58,217
Sweden	6,272	12,431	18,590	2,646	4,732	6,818	5,977	12,060	18,143
United Kingdom	17,370	33,888	50,407	4,284	8,132	11,979	30,019	58,706	87,392

Appendix 8 – Modelling Results

A8.1 Abatement technique uptake per scenario in 2020 and 2030

A8.2 Emissions per Member State per scenario in 2020, 2025 and 2030

A8.3 Monetised benefits from emission reductions per Member State per scenario in 2020 and 2030

A8.4 Compliance costs per Member State per scenario in 2020 and 2030

A8.1 Abatement technique uptake per scenario in 2020 and 2030

Table 49 SO_2 abatement techniques estimated to be taken up in each scenario in 2020 (costs expressed as beyond the reference scenario)

Technique	IED			Upper BAT			Lower BAT		
	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)
replacement / new DSC	24	53	1,346	22	51	1,790	14	25	5,439
replacement / new WSC	149	292	1,280	216	457	1,447	88	297	2,906
replacement / new WSC+	4	34	1,316	10	64	1,945	44	312	7,874
replacement / new WSC++	5	46	5,434	7	74	2,759	342	4,412	8,353
upgrade WSC	37	31	1,037	58	47	1,919	1	0.5	18,718
upgrade WSC+	3	3	2,284	18	14	3,229	0	-	-

Note: the lower BAT scenario includes some model-infeasible SO_2 and NOx cases. In these cases it has been assumed that the same techniques as in the upper BAT scenario are applied.

Table 50 NOx abatement techniques estimated to be taken up in each scenario in 2020 (costs expressed as beyond the reference scenario)

Technique	IED			Upper BAT			Lower BAT		
	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)
replacement / new COMBI2	3	22	797	6	32	1,047	65	290	2,856
replacement / new COMBI3	9	9	802	9	9	802	6	1.3	1,424
replacement / new SCR	58	160	2,663	77	235	2,522	103	403	3,531
replacement / new SCR+	24	81	3,007	29	90	3,106	60	201	4,125
replacement / new SCR++	17	72	1,965	18	62	2,181	126	492	3,070
replacement / new SNCR	103	121	2,422	96	137	2,635	90	161	3,905
upgrade COMBI2	13	0.3	68	18	0.5	86	16	0.9	154
upgrade COMBI3	0	-	-	1	0.4	15,424	0	-	-
upgrade SCR	7	0.5	94	13	0.8	91	9	0.6	112
upgrade SNCR	0	-	-	0	-	-	1	0.7	20,018

Table 51 Dust abatement techniques estimated to be taken up in each scenario in 2020 (costs expressed as beyond the reference scenario)

Technique	IED			Upper BAT			Lower BAT		
	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)
replacement / new ESP	1	3	35,475	3	8	52,737	4	7	40,208
replacement / new ESP+	28	61	13,875	57	156	32,564	42	109	53,002
replacement / new ESP++	6	26	7,717	13	55	8,914	69	306	26,895
Upgrade COMBI I	0			0	-	-	1	0.4	105,170
upgrade ESP	7	2	22,666	6	4	24,796	1	0.2	186,425
upgrade ESP+	10	3	6,676	27	13	17,780	0	-	-
upgrade ESP++	1	0.1	5,175	6	2	13,403	1	0.04	30,879

Note: cost per tonne abated for dust includes the emissions reduced as co-benefit of SO2 techniques.

Table 52 Hg abatement techniques estimated to be taken up in each scenario in 2020 (costs expressed as beyond the reference scenario)

Technique	IED			Upper BAT			Lower BAT		
	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)	Units applied	Costs (€m/yr)	Cost per tonne abated (€/kg)	Units applied	Costs (€m/yr)	Cost per tonne abated (€/kg)
Active carbon injection (ACI)	-	-	-	61	52	32,407	236	263	111,903
Bromide addition to active carbon injection (BACI)	-	-	-	5	2.6	16,971	92	120	33,298

Note: cost per tonne abated for Hg is just in relation to the emissions reduced by the Hg techniques, i.e. excluding the emissions reduced as co-benefit of SO2/NOx/dust techniques.

Table 53 SO_2 abatement techniques estimated to be taken up in each scenario in 2030 (costs expressed as beyond the reference scenario)

Technique	IED			Upper BAT			Lower BAT		
	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)
replacement / new DSC	15	32	2,634	18	33	2,905	13	-1	*
replacement / new WSC	131	98	509	173	132	606	74	133	1,546
replacement / new WSC+	2	10	5,149	11	61	1,676	30	175	4,999
replacement / new WSC++	2	12	3,588	5	24	3,973	247	2,690	8,605
upgrade WSC	6	6	1,864	16	17	2,567	0	-	-
upgrade WSC+	3	3	2,305	16	11	3,406	0	-	-

Note: the lower BAT scenario includes some model-infeasible SO_2 and NOx cases. In these cases it has been assumed that the same techniques as in the upper BAT scenario are applied.

Table 54 NOx abatement techniques estimated to be taken up in each scenario in 2030 (costs expressed as beyond the reference scenario)

Technique	IED			Upper BAT			Lower BAT		
	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)
replacement / new COMBI2	3	21	2,642	4	22	2,651	55	189	2,912
replacement / new COMBI3	4	5	1,577	4	5	1,577	2	0.5	10,051
replacement / new SCR	55	145	2,504	58	165	2,714	78	310	3,912
replacement / new SCR+	13	53	2,648	25	66	2,971	50	153	4,229
replacement / new SCR++	11	21	2,872	14	39	2,294	93	321	3,293
replacement / new SNCR	68	83	2,777	80	117	3,015	71	162	5,708
upgrade COMBI2	10	0.3	125	10	0.3	124	9	0.7	169
upgrade COMBI3	0	-	-	0	-	-	0	-	-
upgrade SCR	0	-	-	0	-	-	3	0.2	194
upgrade SNCR	0	-	-	0	-	-	0	-	-

Table 55 Dust abatement techniques estimated to be taken up in each scenario in 2030 (costs expressed as beyond the reference scenario)

Technique	IED			Upper BAT			Lower BAT		
	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)
replacement / new ESP	1	3	35,475	3	8	52,731	4	7	40,204
replacement / new ESP+	25	38	13,237	48	78	20,409	39	65	34,540
replacement / new ESP++	4	11	3,520	10	36	7,927	54	183	21,464
Upgrade COMBI I	1	0.1	21,780	1	0.1	21,780	0	-	-
upgrade ESP	0	-	-	7	4	22,801	0	-	-
upgrade ESP+	0	-	-	6	4	30,095	0	-	-
upgrade ESP++	0	-	-	2	0.8	7,985	1	0.04	30,879

Note: cost per tonne abated for dust includes the emissions reduced as co-benefit of SO_2 techniques.

Table 56 Hg abatement techniques estimated to be taken up in each scenario in 2030 (costs expressed as beyond the reference scenario)

Technique	IED			Upper BAT			Lower BAT		
	Units applied	Costs (€m/yr)	Cost per tonne abated (€/t)	Units applied	Costs (€m/yr)	Cost per tonne abated (€/kg)	Units applied	Costs (€m/yr)	Cost per tonne abated (€/kg)
Active carbon injection (ACI)	-	-	-	42	35	37,521	173	192	139,309
Bromide addition to active carbon injection (BACI)	-	-	-	3	0.9	45,792	78	102	35,406

Note: cost per tonne abated for Hg is just in relation to the emissions reduced by the Hg techniques, i.e. excluding the emissions reduced as co-benefit of SO_2/NOx/dust techniques.

A8.2 Emissions per Member State per scenario in 2020, 2025 and 2030

Table 57 Annual SO_2, NO_X, dust and Hg emissions in the baseline and reference scenario.

Member State	Baseline (2013)				Reference scenario in 2020				Reference scenario in 2025				Reference scenario in 2030			
	SO_2 (t)	NO_X (t)	Dust (t)	Hg (kg)	SO_2 (t)	NO_X (t)	Dust (t)	Hg (kg)	SO_2 (t)	NO_X (t)	Dust (t)	Hg (kg)	SO2 (t)	NOX (t)	Dust (t)	Hg (kg)
Austria	457	1,805	203	21	150	1,041	108	10	8	644	59	3	8	644	59	3
Belgium	1,139	2,573	80	62	263	1,524	72	33	263	1,524	72	33	263	1,524	72	33
Bulgaria	111,993	32,698	4,303	574	76,754	25,213	2,432	479	81,144	26,596	2,564	507	68,055	23,368	2,229	427
Czech Republic	68,735	51,548	2,876	1,603	33,418	31,868	1,619	989	33,574	30,075	1,555	968	28,746	20,567	1,098	757
Germany	144,648	183,467	4,920	5,630	130,424	142,292	4,558	4,526	123,593	120,677	4,226	4,084	75,556	79,142	2,916	2,524
Denmark	1,401	3,872	506	103	824	1,752	295	67	491	1,170	182	46	126	617	44	25
Spain	106,001	80,810	4,871	609	91,654	81,646	4,731	652	90,412	82,583	4,852	692	86,055	77,595	4,513	646
Finland	9,590	13,979	493	115	7,176	10,480	404	101	7,091	9,855	401	103	7,014	9,735	398	102
France	45,979	32,925	2,820	227	4,633	6,173	125	72	2,583	3,854	104	50	469	770	63	28
Greece	48,216	32,850	12,191	1,086	41,419	27,451	2,717	1,077	5,871	7,655	360	258	5,011	6,128	334	214
Croatia	4,695	3,735	45	35	511	1,362	20	19	287	765	11	11	206	550	8	8
Hungary	7,486	9,198	299	148	1,649	3,086	137	50	1,649	3,124	140	50	1,458	2,988	133	49
Ireland	7,296	5,292	229	28	8,335	5,984	260	30	4,892	3,693	155	25	561	821	9	18
Italy	22,790	24,935	910	159	25,606	28,003	1,039	180	21,455	21,160	868	124	21,882	21,589	884	126
Lithuania	0	0	0	0	97	388	14	14	97	388	14	14	97	388	14	14
Netherlands	8,635	9,026	238	96	9,424	10,451	378	132	9,293	10,350	374	131	7,721	7,709	327	111
Poland	306,219	207,890	14,286	2,867	166,912	163,381	8,308	2,024	153,923	147,997	8,081	1,879	116,769	111,891	5,860	1,400
Portugal	5,540	6,612	88	122	3,868	4,622	61	85	366	456	7	8	138	191	4	3
Romania	153,490	37,159	10,487	395	69,377	26,354	4,261	301	41,435	26,587	3,996	251	34,500	21,984	3,673	245
Sweden	686	1,584	48	34	1,826	2,689	178	73	1,815	2,670	178	72	1,809	2,658	178	72
Slovenia	5,148	8,117	252	17	2,226	3,594	108	35	1,950	2,830	123	57	1,726	2,524	108	51
Slovakia	31,766	4,315	307	75	1,401	3,214	180	63	886	2,572	145	42	745	2,396	136	37
United Kingdom	159,433	186,008	5,869	1,452	57,657	106,515	2,069	768	48,873	95,860	2,021	674	16,408	33,163	969	278
EU	**1,251,342**	**940,398**	**66,316**	**15,459**	**735,606**	**689,083**	**34,077**	**11,780**	**631,955**	**603,087**	**30,489**	**10,083**	**475,322**	**428,943**	**24,029**	**7,172**

Table 58 Annual SO_2, NO_X, dust and Hg emissions in 2020 for each modelled scenario.

	IED scenario emissions				Upper BAT-AEL				Lower BAT-AEL			
	SO_2 (t)	NO_X (t)	Dust (t)	Hg (kg)	SO_2 (t)	NO_X (t)	Dust (t)	Hg (kg)	SO_2 (t)	NO_X (t)	Dust (t)	Hg (kg)
Austria	150	934	56	10	150	719	12	9	32	303	8	5
Belgium	263	1,237	59	33	206	1,237	43	33	62	274	6	7
Bulgaria	28,340	16,974	403	455	23,724	16,255	344	451	19,977	8,612	81	90
Czech Republic	19,916	22,479	1,204	862	15,813	20,409	726	588	1,284	9,576	121	108
Germany	95,118	135,317	3,603	4,463	75,273	126,628	2,700	3,388	5,050	52,979	543	672
Denmark	824	1,551	186	63	784	1,551	186	67	190	1,146	26	24
Spain	34,533	28,226	1,765	428	24,017	26,766	1,042	339	10,334	13,527	324	104
Finland	5,308	6,082	267	89	3,488	5,378	165	81	894	2,726	42	46
France	4,112	5,271	112	71	3,253	4,720	53	59	304	3,833	8	19
Greece	17,889	20,823	1,004	961	12,048	20,823	752	822	784	11,490	75	122
Croatia	511	953	20	19	511	953	20	19	73	392	1	6
Hungary	1,649	2,363	137	50	614	2,363	84	50	112	1,042	24	10
Ireland	1,501	2,525	47	19	1,174	1,761	36	25	126	998	9	7
Italy	16,782	22,486	717	171	13,653	19,018	623	153	622	5,806	70	83
Lithuania	97	194	14	14	58	194	14	14	21	65	2	2
Netherlands	8,903	9,051	378	125	7,732	9,051	344	132	105	3,536	24	64
Poland	103,070	125,272	4,232	1,869	75,203	117,163	3,164	1,541	8,131	53,502	843	643
Portugal	3,868	4,506	61	85	2,390	2,658	49	83	39	1,491	4	23
Romania	19,017	13,462	814	234	17,094	12,969	516	190	10,763	6,581	137	64
Sweden	1,826	2,689	178	73	1,416	2,661	119	73	91	1,101	24	15
Slovenia	2,226	1,945	108	34	1,257	1,742	42	31	22	747	7	12
Slovakia	1,120	3,214	180	63	902	2,746	180	63	215	1,643	110	19
United Kingdom	34,838	38,579	1,995	604	22,176	33,097	850	601	1,506	16,179	205	325
EU	**401,862**	**466,134**	**17,542**	**10,794**	**302,936**	**430,861**	**12,061**	**8,812**	**60,736**	**197,551**	**2,695**	**2,470**

Table 59 Annual SO_2, NO_X, dust and Hg emissions in 2025 for each modelled scenario.

	IED scenario emissions				Upper BAT-AEL				Lower BAT-AEL			
	SO_2 (t)	NO_X (t)	Dust (t)	Hg (kg)	SO_2 (t)	NO_X (t)	Dust (t)	Hg (kg)	SO_2 (t)	NO_X (t)	Dust (t)	Hg (kg)
Austria	8	537	6	3	8	322	6	3	8	107	0	2
Belgium	263	1,237	43	33	206	1,237	35	33	62	274	6	7
Bulgaria	29,317	17,337	383	479	24,732	16,665	292	474	23,469	8,467	71	97
Czech Republic	18,974	21,241	1,093	775	13,815	18,628	667	539	1,115	8,621	99	103
Germany	86,770	116,877	3,045	4,023	68,339	108,307	2,361	2,954	3,930	43,118	470	557
Denmark	491	969	96	46	451	969	96	46	103	620	21	15
Spain	28,965	25,518	1,632	460	20,748	23,301	867	346	6,437	9,989	123	106
Finland	4,656	5,700	221	88	2,839	5,121	134	80	158	1,924	17	46
France	2,583	3,618	95	50	2,298	3,618	62	41	60	3,179	6	12
Greece	5,871	7,655	360	258	4,765	7,655	360	258	111	3,844	32	46
Croatia	287	670	11	11	287	536	11	11	41	220	1	3
Hungary	1,649	2,400	140	50	614	2,400	86	50	112	989	24	10
Ireland	926	1,652	29	18	736	1,202	23	18	92	616	6	6
Italy	14,607	20,249	592	121	12,329	18,264	397	114	591	3,553	60	71
Lithuania	97	194	14	14	58	194	8	14	21	65	2	2
Netherlands	8,779	9,793	374	123	7,223	8,955	326	128	103	2,873	24	64
Poland	96,024	112,996	3,942	1,742	70,261	105,600	2,881	1,445	7,973	47,531	840	596
Portugal	366	442	7	8	366	442	7	8	4	442	0	2
Romania	11,354	12,550	749	205	9,564	12,193	403	184	1,094	5,407	46	55
Sweden	1,815	2,670	178	72	1,404	2,641	116	72	81	1,094	18	16
Slovenia	1,273	2,600	123	57	1,058	1,271	69	54	20	312	8	7
Slovakia	721	2,572	145	42	593	2,297	145	42	189	1,451	104	17
United Kingdom	32,967	31,455	1,627	515	19,897	27,809	842	517	1,129	10,354	176	285
EU	**348,767**	**400,932**	**14,905**	**9,194**	**262,591**	**369,628**	**10,198**	**7,433**	**46,904**	**155,049**	**2,153**	**2,125**

Table 60 Annual SO_2, NO_X, dust and Hg emissions in 2030 for each modelled scenario.

	IED scenario emissions				Upper BAT-AEL				Lower BAT-AEL			
	SO_2 (t)	NO_X (t)	Dust (t)	Hg (kg)	SO_2 (t)	NO_X (t)	Dust (t)	Hg (kg)	SO_2 (t)	NO_X (t)	Dust (t)	Hg (kg)
Austria	8	537	6	3	8	322	6	3	8	107	0	2
Belgium	263	1,237	43	33	206	1,237	35	33	62	274	6	7
Bulgaria	24,531	14,639	350	393	20,548	14,083	276	396	19,462	7,210	59	81
Czech Republic	13,823	14,797	611	690	10,347	13,098	424	366	935	6,887	64	70
Germany	59,128	76,788	2,422	2,466	46,353	70,757	1,908	1,877	2,997	27,702	369	383
Denmark	126	416	28	25	86	416	28	25	41	282	13	9
Spain	27,155	24,072	1,328	418	19,620	21,952	845	321	6,375	9,429	117	99
Finland	4,613	5,646	219	87	2,807	5,074	133	80	157	1,902	17	46
France	469	569	63	28	183	569	31	28	26	159	5	4
Greece	4,113	6,128	334	214	3,006	4,931	274	214	103	2,316	31	42
Croatia	206	482	8	8	206	482	8	8	30	482	0	2
Hungary	1,458	2,284	133	49	550	2,284	81	49	110	1,024	24	10
Ireland	204	611	5	17	204	611	5	17	48	137	1	3
Italy	14,905	20,663	604	123	11,928	18,639	434	116	599	5,092	61	73
Lithuania	97	194	14	14	58	194	8	14	21	65	2	2
Netherlands	7,175	7,565	327	104	5,518	7,565	275	111	88	3,132	20	50
Poland	73,365	89,600	3,126	1,313	55,876	83,151	2,429	1,096	6,362	38,884	703	472
Portugal	138	176	4	3	138	176	4	3	1	176	0	1
Romania	9,074	10,366	521	190	6,928	9,472	293	171	1,482	4,371	23	41
Sweden	1,809	2,658	178	72	1,398	2,603	116	72	80	1,234	18	14
Slovenia	1,726	1,975	108	51	534	1,782	34	47	17	280	7	11
Slovakia	611	2,396	136	37	508	2,174	129	37	182	1,398	103	17
United Kingdom	15,995	16,276	968	263	6,488	14,413	442	263	621	4,557	86	169
EU	**260,992**	**300,073**	**11,538**	**6,602**	**193,499**	**275,982**	**8,220**	**5,347**	**39,808**	**117,101**	**1,727**	**1,609**

A8.3 Monetised benefits from emission reductions per Member State per scenario in 2020 and 2030

Table 61 Benefits of emission reductions from the reference scenario for year 2020, expressed in 2015 EUR (€m per annum). Based on central damage costs.

Member State	IED ELV scenario					Upper BAT-AEL					Lower BAT-AEL				
	SO_2	NOx	Dust	Hg	Total	SO_2	NOx	Dust	Hg	Total	SO_2	NOx	Dust	Hg	Total
Austria	0	-2	-3	0.0	**-5**	0	-6	-5	0.0	**-12**	-6	-15	-6	-0.2	**-26**
Belgium	0	-3	-1	0.0	**-4**	-3	-3	-2	0.0	**-8**	-11	-12	-6	-1.4	**-30**
Bulgaria	-756	-85	-79	-1.3	**-922**	-828	-93	-81	-1.5	**-1,004**	-887	-172	-92	-20.6	**-1,170**
Czech Republic	-398	-136	-24	-1.9	**-560**	-519	-166	-51	-16.5	**-753**	-947	-323	-86	-42.0	**-1,399**
Germany	-1,626	-109	-69	-3.3	**-1,807**	-2,540	-244	-134	-60.4	**-2,978**	-5,773	-1,391	-291	-204.8	**-7,660**
Denmark	0	-1	-3	-0.2	**-4**	-1	-1	-3	0.0	**-5**	-17	-4	-6	-2.3	**-30**
Spain	-985	-239	-111	-11.9	**-1,347**	-1,166	-245	-138	-16.7	**-1,567**	-1,402	-304	-165	-29.1	**-1,901**
Finland	-18	-14	-1	-0.6	**-34**	-35	-16	-2	-1.0	**-55**	-60	-25	-3	-2.9	**-91**
France	-19	-11	-1	-0.2	**-31**	-51	-17	-3	-0.8	**-73**	-161	-27	-6	-3.0	**-197**
Greece	-222	-18	-48	-6.2	**-294**	-277	-18	-55	-13.5	**-364**	-383	-44	-74	-50.7	**-552**
Croatia	0	-6	0	0.0	**-6**	0	-6	0	0.0	**-6**	-11	-15	-1	-0.7	**-27**
Hungary	0	-12	0	0.0	**-12**	-29	-12	-3	0.0	**-45**	-44	-34	-7	-2.1	**-87**
Ireland	-179	-28	-4	-0.6	**-212**	-187	-34	-4	-0.3	**-226**	-214	-41	-5	-1.2	**-261**
Italy	-323	-102	-24	-0.5	**-451**	-438	-167	-31	-1.4	**-638**	-916	-412	-73	-5.2	**-1,406**
Lithuania	0	-2	0	0.0	**-2**	-1	-2	0	0.0	**-3**	-2	-3	0	-0.6	**-5**
Netherlands	-31	-17	0	-0.4	**-48**	-102	-17	-3	0.0	**-121**	-559	-82	-27	-3.6	**-672**
Poland	-1,746	-435	-241	-8.5	**-2,431**	-2,508	-528	-305	-25.9	**-3,366**	-4,342	-1,255	-442	-73.7	**-6,113**
Portugal	0	0	0	0	**-0.4**	-18	-7	0	-0.1	**-26**	-46	-12	-2	-3.3	**-63**
Romania	-1,277	-216	-180	-3.6	**-1,677**	-1,325	-225	-196	-5.9	**-1,752**	-1,486	-332	-216	-12.6	**-2,046**
Sweden	0	0	0	0.0	**0**	-5	0	-1	0.0	**-6**	-22	-8	-2	-3.1	**-34**
Slovenia	0	-35	0	-0.1	**-35**	-37	-39	-3	-0.3	**-80**	-84	-60	-5	-1.2	**-151**
Slovakia	-7	0	0	0.0	**-7**	-12	-7	0	0.0	**-19**	-29	-23	-3	-2.3	**-58**
United Kingdom	-773	-552	-4	-8.7	**-1,339**	-1,202	-597	-68	-8.9	**-1,876**	-1,903	-735	-104	-23.5	**-2,765**
EU	**-8,360**	**-2,024**	**-794**	**-48**	**-11,226**	**-11,286**	**-2,451**	**-1,092**	**-153**	**-14,981**	**-19,305**	**-5,327**	**-1,621**	**-490**	**-26,744**

Table 62 Benefits of emission reductions from the reference scenario for year 2030, expressed in 2015 EUR (€m per annum). Based on central damage costs.

Member State	IED ELV scenario					Upper BAT-AEL					Lower BAT-AEL				
	SO_2	NOx	Dust	Hg	Total	SO_2	NOx	Dust	Hg	Total	SO_2	NOx	Dust	Hg	Total
Austria	0	-2	-3	0.0	**-5**	0	-6	-3	0.0	**-9**	0	-11	-3	-0.1	**-14**
Belgium	0	-3	-2	0.0	**-5**	-3	-3	-3	0.0	**-9**	-11	-12	-6	-1.4	**-30**
Bulgaria	-680	-90	-73	-1.8	**-845**	-742	-96	-76	-1.7	**-916**	-759	-167	-85	-18.4	**-1,029**
Czech Republic	-440	-84	-28	-3.5	**-555**	-543	-108	-39	-20.8	**-710**	-820	-198	-59	-36.5	**-1,114**
Germany	-756	-37	-36	-3.1	**-832**	-1,345	-131	-73	-34.4	**-1,583**	-3,341	-801	-184	-113.8	**-4,441**
Denmark	0	-1	0	0.0	**-2**	-1	-1	0	0.0	**-3**	-2	-2	-1	-0.9	**-6**
Spain	-1,016	-239	-120	-12.1	**-1,387**	-1,146	-249	-138	-17.2	**-1,549**	-1,374	-305	-165	-29.1	**-1,873**
Finland	-23	-13	-2	-0.8	**-38**	-40	-15	-2	-1.2	**-59**	-66	-25	-3	-3.0	**-97**
France	0	-2	0	0.0	**-2**	-11	-2	-2	0.0	**-15**	-16	-7	-3	-1.3	**-28**
Greece	-8	0	0	0.0	**-8**	-19	-3	-2	0.0	**-24**	-46	-10	-9	-9.2	**-74**
Croatia	0	-1	0	0.0	**-1**	0	-1	0	0.0	**-1**	-4	-1	0	-0.3	**-6**
Hungary	0	-12	0	0.0	**-12**	-26	-12	-3	0.0	**-41**	-38	-33	-6	-2.1	**-80**
Ireland	-9	-2	0	-0.1	**-11**	-9	-2	0	-0.1	**-11**	-13	-6	0	-0.8	**-20**
Italy	-256	-17	-21	-0.2	**-294**	-365	-55	-34	-0.5	**-454**	-780	-306	-62	-2.8	**-1,151**
Lithuania	0	-2	0	0.0	**-2**	-1	-2	0	0.0	**-3**	-2	-3	0	-0.6	**-5**
Netherlands	-33	-2	0	-0.4	**-35**	-132	-2	-4	0.0	**-138**	-458	-54	-24	-3.3	**-539**
Poland	-1,187	-255	-162	-4.6	**-1,608**	-1,665	-328	-203	-16.2	**-2,213**	-3,019	-834	-306	-49.3	**-4,208**
Portugal	0	0	0	0.0	**0**	0	0	0	0.0	**0**	-2	0	0	-0.1	**-2**
Romania	-645	-195	-165	-2.9	**-1,007**	-699	-210	-177	-3.9	**-1,090**	-837	-296	-191	-10.8	**-1,334**
Sweden	0	0	0	0.0	**0**	-5	0	-1	0.0	**-6**	-21	-7	-2	-3.1	**-33**
Slovenia	0	-12	0	0.0	**-12**	-46	-16	-4	-0.2	**-65**	-65	-47	-5	-2.1	**-120**
Slovakia	-3	0	0	0.0	**-3**	-6	-3	0	0.0	**-9**	-14	-15	-2	-1.1	**-31**
United Kingdom	-14	-137	0	-0.8	**-152**	-336	-152	-29	-0.8	**-519**	-535	-233	-49	-5.8	**-823**
EU	**-5,070**	**-1,105**	**-612**	**-30**	**-6,817**	**-7,139**	**-1,397**	**-793**	**-97**	**-9,426**	**-12,225**	**-3,373**	**-1,165**	**-296**	**-17,058**

A8.4 Compliance costs per Member State per scenario in 2020 and 2030

Table 63 Total costs for year 2020 beyond the reference scenario (2015 EUR €m/yr).

Member State	IED ELV scenario					Upper BAT-AEL					Lower BAT-AEL				
	SO_2	NOx	Dust	Hg	Total	SO_2	NOx	Dust	Hg	Total	SO_2	NOx	Dust	Hg	Total
Austria	0	0	1	0	**2**	0	1	5	0	**5**	4	3	3	0	**10**
Belgium	0	0	0	0	**0**	0	0	2	0	**2**	6	8	9	2	**25**
Bulgaria	34	18	9	0	**61**	42	20	16	0	**79**	104	52	38	16	**210**
Czech Republic	34	38	2	0	**74**	47	50	30	4	**131**	387	119	23	35	**564**
Germany	28	9	3	0	**41**	78	35	15	33	**161**	1,436	368	10	157	**1,971**
Denmark	0	0	3	0	**3**	0	0	3	0	**3**	27	5	17	7	**56**
Spain	105	125	20	0	**250**	151	131	57	3	**342**	353	178	114	22	**667**
Finland	6	16	3	0	**25**	17	18	3	0	**38**	117	43	11	7	**178**
France	1	5	2	0	**8**	11	6	2	1	**19**	142	12	4	7	**166**
Greece	19	8	6	0	**33**	27	8	8	1	**45**	169	27	7	16	**220**
Croatia	0	1	0	0	**1**	0	1	0	0	**1**	25	4	0	2	**31**
Hungary	0	1	0	0	**1**	0	1	0	0	**1**	6	7	6	2	**21**
Ireland	13	3	0	0	**17**	18	6	0	0	**24**	39	11	0	0	**50**
Italy	16	11	0	0	**27**	23	16	4	0	**43**	292	66	0	2	**361**
Lithuania	0	0	0	0	**0**	0	0	0	0	**0**	1	2	4	1	**8**
Netherlands	1	5	0	0	**6**	5	5	1	0	**10**	208	26	0	9	**242**
Poland	116	107	22	0	**244**	154	140	40	10	**343**	1,037	363	98	53	**1,552**
Portugal	0	0	0	0	**0**	2	1	0	0	**4**	60	14	0	4	**79**
Romania	68	40	22	0	**130**	74	41	35	3	**153**	249	80	59	15	**402**
Sweden	0	0	0	0	**0**	2	0	3	0	**5**	50	15	2	5	**72**
Slovenia	0	5	0	0	**5**	2	6	1	0	**9**	40	14	0	0	**54**
Slovakia	0	0	0	0	**0**	1	0	0	0	**1**	8	13	0	2	**23**
United Kingdom	18	73	0	0	**91**	53	78	15	0	**145**	286	131	19	18	**454**
EU	**460**	**466**	**93**	**0**	**1,019**	**707**	**565**	**238**	**55**	**1,565**	**5,047**	**1,564**	**423**	**383**	**7,417**

Table 64 Total costs for year 2030 beyond the reference scenario (2015 EUR €m/yr).

Member State	IED ELV scenario					Upper BAT-AEL					Lower BAT-AEL				
	SO_2	NOx	Dust	Hg	Total	SO_2	NOx	Dust	Hg	Total	SO_2	NOx	Dust	Hg	Total
Austria	0	0	1	0	**1**	0	1	1	0	**2**	0	1	3	0	**4**
Belgium	0	0	1	0	**1**	0	0	1	0	**2**	3	6	6	2	**16**
Bulgaria	14	21	5	0	**40**	20	23	13	0	**56**	50	55	32	17	**154**
Czech Republic	16	20	7	0	**43**	40	29	24	4	**98**	251	81	13	30	**375**
Germany	12	1	3	0	**16**	20	25	10	21	**75**	885	218	8	122	**1,232**
Denmark	0	0	2	0	**2**	0	0	2	0	**3**	0	2	5	3	**10**
Spain	43	120	11	0	**175**	88	129	26	4	**246**	273	170	75	20	**538**
Finland	4	14	3	0	**22**	10	17	3	0	**30**	94	38	7	6	**145**
France	0	0	0	0	**0**	1	0	0	0	**1**	5	4	2	1	**12**
Greece	1	0	0	0	**1**	3	2	0	0	**5**	41	6	0	6	**53**
Croatia	0	0	0	0	**0**	0	0	0	0	**0**	19	0	0	2	**21**
Hungary	0	1	0	0	**1**	0	1	0	0	**1**	6	8	5	2	**20**
Ireland	3	1	0	0	**4**	3	1	0	0	**4**	11	3	0	0	**14**
Italy	7	1	0	0	**8**	8	5	2	0	**15**	186	33	0	0	**219**
Lithuania	0	0	0	0	**0**	0	0	0	0	**0**	0	2	2	1	**4**
Netherlands	1	4	0	0	**5**	3	4	1	0	**8**	135	18	0	7	**160**
Poland	35	71	8	0	**115**	49	93	22	6	**170**	667	282	51	44	**1,045**
Portugal	0	0	0	0	**0**	0	0	0	0	**0**	17	0	0	2	**20**
Romania	20	25	8	0	**53**	23	27	13	1	**64**	123	53	25	9	**210**
Sweden	0	0	0	0	**0**	1	0	3	0	**4**	41	20	4	5	**69**
Slovenia	0	2	0	0	**2**	4	2	0	0	**6**	23	6	0	2	**32**
Slovakia	0	0	0	0	**0**	1	0	0	0	**1**	3	12	0	2	**18**
United Kingdom	5	47	0	0	**52**	4	56	8	0	**69**	168	123	16	10	**317**
EU	**162**	**329**	**51**	**0**	**542**	**280**	**416**	**131**	**36**	**862**	**3,001**	**1,137**	**255**	**294**	**4,687**

The Gemini Building
Fermi Avenue
Harwell
Didcot
Oxfordshire
OX11 0QR
United Kingdom

t: +44 (0)1235 753000
e: enquiry@ricardo.com

ee.ricardo.com