Decomposition analysis of the changes in GHG emissions in the EU and Member States

Final report

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Final report

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Decomposition analysis of the changes in GHG emissions in the EU and Member States

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<tr>
<td>BAU</td>
<td>Business as Usual</td>
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<tr>
<td>CAP</td>
<td>Common Agricultural Policy</td>
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<tr>
<td>CH₄</td>
<td>Methane</td>
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<tr>
<td>CHP</td>
<td>Combined heat and power</td>
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<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>CO₂-equivalent</td>
<td>Carbon dioxide equivalent</td>
</tr>
<tr>
<td>CRF</td>
<td>Common Reporting Format</td>
</tr>
<tr>
<td>EEA</td>
<td>European Environment Agency</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
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<tr>
<td>ESD</td>
<td>Effort Sharing Decision</td>
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<td>EU</td>
<td>European Union</td>
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<td>EU ETS</td>
<td>European Union Emission Trading System</td>
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<td>F-gases</td>
<td>Fluorinated gases</td>
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<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
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<td>GHG</td>
<td>Greenhouse gas</td>
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<td>IDA</td>
<td>Index Decomposition Analysis</td>
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<td>IEA</td>
<td>International Energy Agency</td>
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<tr>
<td>LCPD</td>
<td>Large Combustion Plant Directive</td>
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<tr>
<td>LMDI</td>
<td>Logarithmic Mean Divisia Index</td>
</tr>
<tr>
<td>MMR</td>
<td>Monitoring Mechanism Regulation</td>
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<tr>
<td>MS</td>
<td>Member States</td>
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<tr>
<td>Mt</td>
<td>Million tonnes</td>
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<tr>
<td>MW</td>
<td>Megawatt</td>
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<tr>
<td>N₂O</td>
<td>Nitrous oxide</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Oxides of nitrogen</td>
</tr>
<tr>
<td>OECD</td>
<td>Organisation for Economic Co-operation and Development</td>
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<tr>
<td>PAM</td>
<td>Policies and measures</td>
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<td>RE</td>
<td>Renewable energy</td>
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<td>RED</td>
<td>Renewable Energy Directive</td>
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<tr>
<td>RES</td>
<td>Renewable energy source</td>
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<tr>
<td>UNFCCC</td>
<td>United Nations Framework Convention on Climate Change</td>
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<td>WIOD</td>
<td>World Input-Output Database</td>
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Executive summary

The European Commission appointed a team comprising ICF International, ZEW, Umweltbundesamt GmbH and Eclareon to examine the causes of changes in greenhouse gas (GHG) emissions in the European Union (EU) during the 1995-2012 period and, specifically, to address the following questions:

- Which were the drivers of the observed changes in GHG emissions during the studied period?
- Which policies had the greatest impact on these drivers and on GHG emissions?
- Of these policies, which were the most cost-effective?

This executive summary presents the research method, results and conclusions together with comments on future research priorities.

Which were the drivers of the observed changes in GHG emissions during the 1995-2012 period?

This question was addressed using two complementary analyses that ‘decomposed’ the changes in greenhouse emissions to identify the relative significance of different drivers. The first built on the methodology applied by a 2014 study for the European Environment Agency. This method provided a detailed sectoral analysis, an examination of the relative significance of different types of renewable energy and the use of specific time frames to reflect the entry into force of specific policies. The second approach involved use of an index decomposition analysis and the World Input-Output Database to analyse a larger number of economic sectors and to investigate the role of structural changes in the economy in the evolution of the EU’s GHG emissions.

The conclusion drawn from the two analyses approaches is the same, i.e. there was a decoupling of economic growth from GHG emissions in the EU during the 1995-2012 period which was mainly driven by technological improvements. GHG emissions did not rise in line with the economic growth experienced during the 1995-2008 period (Figure ES1.1 and Figure ES1.2). After the economic crisis of 2008-9, aggregate economic activity recovered but GHG emissions declined from 2010 to 2012. Both analyses show that the ‘intensity effect’, which is a measure of the overall progress of the GHG intensity of the economy that is triggered by technological improvements, played a key role in the fall in GHG emissions during the study period.

Technological improvements and the deployment of low-carbon technologies were the main determinants behind the emissions reduction which occurred since 1995.

Figure ES1.1 The IDA decomposition analysis of CO₂ emissions for the EU-27 shows how the decline in the intensity effect made a significant contribution to the decoupling of emissions from economic growth

It has sometimes been suggested that the carbon intensity of the EU economy improved due to a shift towards less carbon-intensive economic sectors, e.g. from industry to services, but the study results indicate that this shift has in fact had a limited impact on net emissions. There was a shift in the economy
towards less carbon-intensive sectors within Member States (i.e. within a country structural changes in the economy contribute to decrease emissions). But, at the level of the EU, this effect was offset by a shift of output within the EU towards countries that have a higher emission-intensity (i.e. between-country structural effects).

The fuel-mix effect – which covers the use of renewable energy – was also investigated during the period considered. The analysis confirmed that the increasing use of renewable energy within Europe and the decreased carbon intensity of fossil fuels had the effect of reduced reducing GHG emissions. Nuclear energy production decreased slightly during the studied period and therefore did not contribute to additional emission reduction.

**Figure ES1.2** The EEA decomposition analysis of GHG emissions for the EU-28 confirms the significance of changes in final energy intensity in driving changes in emissions

The decomposition analysis of key economic sectors confirmed the above findings: most sectors experienced output growth and a decline in GHG emissions intensity. Different time periods have been analysed for the various sectors based on availability of data. Results for selected sectors are summarised below:

- **Electricity production**: despite a strong increase in electricity production over the 1990-2012 period, emissions fell as a result of the increasing efficiency of thermal power plants, the increase in the renewable electricity production, including wind, solar and biomass (including biogenic municipal waste) and the use of less carbon intensive fossil fuels (shift from coal to gas) (section 2.1.3.2).

- **Freight transport**: emissions from freight transport increased significantly during the 1995-2008 period. This trend seems to have been reversed during to 2008-2012 period as a result of a decline in GDP, lower tonne-kilometres per GDP, increasing share of biofuels, and a shift from road transport to ships and – to a much lesser extent – rail (section 2.1.3.3).

- **Passenger transport**: during the 1995-2012 period, passenger transport demand increased significantly. However, emissions decreased slightly due to the increasing efficiency of cars and the increase in biofuel use (section 2.1.3.4).

- **Households**: despite an increase in heating demand linked to colder winter temperatures during the study period, emissions fell due to increased energy efficiency of houses, increased use of biofuels and the lower carbon intensity of fossil fuels consumed directly by households (see chapter 2.1.3.6).

- **Iron and steel production**: GHG emissions fell, a change attributed to decreasing steel production and increased use of scrap i.e. recycling of steel (see chapter 2.1.3.5).
Decomposition analysis of the changes in GHG emissions in the EU and Member States

- **Cattle – enteric fermentation**: despite an increase in milk production between 1990 and 2012, emissions decreased considerably due to the increasing milk yield per cow (see chapter 2.1.3.7).

- **Fertiliser use**: GHG emissions from fertilizer use fell due to a strong decline in the amount of fertiliser applied to agricultural land (section 2.1.3.8).

- **Landfilling of municipal solid waste**: the main reasons behind the decreasing GHG emissions from landfills were increased use of other waste treatment (incineration, recycling and composting) and increases in methane recovery from landfills (section 2.1.3.9).

**Which policies had the greatest impact on the drivers behind this decrease in GHG emissions?**

Two approaches were used to answer this question: first, econometric models were developed to assess the mitigation impact of the EU ETS, national policies under the Effort Sharing Decision including energy and transportation taxes and renewable energy policies. Figure ES1.3 illustrates the results of that analysis, showing the emissions expected in the absence of the climate policies included in this analysis. These estimated emissions (represented by the full bars) are compared with the actual emissions (represented in black and dashed black). This summarises the results of the study for the EU-27 as a whole, for the period 1990 to 2012. Figure ES1.3 combines the results of the econometric models applied to estimate the amounts of mitigated CO₂ by policy. It is implicitly assumed that the EU ETS had no effect on the use of renewable energy. In a second stage, the mitigation impact of climate and energy policies and measures within 15 Member States was analysed.

**Figure ES1.3 Overview of the results of the econometric analysis**

The two approaches reached the same conclusions:

- The increased share of **renewable energy** (solar, wind, hydro, biofuel) played an important role in decreasing GHG emissions during the 1995-2012 period. Renewable energy policies both at EU and Member States level played a significant role in that contribution.

- The **EU ETS** also contributed to reductions in total EU emissions during the 2005-2012 period. For Phase 1 (2005-2007) and 2 (2008-2012) together, the estimated abatement is about 7% of the estimated counterfactual baseline scenario emissions covered by the EU ETS. During Phase 2 (2008-2012), the estimated cumulated abatement of the EU ETS was about 1,000 Mt CO₂ equivalent - around 9% of the counterfactual baseline scenario emissions during this period. This estimate is obtained by subtracting actual emissions from projected emissions under a ‘without EU ETS’ scenario.
The econometric analysis also found that national climate and energy policies (excluding renewables policies) made an important contribution to the emission abatement observed recently. According to preliminary estimates it still accounts for less than half of this abatement. These policies, as covered under the Effort Sharing Decision, vary considerably across the EU’s Member States. The more detailed analysis of climate and energy policies showed that a large majority of these national policies and measures are linked to the implementation of EU directives (e.g. Energy Efficiency Directive and Energy Performance of Building Directive). Member States also developed other policies that often took the form of cross-cutting measures such as investment programmes, subsidies or fiscal measures supporting low-carbon development. These commonly targeted GHG emissions from the transport sector.

The qualitative analysis also showed that the implementation of policies not directly targeting climate mitigation objectives, such as the Landfill Directive, the Large Combustion Plant Directive, the Nitrates Directive and other agricultural policies, played a significant role in abating GHG emissions, especially non-\(\text{CO}_2\) emissions.

The results of the econometric analysis and analysis of climate and energy policies and measures support the findings of the decomposition analysis. Indeed, the majority of climate and energy policies and measures identified influenced GHG emissions through the intensity and fuel-mix effect. There was no strong evidence of these policies impacting economic activities.

**Which policies were the most cost-effective at reducing GHG emissions during the 1995-2012 period?**

The response to this question was based on analysis of the (scarce) cost-effectiveness data reported by the Member States pursuant the Mechanism for Monitoring Regulation supplemented by results of two other studies. The question proved very difficult to answer due to the lack of available and comparable data on the costs and benefits of climate and energy policies. The conclusions presented below should therefore be treated with caution and viewed as propositions to be investigated further in future research. The analysis did not take the rebound effect associated with some mitigation policies into account. Noting the caveats above, the conclusions were that:

- Taking a short term view on the cost and benefits of the PAMs, the EU ETS is one of the most cost-effective policies for achieving GHG mitigation objectives. Fuel taxes also appear to be cost-effective, although these were not identified as an important mitigation policy by many stakeholders. The analysis suggests that mandatory inclusion of biofuel into transport fuel had one the highest abatement costs per tonne of \(\text{CO}_2\)-eq of the policies considered.

- Keeping a short term perspective, feed-in tariffs seems to be more cost-effective than direct infrastructure subsidies to support RES. The cost-effectiveness of feed-in tariffs varies greatly across MS depending on their actual design. If a long term “social cost method” is applied to renewable energy investments, these turn to be cost savings as they lead to important benefits.

- The same result appears for PAMs supporting energy efficiency measures. If a long term “social cost method” is applied, these PAMs lead to important cost savings due to the energy savings they generate. However if a short term view is taken there is a high abatement costs per tonne of \(\text{CO}_2\)-eq as they can involve sizeable investment in buildings or industrial plants. Measures targeting energy efficiency within buildings often have multiple purposes, not only supporting GHG mitigation objectives but also having objectives that are not considered in this cost-effectiveness analysis.

**What are the key areas for future research?**

- The Index Decomposition Analysis approach could be further refined if more up to date data were available and if comparable country-specific datasets were available.

- The causal link between the results of the decomposition analyses and specific policies should be studied in more detail.
The econometric analysis applied for the *ex post* evaluation of renewable energy policies and national policies under the Effort Sharing Decision could be refined in order to not just consider the number of policies but also consider their specificities as well as policies with longer term effects such as research and development policies.

Most of the evaluations of mitigation policies and measures are *ex ante* and are very difficult to compare. It would be useful to analyse how to standardise methods for Business as Usual (BAU) assessment, avoiding double counting (i.e. make sure that GHG abated in a particular sector are not attributed to multiple PAMs simultaneously), additionality (e.g. make sure that the mitigation impact attributed to a PAM was actually triggered by this PAM and not by other factors) and ultimately policy impact quantification for national climate policies. This would be particularly valuable for the Monitoring Mechanism Regulation reporting cycles as currently the data reported are difficult to combine and compare. The share of each emitting economic sector (activity) in emission reduction potential is important and this could be assessed upfront.

The qualitative assessment showed a significant impact of ‘other, non-climate’ policies such as the Common Agricultural Policy and Landfill Directive on non-CO₂ GHGs. In the future, it would be useful to identify ways of integrating such policies in the quantitative analysis.

The evidence base on the cost-effectiveness analysis of climate and energy PAMs is very sparse. More studies are needed to define a framework to develop such cost-effectiveness assessment and to apply this framework at the sectoral, national and EU levels.
1 Introduction

This is the final report under contract 340203/2014/691826/SER/CLIMA.A.3 “Decomposition analysis of the changes in greenhouse gas emissions in the EU and Member States”. It was prepared for DG CLIMA of the European Commission by ICF International working in cooperation with ZEW, Umweltbundesamt GmbH and Eclareon.

1.1.1 Objectives

The objective of this study is to assess the main drivers of changes in greenhouse gas (GHG) emissions in the European Union during the 1995-2012 period using decomposition analysis and econometric analysis. The aim of this ex post evaluation of climate policies is to strengthen the understanding of the effects of various policies and other drivers on the changes in GHG emissions, and inform further climate policy developments.

The study builds upon, further develops and extends the analysis carried out by the European Environment Agency (EEA) in its report 'Why did greenhouse gas emissions decrease in the EU between 1990 and 2012?'. It applies two decomposition analysis approaches to identify the main drivers of changes in GHG emissions. The decomposition analyses covers the EU, the individual 28 Member States (MS) and specific economic sectors. Particular attention is given to the evaluation of the impacts of the economic recession which occurred between 2008 and 2012.

For a selection of 15 Member States, the decomposition analysis is complemented by an in-depth assessment of the effects of specific climate and energy policies on changes in GHG emissions.

Finally the emission reduction performance and cost-effectiveness of specific policies in Member States is assessed in order to identify which policies functioned well and which ones performed less well.

1.1.2 Overview of study methodology

This study combines different methodologies and approaches to develop a comprehensive analysis and build findings based on different inputs (Figure 1.1). The study started with a quantitative task (task 2) that combined two different approaches to decomposition analysis to identify the key drivers of the evolution of GHG emissions during the 1995-2012 period. These two complementary approaches, described in detail in Annex 1 and Annex 2, allowed analysis of different sectors and decision-making levels from various perspectives.

The next task (task 3) combined an econometric analysis (task 3B), building on the results of the decomposition analyses, with a survey of national PAMs and consultation with MS representatives (task 3A, 3C, 3D). This informed an analysis of the causal links between specific policies and the different drivers behind changes in GHG emissions.

The final task (task 4) involved analysis of the cost-effectiveness of specific policies and measures (PAMs) and policy groups. This gives an indication of the performance of the selected policy groups and highlights key research needs to develop more comprehensive cost-effectiveness analysis of climate and energy PAMs.

The detailed results of each of the tasks were discussed with the EC and key stakeholders during the project.

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1.1.3 Structure of this report

This report follows the task structure of the study and presents the key results of each stage:

- **Section 2** presents the findings of the two decomposition analyses;
- **Section 3.1** presents the results of the econometric analysis that assessed the impact of the EU Emission Trading System (EU ETS), national policies put in place under the Effort Sharing Decision (ESD) and renewable energy policies;
- **Section 3.2** presents the findings of the survey of national PAMs and a consultation with MS representatives which informed the analysis of key climate and energy PAMs in 15 Member States;
- **Section 4** describes the results of the cost-effectiveness analysis;
- **Section 5** presents a discussion of the study approach and methodologies used. It covers the strengths and limitations of the different approaches together with an assessment of how well they complemented each other and which areas would require more research and analysis in the near future.
Finally, section 6 presents the key conclusions of the study.

Detailed results and background information on the methodologies used in the project are presented in the annexes.
2 Quantitative decomposition analysis of the changes in GHG emissions in the EU and its Member States

2.1 Decomposition approach A: Development of the EEA approach

2.1.1 Objectives

The objective of task 2A was to build upon the decomposition analysis performed by the EEA in 2014. The results of this task also fed into task 3 and 4 of this project, including the country fiches prepared for individual Member States.

2.1.2 Methodology

The methodology applied by the EEA in its 2014 study ‘Why did greenhouse gas emissions decrease in the EU between 1990 and 2012?’ has been used as the basis for the decomposition analysis undertaken in this task. The method has been further enhanced to improve the value of the outputs and better address the questions posed in this project. Key improvements include:

- Conducting sector-specific decomposition analysis for eight sectors to better capture the influence of certain drivers, PAMs or autonomous developments;
- Refining the analysis by disaggregating the drivers (e.g. splitting renewables into different renewable energy sources (RES));
- Setting specific time frames were used for the decomposition analysis of each sector to reflect the entry into force of relevant policies.

The method used and data sources are set out in detail in Annex 1.

2.1.3 Key findings

The results from the following nine decomposition analyses are provided in the sub-sections below:

1. General economy-wide analysis
2. Electricity production
3. Freight transport
4. Passenger transport
5. Iron and steel production
6. Households
7. Cattle – enteric fermentation
8. Fertiliser use
9. Landfilling of municipal solid waste.

For each sectoral decomposition analysis and the general economy-wide analysis, the key results are first presented graphically. An analysis of the key drivers behind the GHG emissions of each sectors then follows.

2.1.3.1 General economy-wide decomposition analysis

The figures below show the results of the decomposition analysis performed for the EU-28.

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2 Ibidem.
3 The decomposition of the cement sector was not possible due to a delay in the submission of the 2015 United Nations Framework Convention on Climate Change (UNFCCC) Common Reporting Format (CRF) data.
Decomposition analysis of the changes in GHG emissions in the EU and Member States

Figure 2.1  Decomposition analysis of GHG emissions for EU-28

Figure 2.2  Decomposition analysis of GHG emissions for EU-28 (broken into 3 time periods)
## Table 2.1 Analysis of key factors

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>Activity:</strong> Population</td>
<td>Population shows a steady increase and therefore pushes emissions higher (<em>ceteris paribus</em>).</td>
<td>Population is a basic driver for emissions. Human activity is linked to energy consumption and carbon dioxide (CO₂) emissions. Therefore, increases in population lead to increases in CO₂ emissions.</td>
</tr>
<tr>
<td>Economic development: GDP per capita</td>
<td>GDP is the most important driver of increasing emissions between 1995 and 2008 (GDP increased by 36%); however between 2008 and 2012 GDP decreased by 1%, contributing to a reduction in emissions.</td>
<td>GDP per capita reflects the economic activity within a country and is an indicator for national wealth. GDP per capita is a driver of CO₂ emissions because economic activity is linked to energy consumption and CO₂ emissions. Therefore, increases in GDP lead to increases in CO₂ emissions. This driver reflects the economic crisis.</td>
</tr>
<tr>
<td>Energy efficiency: Final energy intensity</td>
<td>Final energy intensity is the most important driver of decreasing emissions in both periods. Between 1995 and 2008 GDP increased by 36% and final energy consumption increased by 9%. This means that final energy intensity decreased by 20%. Between 2008 and 2012 GDP decreased by 1% and final energy consumption decreased by 6%. This means that final energy intensity decreased by 5%</td>
<td>The final energy intensity reflects the decoupling of final energy demand and GDP. This driver reflects energy efficiency related legislation such as the Energy Performance of Buildings Directive, Energy Efficiency Directive, Ecodesign Directive, Energy Labelling Directive, etc.</td>
</tr>
<tr>
<td>Energy efficiency: Energy transformation efficiency</td>
<td>Overall this driver did not have a significant impact on emissions in either period.</td>
<td>This driver reflects changes in fuel conversion efficiency (how effectively fuel is transformed into usable energy, in particular in power production). Efficiency improvements result in a decrease of GHG emissions.</td>
</tr>
<tr>
<td>Fuel mix: Non-carbon fuels intensity</td>
<td>The non-carbon fuels intensity (renewables and nuclear power) has a significant influence on decreasing emissions in both periods. In general, the share of nuclear power decreased over the period, so nuclear power production did not contribute to additional emission reductions. All reductions shown in the graphs are due to increases in renewable energies. The share of non-carbon fuels increased from 19% in 1990 to 21% in 2008 and to 24% in 2012.</td>
<td>This driver reflects changes in nuclear power production and consumption of renewable energies. Renewable energy means energy from renewable non-fossil sources (wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases). An increase in non-carbon energy sources results in decreasing GHG emissions. The driver reflects effects of the Renewable Energy Directive (RED).</td>
</tr>
<tr>
<td>Fuel mix: Carbon intensity</td>
<td>Carbon intensity was a factor contributing to lower emissions between 1990 and 2008: the main reason being a switch from coal to gas: whereas coal consumption decreased by 33%, gas consumption increased by 49% (overall fossil fuel</td>
<td>This driver reflects fuel shifts from carbon-intensive fossil fuels (e.g. coal) to gas. The lower the carbon intensity the less CO₂ is emitted per energy consumed.</td>
</tr>
</tbody>
</table>
2.1.3.2 Electricity production

The figure and tables below show the results of the decomposition analysis performed for the EU-28 for electricity production.

**Figure 2.3** Decomposition analysis of CO₂ emissions for electricity production in the EU-28 broken into three time periods.
Table 2.2  Contribution of drivers to total emission change over three time periods (percentage points, pp)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity and heat demand</td>
<td>16.3 pp</td>
<td>19.1 pp</td>
<td>-2.2 pp</td>
</tr>
<tr>
<td>Share of domestic electricity production</td>
<td>0.8 pp</td>
<td>0.8 pp</td>
<td>0.1 pp</td>
</tr>
<tr>
<td>Share of nuclear power</td>
<td>2.3 pp</td>
<td>1.3 pp</td>
<td>1.1 pp</td>
</tr>
<tr>
<td>Share of wind power</td>
<td>-6.0 pp</td>
<td>-3.5 pp</td>
<td>-2.7 pp</td>
</tr>
<tr>
<td>Share of solar power</td>
<td>-2.3 pp</td>
<td>-0.2 pp</td>
<td>-2.1 pp</td>
</tr>
<tr>
<td>Share of hydro and geothermal power</td>
<td>-1.3 pp</td>
<td>-0.2 pp</td>
<td>-1.2 pp</td>
</tr>
<tr>
<td>Share of electricity generation by auto-producers</td>
<td>-1.7 pp</td>
<td>1.4 pp</td>
<td>0.4 pp</td>
</tr>
<tr>
<td>Fuel efficiency</td>
<td>-12.4 pp</td>
<td>-12.2 pp</td>
<td>-0.6 pp</td>
</tr>
<tr>
<td>Share of biomass</td>
<td>-9.1 pp</td>
<td>-5.8 pp</td>
<td>-3.7 pp</td>
</tr>
<tr>
<td>Carbon intensity</td>
<td>-5.1 pp</td>
<td>-8.8 pp</td>
<td>3.6 pp</td>
</tr>
<tr>
<td>Total emission change (percent)</td>
<td>-15.0%</td>
<td>-8.2%</td>
<td>-7.4%</td>
</tr>
</tbody>
</table>

**Note:** This table shows the contribution of a driver to total emission changes in electricity and heat production in percentage points. It does not show the change of the driver itself in percent. The sum of the drivers in this table equals the change in percent of total emissions from electricity and heat production. In the table below the figures refer to the change of the drivers themselves in percent.

Table 2.3  Analysis of drivers – electricity production

<table>
<thead>
<tr>
<th>Driver</th>
<th>Description of trends for time spans (1990-2008/2008-2012)</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Activity:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity and heat demand</td>
<td>Electricity and heat demand is the most important driver of emissions. Between 1990 and 2008 electricity and heat demand increased by 22%, driving emissions upwards. Between 2008 and 2012 electricity and heat demand decreased by 2% thus contributing to decreasing emissions.</td>
<td>This driver covers electricity and heat consumption from all sectors of the economy, as well as households. Electricity and heat demand is closely linked to fossil fuel consumption for electricity and heat production and associated CO₂ emissions. Therefore, ceteris paribus increases in electricity and heat demand lead to increases in CO₂ emissions. This driver also reflects the economic crisis because during economic crises usually less electricity is used.</td>
</tr>
<tr>
<td>Share of domestic electricity production</td>
<td>Almost all electricity and heat consumed in the EU is produced within the EU. The share of domestic electricity and heat production was slightly higher in 2012 (99.5 %) than in 1990 (98.6 %). As there are fluctuations every year no significant trend towards increasing or decreasing emissions can be observed from this driver.</td>
<td>This driver reflects changes in net imports (imports minus exports) of electricity because the national greenhouse gas emission inventories only include emissions from electricity produced within the national territory. Therefore, ceteris paribus increases in the share of domestic electricity production increases CO₂ emissions. This driver reflects differences in electricity prices across countries.</td>
</tr>
<tr>
<td>Driver</td>
<td>Description of trends for time spans (1990-2008/2008-2012)</td>
<td>Background</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Fuel mix:</strong> Share of nuclear in total electricity generation</td>
<td>The share of nuclear power decreased in both periods, putting upward pressure on emissions. The share of nuclear power in total electricity generation decreased from 31% in 1990 to 28% in 2008 and further declined to 27% in 2012.</td>
<td>Electricity generated by nuclear power plants does not cause end-of-pipe GHG emissions. An increasing share of nuclear electricity generation in total electricity generation therefore contributes, <em>ceteris paribus</em>, to GHG emission reductions.</td>
</tr>
<tr>
<td><strong>Fuel mix:</strong> Share of wind in total electricity generation</td>
<td>Increased wind power production contributed to lower emissions in both time periods: the share of wind power in total electricity generation increased from 0.03% in 1990 to 3% in 2008 and further increased to 6% in 2012.</td>
<td>Electricity generated by wind power plants does not cause end-of-pipe GHG emissions. A high share of wind electricity generation in total electricity generation therefore contributes, <em>ceteris paribus</em>, to GHG emission reductions. This driver reflects effects of the RED.</td>
</tr>
<tr>
<td><strong>Fuel mix:</strong> Share of solar power in total electricity generation</td>
<td>Increased solar power production contributed to lower emissions between 2008 and 2012: the share of solar power in total electricity generation increased from 0.2% in 2008 to 2% in 2012.</td>
<td>Electricity generated by solar power plants does not cause end-of-pipe GHG emissions. A high share of wind electricity generation in total electricity generation therefore contributes, <em>ceteris paribus</em>, to GHG emission reductions. This driver reflects effects of the RED.</td>
</tr>
<tr>
<td><strong>Fuel mix:</strong> Share of hydro and geothermal power in total electricity generation</td>
<td>The share of hydro and geothermal power was slightly higher in 2012 (10 %) than in 1990 (9 %). However, as there are significant fluctuations every year depending on weather conditions (e.g. rainfall) no significant trend towards increasing or decreasing emissions can be observed from this driver.</td>
<td>Electricity generated by hydro and geothermal power plants does not cause end-of-pipe GHG emissions. A high share of hydro and geothermal electricity generation in total electricity generation therefore contributes, <em>ceteris paribus</em>, to GHG emission reductions. This driver reflects effects of the RED.</td>
</tr>
<tr>
<td><strong>Activity:</strong> Share of electricity generation by auto-producers</td>
<td>The share of auto-producer plants in total electricity and heat production was slightly lower in 2012 (12 %) than in 1990 (14 %). However, as there are fluctuations every year no clear trend towards increasing or decreasing emissions can be observed from this driver.</td>
<td>This driver reflects changes in the share of auto-producers in total electricity and heat production. The share of auto-producers is relevant because this decomposition analysis only refers to public electricity and heat production. Auto-producer plants are located at industrial sites and generate electricity and/or heat, wholly or partly for their own use. Emissions from auto-producers are allocated to the respective industry. Therefore, <em>ceteris paribus</em> increases in electricity and heat production from auto-producers lead to decreases in CO₂ emissions from public electricity and heat production (but increase emissions in industry).</td>
</tr>
<tr>
<td><strong>Energy efficiency:</strong> Fuel efficiency of public thermal</td>
<td>Fuel efficiency of public electricity production is an important driver towards reducing emissions between 1990-2008: whereas electricity and heat production in</td>
<td>The output of electricity and heat compared to input of fuel to thermal power plants describes their efficiency. A higher input of fuels...</td>
</tr>
</tbody>
</table>
## Decomposition analysis of the changes in GHG emissions in the EU and Member States

<table>
<thead>
<tr>
<th>Driver</th>
<th>Description of trends for time spans (1990-2008/2008-2012)</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>power plants</td>
<td>public thermal power plants increased by 21% fuel input increased by only 7%. The picture changes between 2008 and 2012: both electricity and heat production and fuel input decreased by 7% thus no changes in fuel efficiency.</td>
<td>does not always have to lead to higher emissions, as fuel type, technology and equipment influence fuel efficiency. An increased share of combined heat and power (CHP) leads to a higher heat output with the same amount of fuel input.</td>
</tr>
<tr>
<td><strong>Fuel mix:</strong> Share of biomass for public electricity and heat in thermal power plants</td>
<td>Increased use of biomass contributed to lower emissions in both time periods. The share of biomass use in thermal power stations increased from 1% in 1990 to 7% in 2008 and further increased to 10% in 2012.</td>
<td>Increased use of biomass in public electricity and heat production plants has, <em>ceteris paribus</em>, a decreasing effect on GHG emissions as it replaces - at least partially - the use of fossil fuels. CO₂ emissions resulting from the combustion of biomass are not accounted for in national total CO₂ emissions as they are considered carbon neutral and a renewable resource. This driver reflects effects of the RED.</td>
</tr>
<tr>
<td><strong>Fuel mix:</strong> Carbon intensity of fossil fuels of thermal public electricity and heat production</td>
<td>Carbon intensity of fossil fuels was an important driver contributing to lower emissions between 1990 and 2008. The main reason for declining carbon intensity was a switch from coal to gas. The share of natural gas consumption in thermal power production increased from 12% in 1990 to 32% in 2008 whereas the share of coal declined from 71% in 1990 to 54% in 2008. However, during 2008 and 2012 the carbon intensity increased again due to a switch from gas to coal: the share of natural gas consumption in thermal power stations decreased from 32% in 2008 to 24% in 2012 whereas the share of coal increased from 54% in 2008 to 59% in 2012. The main reason for this is higher gas prices for electricity production.</td>
<td>Each type of fossil fuel has a different emission factor (that for solid fuels being the highest). Shifting from coal to oil and natural gas increasingly reduces emissions.</td>
</tr>
</tbody>
</table>
2.1.3.3 **Freight transport**

The figures below show the results of the decomposition analysis performed for the EU-28 for freight transport.

**Figure 2.4** Decomposition analysis of CO₂ emissions for freight transport in the EU-28

**Figure 2.5** Decomposition analysis of CO₂ emissions for freight transport in the EU-28, broken into three time periods
### Table 2.4 Analysis of drivers – freight transport

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>Activity:</strong> GDP</td>
<td>GDP is the most important driver of emissions between 1995 and 2008. GDP increased by 36% whereas GHG emissions increased by 34%. Between 2008 and 2012 GDP decreased by 1%, contributing to the 3% decrease of emissions.</td>
<td>Economic activity influences the need for freight transport. Declines in freight transport can be due to economic downturn. This driver reflects the economic crisis.</td>
</tr>
<tr>
<td><strong>Activity:</strong> Freight transport intensity (land, waterways, pipelines) per GDP</td>
<td>During 1995-2008 freight transport demand increased at the same pace as GDP (+36%) whereas between 2008 and 2012 freight transport declined much more rapidly (-15%) than GDP (-1%). Thus the driver freight transport intensity contributed to declining emissions during 2008-2012.</td>
<td>Freight transport intensity is defined as the amount of goods transported (in terms of tonne/km) per unit of GDP. It includes freight transported on road, rail, inland waterways and pipelines. This driver reflects the demand for freight transportation and often correlates with economic growth. It shows if freight transport decouples from economic growth.</td>
</tr>
<tr>
<td><strong>Modal split:</strong> Share of road transport in total freight transport</td>
<td>The share of road transport in total freight transport increased from 67% in 1995 to 73% in 2008, thus pushing emissions higher. In contrast, during 2008-2012 the share of road transport declined slightly from 73% in 2008 to 71% in 2012, contributing to the decreases of emissions in that period.</td>
<td>This measures the road freight transport as compared to total freight transport (road, rail, inland waterways and pipelines). Operators’ modal choice and the efficacy of policies encouraging a shift to less carbon-intensive transport modes are reflected here.</td>
</tr>
<tr>
<td><strong>Energy efficiency:</strong> Fuel intensity of road freight transport</td>
<td>Fuel intensity decreased by 6% between 1995 and 2008, contributing to lower emissions. Between 2008 and 2012 fuel intensity increased by 10% and was a large driver of higher emissions. Between 2008 and 2012 freight transport on road decreased by 11% whereas fuel consumption of trucks decreased by 1% only. The 2008-2012 analysis of this driver is very likely a statistical artefact because the PRIMES model was used for the split of road fuels into trucks and cars. As the model did not include the economic crisis the analysis of this driver (the problems relate only to this driver) between 2008 and 2012 are hampered.</td>
<td>Fuel intensity is expressed as the fuel consumption per km driven by trucks. A decrease in intensity (= increasing efficiency) suggests that technical improvement and/or increasing load factors reduced the fuel consumption per km.</td>
</tr>
<tr>
<td><strong>Fuel mix:</strong> Share of biofuels in road freight transport</td>
<td>Increased use of biofuels contributed to lower emissions in both time periods. The share of biofuels in road freight transport increased from almost 0% in 1995 to 3% in 2008 and to 5% in 2012.</td>
<td>This driver is biofuel consumption as a fraction of total fuel consumption (mostly gasoline and diesel). Use of biofuels displaces fossil fuels and thereby, ceteris paribus, reduces emissions. This driver reflects effects of the RED.</td>
</tr>
<tr>
<td><strong>Fuel mix:</strong> Carbon intensity of fossil fuels by road freight transport</td>
<td>Carbon intensity did not change significantly because no fossil fuel shifts took place for trucks.</td>
<td>Carbon intensity is the amount of CO₂ emitted per unit of fossil fuel consumed by trucks. Trucks are fuelled almost entirely by diesel.</td>
</tr>
</tbody>
</table>

**Note:** As no the 2015 CRF data were delayed they could not be integrated in the analysis and old CRF data were used in combination with fuel shares of trucks from PRIMES 2009.
2.1.3.4 Passenger transport

The figures below show the results of the decomposition analysis performed for the EU-28 for passenger transport.

Figure 2.6 Decomposition analysis of CO₂ emissions for passenger transport in the EU-28

Figure 2.7 Decomposition analysis of CO₂ emissions for passenger transport in the EU-28, broken into three time periods
Table 2.5  Analysis of drivers – passenger transport

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Activity: Passenger land transport demand</td>
<td>During 1995-2008 passenger transport demand increased by 18%, pushing emissions upwards. Between 2008 and 2012 passenger transport declined by 2% and contributed to the 10% decrease in emissions.</td>
<td>This indicator includes passenger kilometres travelled in public road transport, private cars and rail. It does not include aviation and inland navigation. Ceteris paribus increased passenger transport leads to increases in CO₂ emissions from passenger cars. The driver itself is influenced by income levels and oil prices.</td>
</tr>
<tr>
<td>Modal split: Share of road transport in total passenger transport</td>
<td>The share of road transport in total passenger transport did not change significantly in either of the two periods.</td>
<td>The share of road transport represents the share of passenger transport on road (public road transport and private cars) compared to all transport modes on land (road and rail). The effectiveness of policies aiming at encouraging the shift to less carbon-intensive transport modes is reflected here.</td>
</tr>
<tr>
<td>Modal split: Share of passenger cars in total road transport</td>
<td>During 1995-2008 the share of passenger cars in road transport increased slightly from 88.7% in 1995 to 89.5% in 2008 thus contributing to raising emissions. Between 2008 and 2012 there was hardly any change in the modal split of road transport.</td>
<td>The share of passenger cars reflects the passenger km driven by passenger cars compared to total road transport (coaches, buses and passenger cars). An increasing share often correlates with income growth.</td>
</tr>
<tr>
<td>Energy efficiency: Fuel intensity of road passenger cars</td>
<td>Fuel intensity of road passenger cars (i.e. fuel consumption per passenger kilometre in cars) was the most important driver towards lower emissions. During 1995-2008 the fuel intensity declined by 6% and during 2008-2012 it decreased 7%. The 2008-2012 analysis of this driver is hampered because the PRIMES model was used for the split of road fuels into trucks and cars. The model does not include the economic crisis (the problems relate only to this driver).</td>
<td>The fuel intensity of transport is expressed as fuel consumption per km driven by passenger cars. A decrease in intensity can be explained by improvements in motor efficiency, different driving behaviour, use of smaller cars or a shift from gasoline-driven cars to more efficient diesel-driven cars of the same size. All these factors can reduce the fuel consumption per km and hence also CO₂ emissions. The fuel intensity is also sensitive to occupancy rate of cars. Higher rates result in fewer vehicle-kilometres being needed to transport the same number of passengers and consequently less fuel is used for that transport. This driver reflects effects of the CO₂ and cars regulation.</td>
</tr>
<tr>
<td>Fuel mix: Share of biofuels in passenger cars</td>
<td>Increased use of biofuels contributed to lower emissions in both time periods. Biofuels’ share in road passenger transport increased from almost 0% in 1995 to 3% in 2008 and to 5% in 2012.</td>
<td>The share of biofuels in private cars reflects the share of biofuel use in total fuel consumption of private cars (mostly gasoline and diesel). This driver reflects the effects of the RED.</td>
</tr>
<tr>
<td>Fuel intensity of fossil fuels by passenger cars</td>
<td>Carbon intensity did not change significantly.</td>
<td>Carbon intensity is defined as the amount of CO₂ emitted per unit of fossil fuel consumed by private cars and is mainly dependent on the type of fossil fuel used (gasoline has a lower CO₂ emission factor than diesel).</td>
</tr>
</tbody>
</table>

Note: As no new CRF is available the old CRF was used in combination with fuel shares of trucks from PRIMES 2009. The use of the new CRF may significantly change the analysis.
2.1.3.5 Iron and steel production

The figures below show the results of the decomposition analysis performed for the EU-28 for the iron and steel sector.

Figure 2.8 Decomposition analysis of CO$_2$ emissions for the iron and steel sector in the EU-28

Figure 2.9 Decomposition analysis of CO$_2$ emissions for iron and steel in the EU-28, broken into three time periods
## Table 2.6 Analysis of drivers – iron and steel production

<table>
<thead>
<tr>
<th>Driver</th>
<th>Description of trends for time spans (1990-2008/2008-2012)</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Activity:</strong> Steel production</td>
<td>In 2008 steel production was at the same level as in 1990 so this driver did not force emissions higher or lower during this period. However, between 2008 and 2012 it was by far the most important driver towards decreasing emissions: steel production decreased by 16% whereas emissions declined by 19%.</td>
<td>Steel production is closely linked to energy consumption and CO₂ emissions from iron and steel production. <em>Ceteris paribus</em> increases in steel production lead to increases in CO₂ emissions from iron and steel production. This driver reflects the economic crisis.</td>
</tr>
<tr>
<td><strong>Activity:</strong> Blast furnace iron production</td>
<td>Between 1990 and 2008 blast furnace iron production decreased by 16% (steel production in 2008 was at the same level as in 1990). This contributed to declining emissions. The main reason for the decoupling is increased use of scrap / increased steel production in electric arc furnaces. Between 2008 and 2012 blast furnace iron production declined at a similar pace to steel production. Therefore no push towards high or lower emissions is visible from this driver.</td>
<td>The share of blast furnace iron production in steel production reflects changes in the use of scrap for steel production. A decoupling of steel production from blast furnace iron production indicates increased use of scrap i.e. recycling of steel.</td>
</tr>
<tr>
<td><strong>Energy efficiency:</strong> Energy intensity</td>
<td>A fall in the energy intensity of production was an important driver towards lower emissions between 1990 and 2008. Energy consumption decreased by 28% whereas blast furnace iron production decreased by 16% only. Between 2008 and 2012 energy consumption decreased less rapidly (-13%) than blast furnace iron production (-16%). This means that energy intensity was a driver towards increasing emissions in recent years.</td>
<td>Energy intensity is defined as energy consumption per unit of blast furnace iron produced and reflects efficiency improvements in the production of blast furnace iron.</td>
</tr>
<tr>
<td><strong>Fuel mix:</strong> Fuel intensity</td>
<td>Fuel intensity decreased between 1990 and 2008 by 7%; this reflects the increased use of electricity for steel production during this time period. The fuel intensity did not change in the period 2008-2012.</td>
<td>Fuel intensity is defined as the share of combustible fuels in total energy consumption. Changes in fuel intensity mainly reflect changes in electricity consumed in iron and steel production. It describes the share of public electricity used in iron and steel production. The emissions resulting from the production of public electricity are not accounted for in the iron and steel sector. Therefore, an increase in this driver results in lower emissions from this sector (but it can also result in increasing emissions in the electricity generation sector).</td>
</tr>
<tr>
<td><strong>Fuel mix:</strong> Carbon intensity of fossil fuels</td>
<td>Carbon intensity increased between 1990 and 2008, contributing towards higher emissions. During 2008-2012 carbon intensity decreased and contributed to lower emissions.</td>
<td>The emissions resulting from the combustion of fossil fuels depend on the type of fossil fuel used. A switch to less-carbon-intensive fossil fuels can be monitored.</td>
</tr>
</tbody>
</table>

*Note: This decomposition analysis is the most uncertain one because the emission calculation for iron and steel is very complex and Member States use different methods for calculating emissions. As the energy use is not reported in the CRF, energy consumption was calculated based on Eurostat data.*
2.1.3.6 Households

The figures below show the results of the decomposition analysis performed for the EU-28 for households.

**Figure 2.10** Decomposition analysis of CO₂ emissions for households in the EU-28

**Figure 2.11** Decomposition analysis of CO₂ emissions for households in the EU-28, broken into three time periods
Table 2.7 Analysis of drivers - households

<table>
<thead>
<tr>
<th>Driver</th>
<th>Description of trends for time spans (1990-2008/2008-2012)</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Activity:</strong> Population</td>
<td>Population shows a steady increase and therefore pushes emissions higher.</td>
<td>Population is a basic driver for emissions from households as all people need homes. Therefore, ceteris paribus increases in population lead to increases in CO2 emissions from households.</td>
</tr>
<tr>
<td><strong>Activity:</strong> Household numbers per capita</td>
<td>The household numbers per capita also show a steady increase and therefore pushes towards higher emissions.</td>
<td>The household numbers increase more rapidly than population. This also reflects the fact that people use more space and the number of people per household is decreasing. Therefore, increasing household numbers is – ceteris paribus – a driver towards higher emissions.</td>
</tr>
<tr>
<td><strong>Energy efficiency:</strong> Energy use per household</td>
<td>Energy use per household is the largest driver towards decreasing emissions. Temperature-corrected energy consumption per household fell in both periods (-12% between 1990 and 2008; -9% between 2008 and 2012).</td>
<td>The energy use per households includes energy used for all purposes - heating, warm water, cooking, electric appliances, etc. Changes in this driver indicate increased energy savings from better insulation or more efficient appliances. The driver reflects the effects of the Buildings Directive.</td>
</tr>
<tr>
<td><strong>Fuel mix:</strong> Share of electricity in households’ energy use</td>
<td>The share of electricity increased in both periods and therefore contributed to lower emissions on site of the households. The share of electricity in final energy consumption of households increased from 19% in 1990 to 23% in 2008 and to 25% in 2012. The increase of this driver reflects an increase in electrical appliances in households.</td>
<td>The share of electricity used relates final energy consumption excluding electricity to total final energy consumption. The emissions resulting from the production of public electricity are not accounted for in the households sector. Therefore, an increase in this driver results in lower emissions from this sector (but it can also result in increasing emissions in the electricity generation sector).</td>
</tr>
<tr>
<td><strong>Fuel mix:</strong> Share of solar, geothermal and heat pumps in households’ energy use</td>
<td>The use of solar energy, geothermal energy and heat pumps increased in both periods (+350% between 1990 and 2008; +50% between 2008 and 2012). However, as the overall share of solar, geothermal and heat pumps in final energy consumption remained small (at around 1%) it had only a small effect on decreasing emissions.</td>
<td>The share of solar thermal, geothermal and heat pumps in total final energy consumption reflects changes in renewable non-combustible energy sources used for heating and warm water production. This driver incorporates effects of the RED.</td>
</tr>
<tr>
<td><strong>Fuel mix:</strong> Share of biofuels in direct fuel combustion by households</td>
<td>The share of biofuels in final energy consumption increased in both periods and had a significant effect on decreasing emissions. In 1990 the share of biofuels in final energy consumption of households was 8%; it increased to 12% in 2008 and 13% in 2012.</td>
<td>The share of biofuels in total fuel consumption reflects the level of independence of heating and cooling processes from fossil fuels. An increasing share of biofuels leads to decreasing emissions. This driver reflects the effects of the RED.</td>
</tr>
<tr>
<td><strong>Fuel mix:</strong> Carbon intensity of direct fossil fuel combustion by households</td>
<td>The carbon intensity of direct fossil fuel consumption in households decreased by 9% between 1990 and 2008 and decreased further by 1% between 2008 and 2012. The main reason for the decrease 1990-2008 was a switch from coal to natural gas. The decrease</td>
<td>The emissions resulting from the combustion of fossil fuels depend on the type of fuel used. A switch to less-carbon-intensive fossil fuels (such as natural gas) can be monitored through this driver.</td>
</tr>
</tbody>
</table>
Decomposition analysis of the changes in GHG emissions in the EU and Member States

<table>
<thead>
<tr>
<th>Driver</th>
<th>Description of trends for time spans (1990-2008/2008-2012)</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>between 2008 and 2012 was mainly due to a significant decline in liquid fuel use whereas the use of natural gas remained constant.</td>
<td>Temperature significantly influences heating demand and is an important emission driver of emissions from households. Temperature refers only to winter temperature not to summer temperature (thus reflects increased need for heating but not for cooling).</td>
</tr>
</tbody>
</table>

2.1.3.7 **Cattle – enteric fermentation**

The figures below show the results of the decomposition analysis performed for the EU-28 for the cattle.

**Figure 2.12 Decomposition analysis of CO₂ emissions for cattle in the EU-28**
Decomposition analysis of the changes in GHG emissions in the EU and Member States

Figure 2.13 Decomposition analysis of CO\textsubscript{2} emissions for cattle in the EU-28, broken into three time periods

Table 2.8 Analysis of drivers – cattle (enteric fermentation)

<table>
<thead>
<tr>
<th>Driver</th>
<th>Description of trends for time spans (1990-2008/2008-2012)</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Activity:</strong> Milk production</td>
<td>Milk production was stable between 1990 and 2008 and therefore did not have a significant impact on falling methane (CH\textsubscript{4}) emissions from cattle during this period. The amount of milk production was managed by a milk quota system until 2015 to avoid overproduction. However, from 2008 to 2012 milk production increased by 4% thus putting pressure towards increasing emissions.</td>
<td>Milk production is one of the main drivers of CH\textsubscript{4} emissions from enteric fermentation of dairy cattle. The milk quota system introduced by the EU ends in 2015.</td>
</tr>
<tr>
<td><strong>Efficiency:</strong> Milk yield per cow</td>
<td>The number of dairy cattle decreased significantly between 1990 and 2008 (-38%), and further declined by 5% after 2008, whilst the amount of milk produced was relatively stable (or even increased). The milk yield per cow increased by 62% between 1990 and 2008, and further increased by 10% after 2008. The fact that a smaller number of dairy cows can produce the same amount of milk is the main driver for decreasing emissions.</td>
<td>The milk yield represents the quantity of milk produced each year by a dairy cow. This driver reflects the ‘productivity’ of dairy cattle.</td>
</tr>
<tr>
<td>Efficiency: Emission intensity (diary)</td>
<td>CH\textsubscript{4} emissions per dairy cow (emission intensity) increased, especially in the first period (+16% 1990-2008 and +3% 2008-2012). The main reason is the energy rich feeding of efficient dairy cattle. This effect – to some extent – offsets the emission reductions achieved through higher productivity of dairy cattle.</td>
<td>The emission intensity of dairy cattle reflects the level of emissions per animal. It depends mainly on the type of feed (energy intake and digestibility).</td>
</tr>
<tr>
<td>Emission share of other cattle</td>
<td>Emissions of other cattle decreased between 1990 and 2012, but not as strongly as emissions from dairy cattle. Between 1990 and 2008, the emission share of As also CH\textsubscript{4} emissions from other cattle than dairy are a main</td>
<td></td>
</tr>
</tbody>
</table>
### 2.1.3.8 Fertiliser use

The figures below show the results of the decomposition analysis performed for the EU-28 for fertiliser use.

**Figure 2.14 Decomposition analysis of CO₂ emissions for fertiliser use in the EU-28**

---

<table>
<thead>
<tr>
<th>Driver</th>
<th>Description of trends for time spans (1990-2008/2008-2012)</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other cattle</td>
<td>other cattle increased and therefore partly offset the emission reductions achieved through falling dairy cattle numbers. Generally the emission intensity of non-dairy cattle are about half of the emission intensity of dairy cattle.</td>
<td>contributor to emissions from enteric fermentation, this driver shows the share of other cattle.</td>
</tr>
</tbody>
</table>
Decomposition analysis of the changes in GHG emissions in the EU and Member States

Figure 2.15 Decomposition analysis of CO₂ emissions for fertiliser use in the EU-28, broken into three time periods

Table 2.9 Analysis of drivers – fertiliser use

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Activity: Cropland and grassland</td>
<td>The area on which fertiliser is applied increased by 1% between 1990 and 1995 and fell 4% between 1995 and 2012. This means that the reduction of cropland and grassland was a driver of falling emissions between 1995 and 2012.</td>
<td>The area of land that is used for growing crops and grass is a primary factor determining the amount of animal manure and fertiliser used in agriculture.</td>
</tr>
<tr>
<td>Efficiency: Fertiliser applied per land</td>
<td>The amount of nitrogen applied to soils is the main driver of nitrous oxide (N₂O) emissions. Nitrogen input to soils comes from synthetic fertiliser, animal manure, use of crop residues and the use of nitrogen fixing crops. The share of each fertilising method did not change significantly over the time period. During 1990-1995 the amount of fertiliser applied per hectare decreased by 22% and in the period 1995-2012 it decreased by 9%.</td>
<td>This factor refers to the nitrogen applied to cropland and grassland. It includes inorganic and organic fertilisers (animal manure and sewage sludge). This driver reflects the effects of the Nitrates Directive.</td>
</tr>
<tr>
<td>Emission intensity per fertiliser</td>
<td>The emission intensity per quantity of fertiliser applied partly offsets emission reduction achieved through falling fertiliser amounts. The emission intensity increased by 4% between 1990 and 1995 and by 3% between 1995 and 2012. The reason for increasing emission intensity is that the different types of nitrogen are applied to soils depends on the nitrogen content, the type of nitrogen application, irrigation practices, soil cultivation, climatic variables, soil humidity and temperature.</td>
<td>The amount of N₂O emissions per amount of fertiliser applied to soils depends on the nitrogen content, the type of nitrogen application, irrigation practices, soil cultivation, climatic variables, soil humidity and temperature.</td>
</tr>
</tbody>
</table>
2.1.3.9 **Landfilling of municipal solid waste**

The figures below show the results of the decomposition analysis performed for the EU-28 for municipal solid waste.

**Figure 2.16** Decomposition analysis of CO₂ emissions for municipal solid waste in the EU-28

**Figure 2.17** Decomposition analysis of CO₂ emissions for municipal solid waste in the EU-28
### Table 2.10  Analysis of drivers – landfilling of municipal solid waste

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Activity: Population</strong></td>
<td>The increase in population puts upward pressure on the quantity of municipal waste generated. It is therefore pushing towards rising emissions.</td>
<td>The quantity of waste generated is dependent on population. <em>Ceteris paribus</em> increases in population lead to increases in waste generation and emissions from landfilling.</td>
</tr>
<tr>
<td><strong>Activity: Waste generation per person</strong></td>
<td>The amount of municipal waste generated increased faster than the population of the EU-28 between 1995 and 2004, but not between 2004 and 2012, which is probably an effect of measures targeting waste prevention. Between 1995 and 2004 waste generation per capita increased by 8%; but in the 2004 – 2012 period it fell 1%.</td>
<td>This driver includes the amount of municipal waste generated per capita. It includes waste generated from households, commerce, offices and public institutions. This driver reflects the effects of the Waste Framework Directive.</td>
</tr>
<tr>
<td><strong>Activity: Share of waste incinerated</strong></td>
<td>The amount of municipal solid waste incinerated increased by 37% (1995-2004) and 33% (2004-2012). It therefore contributed to decreasing emissions from solid waste disposal in both time spans (but may have contributed to higher emissions in the waste incineration sectors). The share of waste incineration in total waste generation increased from 15% in 1995 to 19% in 2004 and was at 25% in 2012.</td>
<td>Waste can be used as an energy source; here incineration without energy recovery is also included. Resulting emissions are either accounted under the energy production sector or the waste sector. Only the emissions resulting from non-biogenic waste incineration are considered (biogenic waste incineration is considered as carbon-neutral). In case biogenic waste is used to substitute fossil fuels, emissions in the energy but also the waste incineration sector will decline. This driver reflects the effects of the Landfill Directive.</td>
</tr>
<tr>
<td><strong>Activity: Share of waste composted</strong></td>
<td>The amount of waste composted increased by 92% (1995-2004) and 27% (2004-2012). It contributed to decreasing emissions from landfill in both time periods. The share of waste composted in total waste generation increased from 7% in 1995 to 12% in 2004 and was at 15% in 2012.</td>
<td>Composting is a treatment option for municipal solid waste that has become more important in recent years in most EU Member States. Composting is the biological process that submits biodegradable waste to anaerobic or aerobic decomposition. It may be classified as recycling when compost (or digestate) is used on land or for the production of growing media. This driver reflects the effects of the Landfill Directive.</td>
</tr>
<tr>
<td><strong>Activity: Share of waste recycled</strong></td>
<td>The amount of waste recycled increased by 95% (1995-2004) and 37% (2004-2012). This also affected the share, especially between 2004 and 2012 when the share increased even stronger than in the years before. The share of waste recycled in total waste generation increased from 12% in 1995 to 20% in 2004 and was at 28% in 2012.</td>
<td>Recycling means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations. This driver reflects the effects of the Landfill Directive.</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>--------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Carbon content of landfilled waste: CH₄ intensity</td>
<td>The CH₄ intensity is the most important driver contributing to increasing emissions. The waste deposited in previous decades influences the actual emissions. For this reason the direct influence of declining waste being deposited due to the Landfill Directive is counteracted by emissions resulting from waste deposited in previous years and decades. The CH₄ generated increased between 1995 and 2004 by 1%, with a peak in 2002. Between 2004 and 2012 CH₄ generated declined by 13% but as the amount of waste landfilled decreased by 32%, CH₄ intensity is still a driver towards higher emissions in the time period.</td>
<td>Landfill is defined as deposit of waste into or onto land; it includes specially engineered landfills and temporary storage of over one year on permanent sites. The definition covers both landfill in internal sites (i.e. where a generator of waste is carrying out its own waste disposal at the place of generation) and external sites. The waste disposed on landfill sites is the source of CH₄ emission arising during the decomposition of waste. This driver reflects the effects of the Landfill Directive.</td>
</tr>
<tr>
<td>Efficiency of recovery: CH₄ recovery</td>
<td>The installation of landfill gas recovery systems contributed significantly to a decrease of CH₄ emissions. CH₄ recovery increased by 177% between 1995 and 2004 and further increased by 6% between 2004 and 2012.</td>
<td>Landfills are equipped with systems to collect landfill gas (mainly CH₄), which is then flared or used for energy recovery. The higher the recovery of the landfill gas, the lower are the accounted CH₄ emissions into atmosphere. This driver reflects the effects of the Landfill Directive.</td>
</tr>
</tbody>
</table>
2.2 Decomposition approach B: Index Decomposition Analysis with detailed sector definition

This section presents the results for the EU-27 from the Index Decomposition Analysis (IDA) performed in task 2B. The method and data sources are set out in detail in Annex 2.

2.2.1 Objectives

This second approach applies a similar methodology to that in task 2A as it also uses the Logarithmic Mean Divisia Index (LMDI). However, it uses a different database (the World Input-Output Database (WIOD)) which allows to cover additional sectors and factors (the structural effect). It distinguishes the following factors:

- Activity effect: GHG emissions can increase or decline as a result of changes in the activity level of the entire economy;
- Structural effect: the development of GHG emissions depends on changes in the industrial activity composition;
- Intensity effect: changes in overall GHG emissions may also result from sectoral energy intensity improvements or deteriorations linked to technological changes;
- Fuel mix effect: the composition of the fuel mix influences the extent of GHG emissions; and
- Emission factor effect: the emission factors of the specific fuel types may change over time and hence affect the amount of total GHG emissions, e.g. switching from a low to a higher quality type of gasoline.

Our decomposition approach allows us to distinguish different time periods:

- The whole period (1995 – 2012/2013); and
- In a comparative manner, specific sub-periods:
  - the recession between 2008 and 2012 compared to the period before the crisis, and
  - specific policy milestone phases, namely the different EU ETS Phases 2005-2007 compared to 2008-2012

2.2.2 Methodology

The method and data sources for this task are set out in detail in Annex 2. The scope is described in Table 2.11.

Table 2.11 Proposed scope for decomposition analysis

<table>
<thead>
<tr>
<th>Parameter (e.g. time coverage, sectors)</th>
<th>Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time coverage</td>
<td>1995 – 2012/2013: Data for the years from 2010 onwards were estimated based on time-series regression techniques and out-of-sample predictions as well as on interpolation techniques</td>
</tr>
<tr>
<td>Sectors</td>
<td>34 economic sectors and different aggregation schemes</td>
</tr>
<tr>
<td>Countries</td>
<td>EU-28 for the extended EEA-approach, EU-27 for the index decomposition approach, 40 (EU-27 + 13 major economies as China, Russia and USA) for an extended index decomposition approach to compare the European performance to other major countries.</td>
</tr>
</tbody>
</table>
2.2.3 Key findings

2.2.3.1 Overall EU-27 results

The charts and commentary below show the results from the IDA for the EU-27 (except Belgium, Ireland, the UK and Portugal) for the main greenhouse gases (CO₂, N₂O, CH₄ and NH₃) from 1995 to 2012.

Figure 2.18 CO₂ - five factors analysis

Figure 2.19 Analysis for other greenhouse gases
Decomposition analysis of the changes in GHG emissions in the EU and Member States

Note: 1) The dashed vertical lines signify a structural break in the data. Up until 2008, data from the World Input-Output Database (WIOD) have been used to conduct the IDA. From 2009 onwards, data have been taken from Eurostat. WIOD data have been compiled using the NACE 1.1 industry classification. The Eurostat data are based upon NACE 2.0. NACE 2.0 is a completely new classification and not just a revision of its predecessor. There is no unique correspondence between the NACE 1.1 and NACE 2.0. Therefore, data are not directly comparable.

The interpretation of the figures is explained by reference to the example of carbon dioxide, CO₂. The solid red line represents the total effect, i.e. the CO₂ emissions relative to 1995. The other lines represent the five other effects that make up the total effect. A value of 0.91 in case of the total effect in 2012, for instance, means that carbon dioxide emissions were at 91% of the 1995 level. There was a sizeable fall in the total effect from 2008 to 2009.
subsequent years, there is a slight increase in the total effect, though it remains close to the 2009 level.

The activity effect is represented by the blue line. It accounts for the change in total emissions that is due to a change in economic activity (output) only. This means that the activity effect measures the change in total emissions compared to 1995 that would have been observed had there been no technical change, no structural change, no change in the fuel-mix and no change in the emission factors (of the fuel types). The activity effect falls sharply between 2008 and 2009. Movement over the 2009-2011 period is comparable to the pre-crisis trend.

The reason for the relatively stability of total emissions as compared to the activity effect is that other factors, most importantly a change in energy intensity, have counterbalanced the considerable increase of the activity effect. The net impact was to leave total emissions in the most recent years significantly below their 1995 level. The activity effect was 1.41 in 2012. If all other effects had remained on their 1995 levels, CO₂ emissions would have been 41% higher in 2012 than in 1995 due to rising output alone. Considering the activity and the total effect together indicates that there has been a relative decoupling of output from emissions in the EU as a whole. This means that economic growth has been achieved without additional growth in emissions. The IDA only offers descriptive results – it does not indicate causation.

As Europe is considered as a whole, there are two structural effects considered – the between-country structural effect and the within-country structural effect. A third structural effect is also added – the combined structural effect. This is simply the product of both other effects and captures the changes in emissions due to changes in the economic importance of different sectors (and countries) that differ in the carbon- or energy-intensity of their production. The dashed grey line shows this combined effect. This combined effect barely changed in the sample period so that the main dampening effect originated in an improvement of sectoral intensity.

The within-country structural effect (shown by the yellow dashed line) is similar to the simple conventional structural effect used in the country analyses. The one difference is that it does not only hold the energy intensity, economic activity, fuel-mix and emission factor at their 1995 values but also the weight of the Member States in terms of their contribution to the overall EU economic output. Thus, the within-country structural effect only accounts for the change in total European emissions due to changes in the sectoral structure. The value of 0.94 for this effect in 2012 means that total emissions would have been 6% lower because of a higher relative contribution of less energy- or carbon-intensive sectors to total output in the EU (holding all other factors fixed). Less energy-intensive sectors, such as services, have become more important to output than more energy-intensive sectors such as manufacturing and non-metallic minerals. This would have led to a reduction in overall emissions had there been no changes in other factors.

The between-country structural effect holds the sectoral composition of the economy (i.e. sectors’ relative importance in terms of total output) constant at the 1995 level, in addition to activity, etc. It accounts for the change in emissions that would have been observed due to a change in the relative importance of the EU MS that differ in their total energy intensity, had all other factors remained unchanged. The positive value of this effect in 2012 (1.07, 107% of the 1995 level) shows that there has been a shift towards countries with higher energy intensity. In other words, had all other factors remained constant, the EU’s total emissions would be 107% of 1995 value because countries with a higher energy intensity (e.g. Eastern European Member States) have grown faster than countries with a lower energy intensity (e.g. Western European countries such as France, the UK, or Germany). The between-country structural effect is shown by the purple dashed line.

Rising technological efficiency is the most important factor reducing the CO₂ emissions in the EU. This conclusion follows directly from the changes in the intensity effect. In 2012, the intensity effect (dotted blue line) was 0.65. The interpretation of the intensity effect was
confirmed by the decomposition analyses conducted at MS level. It accounts for the change in total CO₂ emissions that is due to technology improvements.

The development of the intensity effect shows that there were significant technical improvements in the EU over the period considered in the analysis. This trend has offset the positive activity effect and has enabled a relative decoupling of emissions from economic growth. The interesting question is what the reasons for this trend are. Candidate factors are European legislation and national regulations under the ESD affecting sectors not affected by the EU ETS, as well as changes in the prices of energy, such as oil, coal, and gas that also drive the technological improvement in this area. Answers to these questions cannot be provided by IDA as the analysis provides descriptive results only. Section 3 of this report covers this question in details.

Another factor considered is the fuel-mix effect. This accounts for changes in emissions due to changes in the fuel-mix of the economy, holding all other factors fixed. The fuel-mix effect includes renewable energy sources. EU 2012 emissions in 2012 would have been 91 percent of 1995 emissions had all other factors, including the aggregate energy efficiency, remained unchanged in the intervening period. The fuel-mix effect only accounts for changes in emissions due to a switch from more carbon-intensive fuel types, such as oil, to less carbon-intensive energy sources, such as gas or renewable energy.

The fuel mix effect also holds constant the emission-factor of the fuel types. Thus, the remaining factor of the decomposition analysis accounts for the change in emissions that is due to a change in the emission factor of a certain fuel type only (holding all other factors fixed). An illustrative example is a change in the energy content of a fuel type, such as a change from 95 octane petrol to 98 octane petrol. The results clearly show that the effect does not significantly contribute to a change in emissions. The effect is close to 1.0 throughout.

The results for the other GHG emissions can be interpreted analogously. The total effect in 2012 was lower for the other pollutants than for CO₂, implying that their emissions decreased further than CO₂ emissions. Due to data restrictions, it is not possible to perform the IDA for all five effects and the fuel-mix and the emission factor effects cannot be calculated for the non-CO₂ pollutants.

The effects explaining the change in emissions have made qualitatively similar contributions for all pollutants. Output growth and between-country structural changes had an increasing impact on emissions. The latter exerted a stronger force than the former. Within-country structural change and falling intensities reduced the emissions. With the exception of ammonia (NH₃), the intensity effect a more significant contributor to falling emissions than structural change.

The results of the IDA suggest that the financial crisis had a notable effect on the results from 2009 to 2011. However, as the crisis coincides with the structural break in the data, it is not possible to distinguish between the impact of the crisis and the impact of the changing sectoral classification of the data.
2.2.3.2 EU-27 results for the electricity, gas, water supply

Figure 2.20 EU-27, sector: electricity, gas and water supply

![Graph showing CO2 emissions, gross output, and CO2 intensity from 1994 to 2012 for the EU-27 sector.]

The energy supply sector is one of the most carbon-intensive sectors in the EU economy. It is also a sector showing a strong reduction in carbon intensity.

Figure 2.20 illustrates the continuous decrease in CO2 intensity since 1995. In 2012, the CO2 intensity was just 35% of its 1995 starting value. The intensity remained more or less unchanged from 2008 onwards. This could be a result of the economic crisis. The crisis may have led to investments in energy efficiency improvements being postponed. The index change for the gross output also exhibits a short decline in 2009, which is also likely to be due to the crisis.

The sector electricity, gas, and water supply is strongly affected by the EU ETS. Moreover, this sector also includes energy supply from RES so the impressive reduction in carbon intensity is also a result of the diffusion of renewable energy technologies, as supported by the European and national policies promoting their development (the RED, feed-in tariffs and other policies).

2.2.3.3 EU-27 results for the coke and refined petroleum sector

Figure 2.21 EU-27, sector: coke, refined petroleum

![Graph showing CO2 emissions, gross output, and CO2 intensity from 1994 to 2012 for the EU-27 sector.]
The index values for both the CO\textsubscript{2} emissions and the CO\textsubscript{2} intensity show continuous improvements since 1995, with a small increase in the carbon-intensity in 2012. The reason for this change is the strong decrease in this sector’s gross output in 2012. Given that the emission index did not change significantly in 2012 compared to the previous year, one explanation for this outcome could be a price effect in petroleum products so that the same physical output is worth much less.

2.2.3.4 EU-27 results for the chemicals sector

The chemicals, pharmaceuticals, plastics, and rubber sector reported a considerable decrease in economic activity (gross output) at the beginning of the economic crisis, recovering thereafter. It appears that the economic crisis did not significantly affect CO\textsubscript{2} intensity.

Figure 2.22 EU-27, sector: chemical, pharmaceuticals, plastics and rubber

2.2.3.5 EU-27 results for the non-metallic minerals sector

This sector includes mineral production such as cement, bricks/lime/plaster, glass and ceramics. Cement contributes the largest share in terms of gross output and GHG emissions.

Figure 2.23 EU-27, sector: other non-metallic minerals

There was a steady decrease in the total effect (up by 40\% in 2012 compared to the 1995 level), primarily because CO\textsubscript{2} intensity improved (by almost 50\% compared to a 1995 baseline)
while gross output rose across the period. Between 2003 and 2007 the total effect remained almost constant; in this period a larger increase in gross output coincided with a slower rate of decline in the intensity effect as compared to the early years of the sample period. A strong negative effect on gross output is observed at the time of the economic crisis which resulted in a sharp decline in total emissions. This may be attributed in part to a decline in construction — the construction sector uses many intermediate products from the non-metallic minerals sector. The intensity effect remained untouched by the crisis.

2.2.3.6 EU-27 results for the pulp, paper and printing sector

The growth in gross output in the pulp, paper, and printing sector was considerably lower than that of the other sectors analysed. In 2009, at the beginning of the crisis, gross output fell significantly but it then recovered relatively rapidly in the following years.

![Figure 2.24](image)

There was a strong decrease in CO₂ intensity from 1995 onwards, so that by 2012 it was less than 50% of its 1995 value. Emissions do not seem to have been affected by the economic events of 2008; a small increase is observed in 2009. The same analysis holds true for carbon intensity.

2.2.3.7 EU-27 results for other manufacturing sectors

The sector ‘other manufacturing’ covers all the other sectors grouped in the aggregate manufacturing sector, for instance food and beverages, wood products, textiles and leather, electrical and optical equipment, and transportation equipment.

Gross output grew strongly from 1995 to 2008 but fell back in the wake of the economic crisis. It recovered during 2010-11 before softening in 2012.
The reduction in gross output levels in 2009 is associated with a decrease in the level of emissions but the CO₂-intensity was not noticeably affected.

2.2.3.8 EU-27 results for the agricultural sector

CO₂ emissions in the agricultural sector fell modestly compared to other sectors; total effect fell by approximately 15% during the sample period. This decline can be attributed to the intensity effect which, over the whole time horizon, fell by more than 20%. Gross output, on the other hand increased steadily, with the exception of the years 2003, 2005, 2010 and 2012.

There is an inverse relationship between changes in the CO₂ intensity effect and the gross output effect: if gross output declines, the intensity effect increases, and vice versa.

2.2.3.9 EU-27 results for the air transport sector

The analysis for the aviation sector shows a strong interest in the gross output effect from 1995 to 2007. CO₂ emissions did not increase because of changes in the CO₂ intensity effect that offset the growth in output. The steep increase of the total effect and the intensity effect in 2009 can be attributed to the fact that data for the 2009-2012 period had to be estimated. The air transport sector is affected to a high extent by this data discontinuity, leading to a
structural break in these parameters 2008 and 2009. The shading on the post-2008 plots in Figure 2.27 is intended to indicate that the particular caveats associated with these results.

**Figure 2.27 EU-27, sector: air transport**

![Graph showing index change for CO2 emissions, gross output, and CO2 intensity from 1994 to 2012.]

**2.2.3.10 EU-27 results for the inland transport sector**

This sector includes road and railway transportation and pipelines. The sector saw a steady decline in CO\(_2\) emissions over the whole sample period. The total effect fell by almost 40% by 2012 compared to the 1995 level.

**Figure 2.28 EU-27, sector: inland transport**

![Graph showing index change for CO2 emissions, gross output, and CO2 intensity from 1994 to 2012.]

This result is driven particularly by the decline in CO\(_2\) intensity. By 2012 the intensity effect fell by almost 60%, suggesting strong technological progress. Conversely, gross output increased almost steadily, with the exception of a dip in 2009.
2.3 Discussion on the results of the two decomposition analysis approaches

The two decomposition analysis approaches used as part of this study provide different insights on the same phenomenon, i.e. the evolution of GHG emissions in Europe during the 1995-2012 period. The EEA approach allows for a detailed analysis of the different factors impacting GHG emissions at sectoral level, while the IDA approach provides a more systematic analysis of different economic sectors and the EU as a whole. Both approaches support the same conclusion: there has been a clear decoupling of economic growth and CO₂ emissions in the EU as a whole as well as in most of the analysed economic sectors.

If one considers the results of both approaches at EU level, it clearly appears that the intensity effect (i.e. progress in GHG intensity triggered by technological change) is the most important driver of CO₂ emissions. Combined with other factors (e.g. increase use of renewable energy, decreased carbon intensity of fossil fuel), this effect was sufficiently important to compensate for the increase in economic activity over the 1995-2012 period and lead to an overall decrease in GHG emissions. Task 2A, which split the timeline into pre-economic crisis and post-economic crisis periods, suggests that GDP growth was the most important driver forcing increases in emissions between 1995 and 2008. Between 2008 and 2012 GDP decreased slightly, contributing to decreasing emissions. Energy consumption and CO₂ emissions from fossil fuel combustion decoupled in both periods (1995/2008 and 2008/2012). Final energy fell by 20% in the period to 2008 and 5% thereafter.

Task 2A also demonstrated that renewable energies contributed significantly to emission reductions in both periods: the share of non-carbon fuels in energy consumption increased from 19% in 1990 to 21% in 2008 and to 24% in 2012. As the share of nuclear power decreased over the period, all emission reductions are due to increases in renewable energies.

The results of task 2B confirm the above analysis and show that the progress (as measured by changes in the energy intensity of the economy) is mostly explained by technological change. The fuel mix effect also fell during the period considered, indicating a gradual shift to more emission-efficient energy carriers. The changing structure of the European economy seems to have had a limited impact on CO₂ emissions; the two structural effects almost cancel each other out. A steady decrease in the within-country structural effect indicates a shift towards less energy and emission-intensive sectors in many Member States. On the other hand, a steady increase in the between-country structural effect indicates a shift in output towards more energy- and emission-intensive countries.

These findings are evident also throughout the sectors considered in the analysis. Each sector shows high output growth, a strong decline in CO₂ intensity due to technological changes and hence an improvement in CO₂ efficiency. Total CO₂ emissions fell in almost all sectors throughout the sample period. The magnitude of the sectoral effects differs. The electricity, gas and water supply sector registered the largest decline in total CO₂ emissions between 1995 and 2012. The intensity effect fell markedly during the sample period. Other sectors with significant decreases in both the total and the intensity effect are coke and refined petroleum, chemicals, and other manufacturing.

There were three stages in the evolution of overall EU emissions. Between 1995 and 2001 there was little change in the total effect; an increase in activity was offset by falls in the intensity and fuel mix effects. Between 2002 and 2007 the total effect increased slightly, mainly due to further strengthening of the activity effect. After 2008 there was a sharp decline in the activity effect and a drop in the intensity effect that together lead to a fall in total CO₂ emissions.

Looking at developments at a Member State level, a similar pattern is observed in most countries, i.e. the intensity effect is the main driver behind declining emissions. Amongst the larger Member States (France, Germany, Italy, Poland, Spain, UK) all countries except Spain saw a reduction in emissions between 1995 and 2012, albeit to different extents:
The trajectory in **France** is similar to that of the EU overall - sharp declines in the intensity effect and sharp increases in the activity effect, whereas the structural, fuel mix and emission factor effects show only slight movements.

**Germany** saw a switch towards more energy and emission intensive sectors, and hence an increasing structural effect. However, considerable reductions in intensity and fuel mix effects resulted in a decline total emissions across the sample period.

In the **UK** and in **Poland**, all components except the activity effect decreased and there was a reduction of total emissions.

In **Spain** and **Italy**, the decoupling of economic growth and CO₂ emissions occurred only in the last years of the sample period. Before that, the total effect followed a similar pattern to the activity effect. The intensity effect was relatively stable in comparison to other countries.

Sector-level conclusions are:

- **Electricity production**: Electricity and heat demand was the most important driver of emissions between 1990 and 2008 (+22%), putting upward pressure on total emissions. Between 2008 and 2012 electricity and heat demand decreased by 2%, contributing to a reduction in emissions. Fuel efficiency of public electricity production is an important driver towards reducing emissions between 1990 and 2008. However, between 2008 and 2012 fuel efficiency did not change. Increased use of biomass contributed to lower emissions in both time periods (1990/2008 and 2008/2012): the share of biomass use in thermal power stations increased from 1% in 1990 to 7% in 2008 and further increased to 10% in 2012. Increases in wind and solar power production contributed to lower emissions in both time periods: their share of total electricity generation increased from 0.03% in 1990 to 3% in 2008 and further increased to 8% in 2012. Changes in the carbon intensity of fossil fuels used was an important driver contributing to lower emissions between 1990 and 2008; the principal factor being a switch from coal to gas. During 2008 and 2012 the carbon intensity increased again due to a switch from gas back to coal.

  In conclusion, despite a strong increase in electricity production during the period concerned, emissions fell due to the increasing efficiency of power plants and increased use of renewable electricity.

- **Transport**: GDP was the most important driver towards increasing emissions from freight transport between 1995 and 2008. Between 2008 and 2012 GDP decreased, contributing to the 3% reduction in emissions. This shows that emissions from freight transport were not decoupled from economic growth. For passenger transport the most important driver between 1995 and 2008 was passenger transport demand which increased 18% over that period, putting upward pressure on total emissions. From 2008 to 2012 passenger transport demand declined and contributed to emission decreases. Increased use of biofuels contributed to lower emissions in both time periods for both passenger and freight transport. The share of biofuels in transport increased from almost 0% in 1995 to 3% in 2008 and to 5% in 2012. For passenger cars fuel intensity was the most important driver towards lower emissions in both periods.

  In conclusion, emissions from freight transport were not decoupled from economic growth during the study period. Despite a strong increase in inland passenger transport, emissions linked to passenger transport fell slightly due to the increasing efficiency of cars and an increase in the use of renewable fuels.

- **Iron and steel production**: Steel production was by far the most important driver towards decreasing emissions from this sector between 2008 and 2012. Steel production in 2008 stood at the same level as in 1990 so had no effect on emissions in that period. Between 1990 and 2008 steel production decoupled from blast furnace iron production which was a strong driver towards lower emissions. The main reason for the decoupling was an increase in the use of scrap and increased steel production in electric arc furnaces. There
is no evidence of decoupling in the 2008 – 2012 period. A reduction in energy intensity was an important driver of lower emissions between 1990 and 2008 but energy intensity became a driver towards increasing emissions between 2008 and 2012 as energy consumption fell less rapidly than blast furnace iron production.

- **Households:** Increases in population and household size put upward pressure on emissions. Energy use per household was the largest driver towards decreasing emissions in both periods (1990-2008 and 2008/2012), reflecting the improved energy efficiency. The share of biofuels in final energy consumption increased in both periods (from 8% in 1990 to 12% in 2008 and 13% in 2012) and had a significant effect on decreasing emissions. The carbon intensity of direct fossil fuel consumption in households fell 9% between 1990 and 2008 and decreased by a further 1% between 2008 and 2012. The main reasons were a switch from coal to natural gas (1990-2008) and a switch from liquid fuels to gas (2008-2012).

Despite an increase in heating demand linked to colder winter temperatures during the period concerned, emissions fell. This change is attributed to increasing household energy efficiency, the increase use of biofuels and the lower carbon intensity of the fossil fuels consumed directly by households.

- **Cattle – enteric fermentation:** Milk production was stable between 1990 and 2008 and so did not have a significant impact on emissions. From 2008 to 2012 milk production increased by 4%, putting upward pressure on emissions. The increase in milk yield per cow was the main driver for decreasing emissions. The number of dairy cattle fell 38% between 1990 and 2008, and by a further 5% after 2008; the amount of milk produced increased by 4% after 2008. Methane (CH\textsubscript{4}) emissions per dairy cow increased, especially in the first period (+16% 1990-2008 and +3% 2008-2012).

  In conclusion, despite a small rise in milk production, emissions fell due to a reduction in the number of dairy cattle and improved yield per cow.

- **Fertiliser:** The area on which fertiliser was applied increased 1% between 1990 and 1995 before falling 4% between 1995 and 2012. This decrease supported the fall in emissions associated with the reduced intensity of use of fertiliser. The amount of nitrogen applied to soils is the main driver for decreasing emissions. During 1990-1995 the amount of fertiliser applied per hectare fell 22% and in the period 1995-2012 it fell 9%. The positive effect was slightly offset by the increased emission intensity per tonne of fertiliser applied.

- **Landfilling of municipal solid waste:** Between 2004 and 2012 there was a decoupling of municipal waste generation from population growth. From 1995 to 2004 municipal waste generation increased faster than the population of the EU-28. Incineration, composting and recycling of waste increased in both periods (1995/2004 and 2004/2012) and contributed to a decrease in emissions from solid waste disposal. The installation of landfill gas recovery systems contributed significantly to a decrease of CH\textsubscript{4} emissions.

To summarise, the analysis shows a decoupling of economic growth from CO\textsubscript{2} emissions in the EU as well as in the sectors and most of the EU Member States considered. The intensity effect resulting from the technological change was the main driver of emissions reductions in most cases. The increased use of renewable energy also contributed to the decoupling. It is often perceived that a structural shift towards less carbon-intensive economic sectors, such as from manufacturing to services, is an important contributor to changes in the carbon intensity of the EU economy. The results of this study indicate, however, that this shift has had a limited impact. The underlying reasons are that many of the sectors that contributing most to emissions, such as transport and electricity generation, have been growing significantly over recent decades, in tandem with growth in the economy as a whole (see task 2A).
3 Econometric analysis of the effects of specific policies on changes in GHG emissions

3.1 Quantitative econometric analysis of the mitigation impact of specific policies on changes in GHG emissions

3.1.1 Objectives
The ultimate objective of the econometric analysis is to assess the effects of different climate policies on CO2 emissions or, more precisely, on emission abatement. In particular, the goal is to provide an ex post evaluation of specific climate policies, including EU policies such as the EU ETS, national climate policies under the ESD and RE policies.

3.1.2 Policies considered and methodology
This section outlines the empirical models used in the econometric analysis. Annex 4 provides technical details. The policies are first analysed separately due to the need to use an assessment method appropriate to the nature, propagation mechanism and lag effects of each policy or policy type. In a second step, the total emissions abatement caused by the climate policy measures is considered.

Policies considered are:
- **EU ETS**: The EU ETS was introduced in 2005 and currently covers 45% of the EU’s GHG emissions. As a cap-and-trade system, it creates a uniform price for emission allowances and facilitates least-cost abatement across a large pool of installations. The capped nature of the system makes it difficult to assess emissions abatement, as discussed below.
- **Member State specific policies**: These include national climate policies put in place to deliver the EU ESD GHG emission reduction targets together with policies related to energy taxes. Various climate policies and policy types, such as energy efficiency standards for buildings or products, are in place in the Member States. Given their diversity, these policies can only be accounted for in this study by using qualitative measures, such as the number of policies in place. The same holds true for energy taxes where two cases are considered, general energy taxes and taxes for transportation (taxes of gasoline and diesel).
- **Renewable energy policies**: There is a wider variety of policies in place to support renewable energy. Examples are: feed-in tariffs, tax credits, direct investments and support programmes, and energy market regulations supporting renewable energy production.

This analysis focuses on climate policies developed at national level and therefore does not considered the policies of local governments (such as the Covenant of Mayors movement and C40).

Different models are used primarily because of the different expected impacts on emissions over time. The analysis uses:
- A model that estimates the mitigation effect of the EU ETS on CO2 emissions. This model is independent of the empirical decomposition analysis and builds on a dynamic model of CO2 emissions.

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4 More information at: [www.covenantofmayors.eu/index_en.html](http://www.covenantofmayors.eu/index_en.html)
5 More information at: [www.c40.org](http://www.c40.org)
The so called ‘econometric decomposition analysis’: This model is used to estimate the effect of several national climate policies in place in a certain year on emissions in the following year.6

A model of GDP growth to study whether climate policies had an effect on GDP that serves as a measure of competitiveness and economic performance of the countries.

The estimates of the emission volumes that would have been observed in the absence of the various policies are added together in a further step to create a counter-factual baseline. This approach allows for the development of a comprehensive picture of the effect of climate policies on emissions and abatement.

3.1.2.1 The model for estimating the effect of the EU ETS on emissions

In the absence of laboratory-like control and treatment groups, the ex post evaluation of the EU ETS relies on widely used counterfactual scenario building applied in recent reputable journal articles. This provides estimates that are not immune to limitations, but are as robust as possible, given existing data.

Given that almost all EU Member States have been affected by the EU ETS since 2005, there is no meaningful control group of countries within Europe but outside the system,7 making it difficult to estimate the effect of this policy by comparing emissions in a country where the regulation is in place to a similar country where it is not. The effect of the EU ETS is therefore estimated based on the difference between the emissions level associated with a modelled counterfactual baseline scenario and the actual emissions levels (see Annex 3 for a detailed review of the literature).

To build the counterfactual baseline, historic CO2 emissions data for the decade immediately preceding the implementation of the EU ETS are mapped8, using econometric analysis, against key determining factors. Following Anderson and Di Maria (2011)9, we estimate a dynamic panel model for (selected) Eurostat CO2 emissions for the period 1995-2004, up to the year prior to the implementation of the EU ETS. Under this dynamic, auto-regressive model CO2 emissions in country i in year t are explained by information on CO2 emissions in the same country in the previous year (t-1) and a set of other explanatory variables, for example GDP or energy prices. The advantage of such a dynamic model is that it can be calibrated to accurately explain the actual data and its predictions are very close to the observed real data points. The model reads as follows:

\[
CO2_{i,t} = \beta_1 CO2_{i,t-1} + \beta x_{i,t} + u_i + \epsilon_{i,t}
\]

The ultimate goal is to estimate the parameters (betas) of the model to use them for forecasting. The parameter estimates represent the effect of a certain explanatory variable on CO2 emissions. Once these effects are estimated it is possible to forecast the emissions for all years where the explanatory variables are known. The parameter \( \beta_1 \) denotes the effect of the emissions in the previous year on the emissions in the current year. One year’s lagged emissions serve as a control variable for the level of emissions while the vector denoted by \( x_{i,t} \) includes different explanatory variables explaining the current level of emissions given the past emissions. The variable \( u_i \) is a country-specific effect (dummy variable for each country).

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6 The basic model presented in this section uses the total emissions as dependent variable. In the Annex, we present a version, where the index values from the IDA (task 2B) serve as dependent variables.

7 Some countries joined the EU ETS in the end of Phase 1 (Bulgaria and Romania in 2007), in the beginning of Phase 2 (Norway, Iceland, and Liechtenstein in 2008), or even later (Croatia in 2013). However, their total emissions are small and not representative.

8 This is based on Eurostat emissions data for 1995-2004 and is mapped across EU ETS sectors as described in detail in the Annex.

that controls for different levels of emissions in the countries for reasons that cannot be explained in this model. Finally, $\varepsilon_{i,t}$ is a random error term with zero mean.

The dynamic panel model is used to estimate the effect of drivers of CO$_2$ emissions during the period 1995-2004 and then, in a second step, these estimates are used to forecast the counterfactual emissions for the period 2005-2012. The counterfactual is then compared to the actual emissions.

The goal is to select variables included in $x_{i,t}$ that are exogenous to regulations, meaning that they are not affected by EU ETS regulation.

- Following Anderson and Di Maria (2011) the vector includes two control variables for economic activity, one in the manufacturing sector and one in the energy supply sector. These two variables are measured as index values, with the reference year (2005) set to 100%. These two variables enter the model in natural logarithms. While the idea of including the lagged dependent variable is to control for the level of CO$_2$ emissions, the idea of economic activity measures is to explain the changes in a certain year given changes in economic activity. However, the problem is that the level of economic activities cannot be considered completely exogenous of EU ETS regulation. While this is not relevant for estimating the model until 2004, it is of some relevance for forecasting. If economic activity is affected by regulation in a negative way, the emissions predicted under the counterfactual baseline scenario would be lower than they should be if the BAU is completely independent from regulation. This is a shortcoming of the model that cannot be ruled out entirely. However, the literature review of the effects of EU ETS regulation on competitiveness, economic activity and structural change (Annex A3.2) suggests that it should not be a concern: the consensus of the literature is that the EU ETS has had no significant effect on economic activity to date.

- Information on heating / cooling degree days and precipitation was included within the $x_{i,t}$ vector. Countries located in northern areas, such as Sweden, are expected to emit more CO$_2$ simply because more energy for heating is required. Spain is expected to emit less CO$_2$ due to lower heating requirements but emit more CO$_2$ because of higher cooling requirements. Countries such as the United Kingdom and Ireland should, in theory, have both, low heating and low cooling requirements (subject to differences in building energy efficiency etc.) than Spain and Sweden. A lot of precipitation may allow countries to make use of hydroelectric energy so precipitation is expected to be associated with lower CO$_2$ emissions.

- Wind speed and sun hours data were not included in the model. The main reason for the omission is the considerable technological change and capacity increase in wind and solar energy generation since the early 2000s. Using parameters estimated on basis of 1995-2004 to forecast these technologies up to 2012 would be inappropriate due to these step changes. For hydroelectric power the rate of technological change was slower. An additional reason for the omission is the aim to produce comparability with Anderson and Di Maria (2011) that also did not include these variables.

- A final set of variables included is prices of natural gas, coal and oil. Energy prices are expected to play a central role for changes in emissions, for instance by triggering fuel switches or efficiency improvements. The prices are measure in constant dollars and enter the model in natural logarithms.

With the exception of economic activity, not estimated for later years, all the variables included are completely exogenous to CO$_2$ emissions and regulations.
Table 3.1  Data and variables used to estimate the EU ETS counterfactual baseline scenario

<table>
<thead>
<tr>
<th>Name of Driving Factor</th>
<th>Effect on Total Emissions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ emissions in previous year (t-1) + 1% CO₂ emissions in previous year</td>
<td>+ 0.66% CO₂ emissions</td>
</tr>
<tr>
<td><strong>Activity Effect:</strong> Manufacturing production + 1% manufacturing production</td>
<td>+ 0.06% CO₂ emissions</td>
</tr>
<tr>
<td>Energy sector production + 1% energy sector production</td>
<td>+ 0.14% CO₂ emissions</td>
</tr>
<tr>
<td><strong>Weather effects:</strong> + 1% heating degree days</td>
<td>+ 0.27% change in CO₂ emissions</td>
</tr>
<tr>
<td>+ 1% cooling degree days</td>
<td>+ 0.01% (not significantly different from zero)</td>
</tr>
<tr>
<td>+ 1% precipitation levels</td>
<td>+ 0.03% (not significantly different from zero)</td>
</tr>
<tr>
<td><strong>Energy Prices:</strong> + 1% oil price</td>
<td>+ 0% (not significantly different from zero)</td>
</tr>
<tr>
<td>+ 1% steam coal price</td>
<td>+ 0.02% (not significantly different from zero)</td>
</tr>
<tr>
<td>+ 1% gas price</td>
<td>+ 0.02% (not significantly different from zero)</td>
</tr>
<tr>
<td>+ 1% electricity price</td>
<td>+ 0.01% (not significantly different from zero)</td>
</tr>
</tbody>
</table>

**Notes:**
1) The equation applies logarithm form to all equations in order to address outlier anomalies.
2) For manufacturing and energy sector production, index values with a base of 2005 are used.

The estimated relationship (for the years until 2004) predicts emissions fairly accurately ($R^2=0.9978$). This relationship is used to forecast emissions as follows: the estimated impacts of the explanatory variables on emissions for 1995 - 2004 are used together with the values of these variables for the whole 1995 - 2012 period to calculate 'fitted' values of CO₂ emissions. This is done for the period when the EU ETS was in place (2005 until 2012). The forecasted emissions are denoted by the blue line in Figure 3.1. Since the historic emissions data are not available differentiated by regulation, but only for sectors, we follow Anderson and di Maria (2011) and perform a mapping of historic CO₂ emissions data. Hence, the forecasted emissions have to be adjusted. The green line shows the counterfactual after the relevant adjustments has been conducted.\textsuperscript{10}

The counterfactual baseline emissions are an estimate of what emissions would have been observed had there been no EU ETS. The final step of the analysis involved calculating the difference between the estimated counterfactual emissions (the green line) and the observed emissions (the grey line). This difference is the estimated CO₂ emission abatement due to the EU ETS, plotted in Figure 3.1 below.

\textsuperscript{10} The procedure is explained in Annex 4.
There is a clear gap between the observed and forecast emissions from 2005 onwards; this provides evidence that the EU ETS had an effect on emissions. The effect of the EU ETS on emission abatement is smaller in 2007 than in the other years. This finding is strongly supported by considering the development of the emission allowances prices (Annex 4) and provides evidence for the robustness of the modelling technique.

The modelling suggests that during Phase 1 the EU ETS brought about abatement of 187 million tonnes (Mt) CO$_2$. This result falls within the range of existing studies.

**Table 3.2  Comparison with abatement finding from the literature**

<table>
<thead>
<tr>
<th>Study</th>
<th>Phase 1 years covered</th>
<th>Estimated annual abatement as a result of the EU ETS, in Mt CO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anderson and Di Maria$^{11}$</td>
<td>2005-2007</td>
<td>247</td>
</tr>
<tr>
<td>Delarue et al.$^{12}$</td>
<td>2005-2006</td>
<td>146</td>
</tr>
<tr>
<td>Ellerman et al.$^{13}$</td>
<td>2005</td>
<td>8-174</td>
</tr>
<tr>
<td>Current study</td>
<td>2005-2006</td>
<td>137</td>
</tr>
<tr>
<td>Current study</td>
<td>2005-2007</td>
<td>187</td>
</tr>
<tr>
<td>Current study</td>
<td>2008-2012</td>
<td>207</td>
</tr>
</tbody>
</table>

No other studies were found that estimated abatement during Phase 2. The estimated CO$_2$ abatement very likely comes via the intensity and fuel-mix effect. This view is confirmed by a


number of recent studies as well as by additional econometric counterfactual analysis undertaken as part of the current study.

The results above do not account for policy interaction. A sensitivity scenario including other policies has been developed. Under the sensitivity analysis, for Phase 1, the abatement resulting from the EU ETS is 8% smaller than the abatement from the standard model; for Phase 2, estimated abatement is around 13% lower than reported above. Expressed in comparison to verified emissions, the difference is very small, 0.1% of verified emissions for Phase 1 and about 1.3% in Phase 2. Details are reported in the Annex 4.

Remaining limitations include:

- The forecast nature of the counterfactual baseline scenario emissions: whereas the model has a very good fit (R² = 0.9978), the forecast estimation is based on the assumption that the relationships established for the years preceding the EU ETS remain constant after the introduction of the EU ETS, and, as is the case with any counterfactual forecasting exercise, the stability of these relationships cannot be guaranteed.

- The possibility that economic activity, a determining factor in the forecasting equation, could vary as a result of the EU ETS: as outlined in Annex 3 there is no substantive evidence supporting this concern. If, however, the EU ETS had affected economic activity in a significantly negative way, the estimates of EU ETS abatement in this report would underestimate its impact on emissions.

Assumptions have been made to fill in missing data points that are explained in details in Annex 4.

### 3.1.2.2 The basic econometric structural decomposition model

This section describes how the effects of climate-relevant policies other than the EU ETS on emissions were estimated and the results of this analysis. The focus is on the effect of national climate policies, energy tax revenues and the proportion of renewables within the total gross energy use. The selection of national climate policies is based on the International Energy Agency’s (IEA) Climate Change Measures Database.

Other aspects such as activity and structural effects are controlled for, in line with a standard model from empirical economic research, the so-called ‘Econometric Structural Decomposition Analysis’. Academic articles using this approach include Grossman and Krueger (1993) and Antweiler et al. (2001). This method is similar to the one applied in Index Decomposition in task 2B, though not identical. The Index Decomposition was a pure calculation mapping changes in emissions from different sectors and countries into several index numbers. Here, estimation (regression) procedures are applied to assess changes in emissions resulting from climate policies while controlling for factors affecting the activity effect, structural effect, intensity and fuel mix effects and other variables such as heating degree days. The model structure is shown in Figure 3.2 below.
The econometric structural decomposition model

\[
\text{Total Effect} = \text{Activity Effect} + \text{Structural Effect} + \text{Intensity and Fuel-Mix Effect}
\]

\[
\ln(CO2_{it}) = \beta_{\text{act}} \cdot \ln(GDP_{it}) + \beta_{\text{str}} \cdot \ln(\frac{\text{va manu}_{it}}{\text{va serv}_{it}}) + \beta_{\text{pol}} \cdot \text{Policies}_{it-1} - 1 + \beta_{\text{tax}} \cdot \ln(\frac{\text{taxes}_{it-1}}{GDP_{it-1}}) - 1 + \beta_{\text{pri}} \cdot \ln(\text{price}_{it-1}) + \beta_{\text{ren}} \cdot \ln\left(\frac{\text{Ren. En}_{it}}{\text{Tot. En}_{it}}\right) + \beta_{\text{nuc}} \cdot \ln\left(\frac{\text{Nuc. En}_{it}}{\text{Tot. En}_{it}}\right) + \beta_{\text{trend}} \cdot \text{trend}_{i} + \beta'_{c} \cdot \text{CONTROLS} + \text{Residual}_{it} + \beta'_{c} \cdot \text{CONTROLS}
\]

The activity and structural effects follow the logic of the IDA, albeit undertaken at country rather than sector level:

- The activity effect (hereafter $\beta_{\text{act}}$) is an estimate of the effect of a change in economic activity, accounted for by GDP, on the change in emissions, holding all other factors fixed.
- The composition, or structural, effect (hereafter $\beta_{\text{str}}$), represents the change in emissions due to changes in the economy’s structure, accounted for by the change in the ratio of the value added of the industry sector to the value added of the service sector in a certain MS.

The fuel mix and intensity effects are modelled in combination as key drivers such as energy prices affect both the choice of individual fuels as well as total energy consumption and therefore, carbon-intensity. The variables included under this heading are:

- The policy effect, referring to the estimated change in emissions due to a change in climate policies and energy taxes of the MS\textsuperscript{14}. These are accounted for by the revenues from general energy and transport taxes and by the number of climate policies in place. For the latter, the following categories of policies from the IEA Climate Change Measures

\textsuperscript{14} These regulations also account for national implementations of European Directives, such as the Eco-Design Directive. The modelling technique requires that the analysis is undertaken at MS level rather than at EU-wide level.
Decomposition analysis of the changes in GHG emissions in the EU and Member States

Database are included: direct regulations or, in IEA’s terminology “regulatory instruments”\(^{15}\), specifically: “codes and standards” such as energy efficiency standards for buildings or products; “obligation schemes”; and “other mandatory requirements.” Policies are assigned to different target sectors such as energy, buildings, transportation and industry. Where regulations address different sectors a clear-cut assignment is not possible;

- Renewable sources as a proportion of total gross energy use;
- Nuclear energy as a proportion of total gross energy use;
- Energy prices, including electricity, oil, natural gas and steam coal\(^{16}\);
- Exogenous changes in emission intensity or the fuel mix not triggered by regulation or price changes are accounted for by year specific effects or a linear time trend;
- Control variables such as heating or cooling degree days;

The residual accounts for all of the variation in emissions that cannot be explained by the explanatory variables above. The econometric regression analysis selects the beta parameters (the corresponding estimates are provided in the right hand column of Figure 3.2 above) that minimise the residual, meaning that these parameters provide the best fit for the CO\(_2\) emissions data.

The data are selected for the period from 1988 until 2012. The timeframes for assessing the effects of the factors of interest are specified as follows:

- The national policies and energy tax analysis is restricted to the period between 1995 and 2012 since the database indicates that no climate policies were in place before 1995, and no energy and transportation tax data are available at MS level for 1990-19;
- For renewable energy, the timeframe is wider and captures the years between 1990 and 2012.

The results of the model, shown in the table below, suggest that national climate policies, energy taxation and the use of renewable energy have all had a statistically significant effect on emissions.

**Table 3.3 Overview of the results from the econometric structural decomposition analysis**

<table>
<thead>
<tr>
<th>Name of the effect</th>
<th>Effect on total emissions:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Activity Effect:</strong></td>
<td></td>
</tr>
<tr>
<td>+ 1% GDP</td>
<td>+ 0.22% CO(_2) emissions</td>
</tr>
<tr>
<td><strong>Structural Effect:</strong></td>
<td></td>
</tr>
<tr>
<td>Manufacturing sector’s value added relative to the service sectors’ value added.</td>
<td>0% (not significantly different from zero)</td>
</tr>
<tr>
<td><strong>Combined Intensity and Fuel-Mix Effect:</strong></td>
<td></td>
</tr>
<tr>
<td>+ 1 National Climate Policy</td>
<td></td>
</tr>
<tr>
<td>+ 1% (Energy Tax Revenues /GDP)</td>
<td>- 0.02% CO(_2) emissions</td>
</tr>
<tr>
<td>+ 1% Share of Renewable Energy Use in Tot.</td>
<td>- 0.09% CO(_2) emissions</td>
</tr>
<tr>
<td>+ 1% Others</td>
<td>- 0.16% CO(_2) emissions</td>
</tr>
<tr>
<td><strong>Other Factors:</strong></td>
<td></td>
</tr>
<tr>
<td>+ 1% heating degree days</td>
<td>+ 0.20% CO(_2) emissions</td>
</tr>
<tr>
<td>+ 1% Others</td>
<td>0% (not significantly different from zero)</td>
</tr>
</tbody>
</table>

\(^{15}\)Voluntary agreements, research and development policies and subsidies are excluded due to the fact that these result in non-country specific outcomes, provided that all countries can make use of new technologies through purchase, imitation other forms of technology transfer.

\(^{16}\)It was decided to only include one price indicator per major fuel type due to multicollinearity. Steam coal was used as indicator for the price development on the hard coal markets.
Notes:
1. Results are for the EU on average, i.e. for all EU-27 MS, before Croatia joint.
2. The time period considered is 1995-2012 for abatement calculation.

The addition of a national climate policy in a single MS is associated in the model with a notable decrease in total EU emissions. In the short run, all the national climate policies under the ESD combined are estimated to have contributed to an emissions abatement of around 4% in 2012, a level comparable to that resulting from the implementation of the EU ETS (see the table below). Abatement in the long run is expected to be higher due to technological changes. By combining and comparing the results of the econometric models applied to estimate CO₂ abatement by policy, it is implicitly assumed that the EU ETS had no effect on the use of renewable energy.

Table 3.4  Calculated CO₂ abatement based on the estimates

<table>
<thead>
<tr>
<th>Policy and renewable energy</th>
<th>Estimated abatement in 2012 (Mt CO₂) – relative to counterfactual</th>
<th>Estimated abatement in % of Emission in 2012 – relative to counterfactual</th>
<th>Estimated abatement in % of Total Abatement (2012)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU ETS</td>
<td>185 Mt</td>
<td>5.0%</td>
<td>16.6%</td>
</tr>
<tr>
<td>National Climate Policies (under the ESD)</td>
<td>146 Mt</td>
<td>3.9%</td>
<td>13.1%</td>
</tr>
<tr>
<td>Renewable Energy (total)</td>
<td>697 Mt</td>
<td>18.8%</td>
<td>62.5%</td>
</tr>
<tr>
<td>Energy Taxes</td>
<td>87 Mt</td>
<td>2.3%</td>
<td>7.8%</td>
</tr>
<tr>
<td></td>
<td>1,114 Mt</td>
<td>30.1%</td>
<td>100%</td>
</tr>
</tbody>
</table>

By far the most important contribution to total abatement comes from RES, given the large share of CO₂ emissions coming from fossil fuel combustion that is substituted by renewable energy. The model predicts that a one percent increase in the share of renewable energy use is associated with a 0.15 percent reduction in CO₂ emissions. This translates into an abatement of 697 Mt CO₂ for the year 2012, which is 62.5 percent of the total abatement and almost 19 percent of the total CO₂ emissions in 2012. The importance of this abatement method is a clear indication that renewable energy is a key element in the decoupling of CO₂ emissions from economic growth.

Among the contextual factors considered are that:
- Economic activity is shown again to play an essential role in the change of emission levels: a one percent increase in economic activity, accounted for by GDP, leads to a 0.22 percent increase in CO₂ emissions.
- No statistically significant correlation between structural change and emissions is identified.
- Countries with a colder climate and less sun, where the heating requirement is higher (accounted for by heating degree days), emit significantly more.

Limitations

As indicated above, data on energy taxation on MS level are only available from 1995 onwards. The use of renewable energy and energy taxation are positively correlated, or interlinked. The omission of energy taxation for the time period between 1990 and 1995 would therefore lead to an upward bias in the estimated effect of renewable energy. To mitigate this bias the data are extrapolated for the time period between 1990 and 1995.

The structure of the econometric decomposition model does not allow a deeper understanding of the drivers of renewable energy use. Since this is such an important determinant of
emissions abatement, a separate model of the effect of policies on the share of renewable energy use is presented separately in section 3.1.2.3.

For further details on the estimation procedure the reader is referred to Annex 4. A detailed explanation of the variables, data sources and how missing data points were filled is provided in Annex 5.

The following assumptions apply:

- The percentage of energy tax revenues and transportation tax revenues of GDP in Cyprus, Hungary, and Portugal is equivalent to the average of the remaining EU-27 countries. Energy tax data for these three countries are not available.

- For Bulgaria, Cyprus, Lithuania, Malta and Slovenia there is no information available on other climate policies (under the ESD). The report assumes that there are no policies in place. This issue does not crucially affect the results as these five countries together account for only 2-3% of the total EU-27 emissions (2.38% in 2012).

3.1.2.3 Renewable energy policies

The previous section explained how the total CO₂ emission abatement due to the use of RES has been calculated. It would be interesting to examine to what extent the abatement is actually caused by renewable energy policies. Providing an answer to this question is challenging as renewable energy policies vary greatly within and across countries. Some policies have direct short-run effects on the installation of renewable energy capacity while others adopt a longer term perspective, as is the case for research and development programmes. The different policies differ in their temporal impact on renewable energy:

- Policies such as feed-in tariffs have a direct impact on the installed renewable energy capacity. However, feed-in tariffs are difficult to measure as the subsidy in most countries depends on the megawatt (MW) capacity, type of renewable energy, year of installation, etc.

- On the other hand research and development support policies and subsidies have a much longer term effect. Such policies have been in place for decades in a number of industrialised countries, in particular since the two oil crises in the late 1970s and early 1980s. Estimating the effect of such policies on installed renewable energy capacity is again difficult. The reason for this is the long time lag from the subsidies until new technologies have been invented and another time lag from the invention date until the new technology enters the market. For the first step in this causality chain, the existing studies conclude that policies, rather than fossil fuel prices, are the main driver of innovation in renewable energy technologies (Johnstone et al. 2010). Reducing the cost differential between operating renewables and conventional fossil fuel technologies is the goal of feed-in tariffs and other policies aiming at stimulating the adoption of renewable technologies.

- There are additional relevant MS policies: Examples include regulations demanding that a certain percentage of biofuels is included in the fuel mix (bio fuel quotas). In several MS, there are combined heat and power (CHP) regulations in force and several electricity market regulations that complement the use of renewable energy by giving them priority over conventional energy sources. Moreover, there are tax exemptions and tax credits for renewable energy in force in some MS and some countries pay direct subsidies for investments in renewable energy installations.

What all these regulations (including also feed-in tariffs) have in common, is that they stimulate the demand for renewable energy technologies while research and development programmes stimulate the supply of such technologies. As the mitigation impact of research and development programmes is difficult to measure, the focus of this analysis is on the demand stimulating policies only. There are feedback channels in place with the demand stimulating policies of today making research and development activities in renewable energy...
technologies more attractive and thus stimulating the technologies of tomorrow and affecting their cost-benefit ratio.

As public policies are the main drivers behind renewable energy technology development and as policies aiming to increase the demand of such technologies by lowering their costs relative to conventional technologies are in place in almost all MS, it can be concluded that the overwhelming majority of the effect of renewables on emissions is likely to be caused by such policies.

The remainder of this section presents the results of a simple analysis assessing the mitigation impact of renewable energy policies. The approach used in this analysis is similar to that used to assess the mitigation impact of the EU ETS. For the reasons mentioned above, it excludes the effects of research and development policies. It also excludes hydro power as the technology is very old and the respective installations were built a long time ago. By omitting hydro power it was possible to focus on more recent RES.

As there is, in general, no theory regarding the yield of the available renewable energy capacity, a dynamic model is used to facilitate the analysis. The use of a dynamic model is helpful as it relates the amount of renewable energy within the total gross energy use to the value of the previous year. There is thus no need to explain the general drivers of renewable energy production. This procedure increases the model fit and reduces problems of omitting relevant and necessary explanatory factors (variables) that could result in biased results.

As for the analysis of national climate policies under the ESD presented above, renewable energy policies are measured qualitatively in this analysis. The only information underpinning the analysis is whether or not a certain policy was in place in a certain MS and year. The data used were extracted from the IEA Renewable Energy Policies Database. The explanatory factor (variables) of the model and their sources are explained in Annex 4 (section A1.2.3).

The results for this model, using the renewable energy use in Tera Joules (TJ) as the dependent variable, are presented in Table 3.5.

Table 3.5 Results from the renewable energy model

<table>
<thead>
<tr>
<th>Name of the explanatory variable</th>
<th>Effect on renewable energy use (excluding hydro power)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lagged Dependent Variable:</td>
<td></td>
</tr>
<tr>
<td>+ 1% renewable energy use (without hydro power) in time (t-1)</td>
<td>+ 0.92% renewable energy use in t</td>
</tr>
<tr>
<td>Energy Demand Effect:</td>
<td></td>
</tr>
<tr>
<td>+1% total energy use (excluding renew.) in t</td>
<td>+ 0.33% renewable energy use in t</td>
</tr>
<tr>
<td>Policy Effect (short-run, no R&amp;D):</td>
<td></td>
</tr>
<tr>
<td>+ 1 Renewable Energy Policy in t-1</td>
<td>+ 0.012% renewable energy use in t</td>
</tr>
<tr>
<td>Other Factors:</td>
<td></td>
</tr>
<tr>
<td>+ 1% Others</td>
<td>0% (not significantly different from zero)</td>
</tr>
</tbody>
</table>

As shown in Table 3.5, renewable energy use in the preceding year (i.e. t-1) explains almost the entire variation in the current renewable energy use (i.e. t): a 1% increase in renewable energy use in the previous period is associated with a 0.92% increase in the current period. In other words, the level of renewable energy produced in the current year is strongly correlated with the level of renewable energy produced in the previous year. This is explained by the incremental changes in capacity and low average variation in renewable energy resource availability. Total energy demand (excluding renewable energy) is positively related to the renewable energy use. This variable only serves as a control for total energy demand.

Of interest here is the effect of the renewable energy policies, referred to as policy effect in Table 3.5. The analysis shows that one additional renewable energy policy in a Member State is associated with a 0.012% increase in the energy produced using renewable resources. This
estimate neglects long-run effects of policies and especially the impact of research and development (R&D) policies in the past on today’s use of renewable energy technologies, which could be substantial. In this sense, the relatively small size of the estimate is not surprising. Given these estimates, the EU-27 as a whole would have had a 1.4% lower share of energy produced using renewable resources had there been no renewable policies in place. This means that for the year 2012, the share for the EU-27 would have been approximately 8% but actually was 9.4% (and with hydropower the share was approximately 11% in 2012). As outlined previously, this effect is very low and excludes the effect of R&D policies and long-run effects.

Given these concerns and the considerations expressed before, it is very likely that a large proportion of the installed renewable energy capacity has its origin in different policy activities. This is especially the case as even today, governmental support (such as feed-in tariffs) is generally needed to make renewable energy technologies competitive compared to conventional technologies. Therefore, this report assumes the estimated abatement of renewable energy technologies presented in Figure 3.3 to be mainly driven by policies, either directly in the short-run or indirectly due to long-run effect of older R&D support policies.

### 3.1.3 Key findings

Figure 3.3 shows the level of the estimated emissions expected in the absence of the climate policies included in this analysis. These estimated emissions – represented by the full bars – are superimposed by the actual emissions – represented in black and dashed black. This summarises the results of the study for the EU-27 as a whole, for the 1990-2012 period. Figure 3.3 combines the results of the econometric models shown in the previous sections. It is assumed, that the EU ETS had no effect on the use of renewable energy.\(^ {17} \)

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\(^ {17}\) An empirical study by Gavard (forthcoming) using data for Denmark found that the carbon price has to reach 27 EUR/t for wind power to be price competitive with coal and 48 EUR/t for it to be competitive with gas plants. Against this backdrop, the assumption that the impact of the EU ETS on renewable investments and use was rather limited so far seems to be reasonable.
The contributions of the different policy types to the overall emission abatement are described as follows:

- The EU ETS is identified as a significant contributor to total EU-27 emissions reductions during the 2005-2012 period. For Phase 1 (2005-2007) and 2 (2008-2012) together, the estimated abatement is about 7% of the estimated counterfactual baseline scenario emissions covered by the EU ETS. During Phase 2 (2008-2012), the estimated abatement of the EU ETS was about 1,000 Mt CO$_2$ equivalent, around 9% of the counterfactual baseline scenario emissions during this period. This estimated abated volume is based on a counterfactual modelling technique of subtracting actual emissions from projected emissions under a ‘without EU ETS’ scenario.

- The study also finds that national climate policies have made a significant contribution to emission abatement. These policies, as covered under the ESD, vary considerably across the EU MS.

- The effect of energy taxes on CO$_2$ emission abatement is estimated to be relatively small compared to that of other policies and the EU ETS, but to vary widely among Member States. The finding on energy taxation is explained by the revenue collection purpose of energy taxation and the small share of energy and transportation taxes as a proportion of the MS’ GDP$^{18}$. Transportation taxes are not identified as having a significant impact on emissions.

$^{18}$ This view is confirmed for the case of Germany by Flues and Lutz (2015) as they find that the electricity tax generates governmental revenues without adversely affecting the performance of German firms. Similar findings are reported by Martin et al. (2014) for a carbon tax that affected British firms in the manufacturing sector.
Renewable energies, including traditional hydro power, make up by far the greatest abatement contribution. During Phase I and Phase II, the abatement due to renewables amounts to about 1,900 Mt CO2 equivalent and 3,400 Mt CO2 equivalent, respectively. Subsequent parts of this work show that policies had a significant impact on renewable energy production. We also know that research and development policies have longer term impacts that are not measured specifically as part of this study, but are very important.

This report finds strong empirical evidence for a significant role of EU ETS and national climate policies in CO2 emission abatement. The impact of the policies on emissions primarily occurred as a result of the intensity effect and not due to the structural or the activity effect. This is confirmed by recent academic literature such as findings by Petrick and Wagner\(^{19}\) and Martin et al.\(^{20}\). These studies do not find any significant effect of climate policies on several performance indicators of firms that are affected by regulation. Specific empirical analyses conducted as a part of this study and presented in Annex 4 strongly supports this view. These are:

- A model for economic activity based on a standard GDP growth model that is directly premised on core economics models. This model does not find any evidence for an effect of national climate policies implemented under the ESD on GDP (or GDP growth).

- A dynamic model relating climate policies to economic structure, i.e. the relevance of the industry sector in relation to the service sector. This model does not reveal any significant effects of climate policies on structural change.

The climate policies are considered have led to significantly lower CO2 emissions by triggering improvements in energy efficiency and in the fuel mix. Taking these considerations into account, the results from the IDA described in task 2B for EU-27 as a whole are updated in the figure below.

**Figure 3.4 IDA including the estimated abatement effect**

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The results for the activity and structural effects are similar to those obtained as part of task 2B. The combined net intensity and fuel mix effect is smaller under this approach, suggesting that in 2012, the EU would have emitted 73% of its 1995 emissions had only the fuel mix and intensity changed and all the other factors been constant. Of the 27% reduction under the updated approach, 12% is attributed to the effect of climate and renewables policies between 1995 and 2012. If the effect of climate policies and renewables is extrapolated to 1990, the abatement estimate increases to 16%. The remaining fuel mix and intensity effect is believed to be linked in part to technical improvements exogenous to the model, responses to energy prices and long-term effects of climate policies not captured directly in the model. Nevertheless, a certain share of changes in the fuel mix effect is a consequence of the EU ETS.

Below is a non-technical description of the scope, data sources, methods and assumptions. The reader with knowledge in statistical and econometric methods is referred to the Annex 4 and Annex 5.

3.1.4 Conclusions

This section provides an ex post evaluation analysis of the effect of different climate policies on CO₂ emissions. The policies considered are:

- The EU ETS;
- National climate policies of the MS (under the ESD);
- Energy taxes; and
- Renewable energy policies.

Given that these policies differ in regulatory design and in their expected impact on emissions in time, three different models have been considered and complemented by additional analysis – presented in Annex 4 – and by the findings from existing empirical economic research studies. Both the additional analyses presented in the Annex and the results from the other studies conclude that there is no evidence that climate policies have so far affected economic growth (or economic activity) and structural change. The effects of climate policies on CO₂ emissions as presented in this report are therefore very likely to apply via the carbon-intensity and fuel-mix effect.

The most significant results are that renewable energy has the strongest impact on emission abatement and renewable energy is a key factor that helped reduce CO₂ emissions while economic growth occurred at the same time. National climate policies (under the ESD) and the EU ETS have also significantly contributed to emission abatement (Table 3.4). The effect of energy taxes is considerably smaller than the effect of EU ETS or the other climate policies. These conclusions are based on modelling results which are based primarily on data from previous trading periods, and which do not reflect recent changes to the EU ETS, such as the introduction of auctioning as the default method for allocation to the power sector and harmonised EU wide rules for free allocation to industry.

The results in this report are estimates of the effects of policies on emissions. The true effect cannot be measured because there is inherent uncertainty about the counterfactual baseline level of emissions, had there been no additional policies in place. The methods used in this report to estimate the counterfactual baseline are robust and the estimation procedures are based on recent existing economic research. However, the estimated effects of the policies are limited in their validity as they represent short-run effects. For both cases, national climate policies and renewable policies, research and development support and subsidy policies have been excluded from the analyses as these policies trigger technological improvements and the introduction of new technologies into the market which occurs over the long term. The effects of new technologies on emissions are, without doubt, substantial but are not accounted for directly in this report. The numbers presented here are therefore regarded as very
conservative and likely represent the lower estimate of the effect of climate policies on CO₂ emissions.

3.2 Analysis of the mitigation impact of key policies and measures within Member States based on the review of the PAM database and interviews with stakeholders

3.2.1 Objectives
The purpose of tasks 3A, 3C and 3D is to complement the results of the decomposition analysis and the estimations of the econometric analysis with additional details and an illustration of the way in which policy and non-policy drivers influence the decomposition factors at MS level. The decomposition analysis shows how factors such as GDP growth, changes in the structure of the economy or in energy intensity affect GHG fluctuations but does not provide insights into the impact of specific climate and energy policies on emissions - this is the primary purpose of this section. This analysis uses a considerably higher level of detail and a methodology different from the econometric analysis, thereby providing a comparator for its findings.

As part of these tasks, 15 countries were selected from among the EU28. Individual country fiches were developed to outline the policy context, the policies with the highest emissions reductions impacts and other key factors that have affected emissions between 1995 and 2012 in each Member State. The country fiches are presented in a separated zip file. The text below provides a summary of the findings presented in the fiches and a comparison of the results with those of the econometric analysis.

3.2.2 Methodology
The approach taken to this task is shown in Figure 3.5. 15 Member States were selected for this analysis. The selection of Member States reflects a mix of individual country contexts, such as total emissions levels (top five EU emitters were included), whether the ESD allows a growth in emissions compared to 2005 levels or requires a drastic reduction, whether the country is a new MS or not. Table 3.6 lists the selected countries.
Figure 3.5  Approach use for the assessment and analysis of national PAMs

Table 3.6  Countries selected for the survey of PAMs and consultations

<table>
<thead>
<tr>
<th>Country</th>
<th>Reason for inclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>Top 5 emitter</td>
</tr>
<tr>
<td>Poland</td>
<td>Top 5 emitter, newer MS</td>
</tr>
<tr>
<td>France</td>
<td>Top 5 emitter</td>
</tr>
<tr>
<td>Germany</td>
<td>Top 5 emitter</td>
</tr>
<tr>
<td>Italy</td>
<td>Top 5 emitter</td>
</tr>
<tr>
<td>Austria</td>
<td>Large ESD reduction target, large proportion of emissions from transport</td>
</tr>
<tr>
<td>Czech Rep</td>
<td>Newer MS</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>ESD permits GHG increase, newer MS</td>
</tr>
<tr>
<td>Lithuania</td>
<td>ESD permits GHG increase, newer MS</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>Large emitter per capita</td>
</tr>
<tr>
<td>Belgium</td>
<td>Large emitter per capita</td>
</tr>
<tr>
<td>Spain</td>
<td>Large emitter</td>
</tr>
<tr>
<td>Ireland</td>
<td>Large ESD reduction target, economy has dominant sector (agriculture and transport)</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Large ESD reduction target, large emitter</td>
</tr>
<tr>
<td>Sweden</td>
<td>Large ESD reduction target, low emission intensity</td>
</tr>
</tbody>
</table>

For each country, approximately ten PAMs were identified based on a review of documents that included:
Decomposition analysis of the changes in GHG emissions in the EU and Member States

- MS reports under the Monitoring Mechanism Regulation (MMR) in 2015, and previous reporting under the EEA PAM database;
- MS National Communications to the UNFCCC;
- IEA databases: Global Renewable Energy\(^\text{21}\), Energy Efficiency\(^\text{22}\), and Policy Measures Addressing Climate Change; and
- Policies not specifically designed to address climate related goals, but that have potentially affected GHG emissions, typically through secondary effects.

It has not been possible in this study to analyse all climate policies in the 15 countries chosen. The selection of policies was based on whether the effects of the policy are understood to have been significant and whether there is a quantifiable impact. This method excludes a number of policies, such as the promotion of research and development in renewable energy and energy efficiency technologies. As discussed in section 3.1.2.3, the impacts of these policies are generally more difficult to quantify due to the long impact lead time. The limitations of the methodology are discussed in detail in section 5.1.4.

Draft country fiches containing the analysis of the selected PAM's impacts were validated by Member State representatives\(^\text{23}\). This process augmented the list of PAMs and improved the quality of the assessments.

To allow further analysis, the annual mitigation impact of each PAM\(^\text{24}\) was compared to the national emissions of the Member State in which the PAMs was implemented. 2012 was taken as year of reference for this exercise. The objective of this analysis was to assess the relative mitigation impact of each PAM. These relative contributions were then aggregated in groups to allow further analysis. The ranges used as reference for this were:

- **Low mitigation impact:** annual mitigation impact representing 0% to 0.49% of the 2012 national GHG emissions;
- **Medium mitigation impact:** annual mitigation impact representing 0.5% to 1.49% of the 2012 national GHG emissions;
- **High mitigation impact:** annual mitigation impact representing 1.5% to 3.99% of the 2012 national GHG emissions;
- **Very high mitigation impact:** annual mitigation impact representing more than 4% of the 2012 national GHG emissions.

Each PAM was also analysed with regard to its sectoral focus\(^\text{25}\) and types of policy instrument put in place to achieve its objectives\(^\text{26}\). Finally each PAM was linked to a decomposition factor, i.e. intensity effect, fuel mix effect, combination of intensity and fuel mix effect or direct emission reduction.


\(^{23}\) Interviews with representatives of 12 MS, excluding those for Poland, Austria and the Netherlands took place between 6 and 23 October 2015.

\(^{24}\) To the extent possible the research team identified an average annual figure of the mitigation impact during the active period of the policy but this has not always been possible due to lack of available data. In these cases the most recent figure was taken as reference.

\(^{25}\) Taking as reference the sectors used in the MMR, i.e.: energy supply, energy consumption, transport, industrial processes, agriculture, waste, forestry / LULUCF and cross-cutting.

\(^{26}\) Taking as reference the policy instruments used in the MMR, i.e.: economic, fiscal, voluntary / negotiated agreement, regulatory, information, education, research, planning and other.
In what follows, a summary of the main PAM patterns is presented, with an indication of which decomposition drivers were likely to have been affected by the selected policies. The results are then compared to those of the econometric analysis.

3.2.3 Key findings

The survey of national PAMs resulted in the identification of 111 climate and energy PAMs spread across a spectrum of policies that included: support to renewable energy diffusion, energy efficiency improvements within buildings and industrial sectors, support to biofuel, etc. Among these, the PAMs map onto decomposition drivers as follows:

- 47% of the PAMs specifically targeted energy efficiency improvements and achieved emissions reductions through the “intensity effect”;
- 30% targeted RES diffusion and achieved emissions reductions through the “fuel mix” effect. Despite the lower policy count of RES policies, these appear to have a prominent impact, as shown in the discussion of the policy ranking below;
- 16% included both aims and, for example, entailed provision of grants for small district heating schemes;
- The remaining 7% of PAMs targeted direct emissions of non-\(\text{CO}_2\) gases, such as \(\text{N}_2\text{O}\) from adipic acid production or from fertiliser use in agriculture. These policies reduced emissions through the “emission factor” effect.

A number of additional policies not specifically directed at climate mitigation but having a strong emissions reduction impact, were identified for most MS considered. These 23 items included the implementation of:

- The Landfill Directive and other waste related policies (representing 41% of the policies with a secondary climate mitigation effect), mainly acting through the “emission factor” effect but also impacting the “fuel mix effect” through for example the use of captured biogas as energy source;
- The Common Agricultural Policy (CAP) and other agricultural policies (18%), acting through the “emission factor” and possibly through the “activity” effect;
- The Large Combustion Plant Directive (LCPD) (14%), acting through the “fuel mix” effect;
- The Nitrate Directive (14%), impacting direct emissions from the agricultural sector;

One MS representative also identified that the Integrated Pollution Prevention and Control Directive is a relevant indirect PAM acting through the ‘intensity effect’. National policies in some new MS modernised the energy supply infrastructure and acted on emissions through the “intensity effect”.

Although the PAM selection and analysis did not include map national policies to EU Directives at the outset, the results of the analysis show that the implementation of key EU policies has played a significant role in all the MS analysed. Where EU Directives did not apply, a number of national policy patterns also emerged across the MS considered. These patterns are discussed below.

3.2.3.1 EU Directives

The majority (76%) of the PAMs identified in the MS implemented EU climate and energy policies. Figure 3.6 groups these PAMs according to the EU policies they aimed to support, i.e. renewable energy policies, energy efficiency in buildings, energy efficiency in industry, support to biofuels, emission standards for vehicles, support to cogeneration heat and power and other EU policies. In some cases one policy could be linked to different EU energy and climate laws; when this was the case, the study team allocated this policy to the most relevant group according to its specific objectives.
The mitigation impact of these national policies varied considerably due to the specificity of each policy and the national contexts in which they are implemented, e.g. PAM with regional scope, etc. Figure 3.6 provides an overview of the performance of each group of policies based on the relative mitigation impact of each policy at national level. It also includes policies for which no quantification of the mitigation impact was available. Each policy group is then discussed in more detail below.

**Figure 3.6 Mitigation impact of the energy and climate PAMs linked to EU legislation**

<table>
<thead>
<tr>
<th>Policy Group</th>
<th>Number of PAMs</th>
<th>Mitigation Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renewable energy</td>
<td>25</td>
<td>Very high</td>
</tr>
<tr>
<td>EE in buildings</td>
<td>20</td>
<td>High</td>
</tr>
<tr>
<td>EE in industry</td>
<td>15</td>
<td>Medium</td>
</tr>
<tr>
<td>Support to biofuel</td>
<td>10</td>
<td>Low</td>
</tr>
<tr>
<td>Emission standards vehicles</td>
<td>5</td>
<td>No data</td>
</tr>
<tr>
<td>CHP</td>
<td>5</td>
<td>No data</td>
</tr>
<tr>
<td>Other</td>
<td>5</td>
<td>No data</td>
</tr>
</tbody>
</table>

Source: ICF International

**Climate and Energy Policies**

- **EU ETS**
  
  The impacts of the EU ETS have not been systematically considered at MS level due to difficulties in attributing emissions reductions to the EU ETS. This aspect is addressed in detail under section 3.1.2.1.

- **Renewable energy policy**
  
  A total of 27 PAMs intended to promote RES were selected across the 15 MS. A quantified mitigation impact was available for 19 of them. Renewable energy policy is the only policy groups with PAMs having a very high mitigation impact, i.e. more than 4% of the 2012 national emissions (Figure 3.6). Eight PAMs have a medium to high mitigation impact and eight have a low mitigation impact. Overall this confirms that renewable energy policies are effective in reducing GHG emissions. The vast majority of these policies (i.e. close to 80%) rely on economic incentives, such as feed-in-tariff and other types of subsidies, to achieve their objectives.

- **Energy efficiency in buildings**
  
  The implementation of policies implementing the 2010 Energy Performance of Buildings Directive features strongly across the 15 MS, with 21 individual policies identified. However, given the relatively low emission baseline tackled and the high number of stakeholders affected, the relative importance of this policy’s contribution to emissions reductions is fairly low. As shown in Figure 3.6, 12 of the identified policies had a low mitigation impact and only one policy had a high mitigation impact. The instruments used by these policies include economic incentives, regulatory obligations and fiscal measures to facilitate energy efficiency investments.

- **Energy efficiency in industry**
This grouping of policies includes the design and implementation of National Energy Efficiency Action Plans, energy efficiency improvement agreements with industry and other support schemes for energy efficiency investments. This category includes 13 policies, four had a medium to high mitigation impact but half had a low mitigation impact. Potential reasons for this relatively weak performance include the use of softer policy mechanisms – seven of these policies are mainly based on voluntary / negotiated agreements with industrial actors and the potentially weak response of operators to these softer policy mechanisms. The potential overlap in results with other policies, primarily the EU ETS, might also explain this relatively weak performance.

- **Support to biofuels in transport**
  In 11 of the 15 MS, the use of biofuels in transport features among the key PAMs. These policies performed relatively well as half of them proved to have a medium to high impact on GHG emissions. However, the relative mitigation impact remains lower than that under RES promotion in stationary sources.

  Belgium, the Czech Republic, Germany and Sweden all list policies linked to the measurement and publication of the CO₂ performance of cars as an important GHG reduction contributor during the study period together with the inclusion of emissions standards for new cars. Other countries adopted policies – such as the greening of their vehicles taxes or support for the purchase of clean vehicles - to pursue the same objective, i.e. the greening of the national vehicle fleet. Attribution to EC law is therefore difficult as some MS may have acted as early adopters through national policy decisions and others adopted complementary measures.

  The majority of the policies within this group, for which a quantified mitigation impact was identified, performed relatively poorly as they had a low mitigation impact. This might partly be due to the time lapse required to renew a vehicle fleet.

- **Promotion of CHP production**
  The promotion of CHP, either through electricity supply obligations or through financing of distributed CHP systems as part of district heating promotion mechanisms, features in nine policies in Austria, Bulgaria, Germany, France, Ireland, Lithuania, Poland and Spain. These policies primarily used economic instruments such as subsidies.

- **Other policies linked to EU legislations**
  Finally a series of policies linked to other EU legislation have been identified as important mitigation option in a series of MS. This includes two policies linked to the implementation of the Eco-design Directive and three policies linked to the EU legislation to control Fluorinated-gases (F-gases). These policies had a medium to high mitigation impact.

**EU Directives with a strong secondary climate mitigation impact**

As noted above a series of policies linked to various EU Directives had a secondary impact on GHG emissions. This concerns policies linked to the Landfill Directive, the CAP, the Nitrate

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27 Directive 1999/94/EC relates to the availability of consumer information on fuel economy and CO₂ emissions in respect of the marketing of new passenger cars.

28 Decision 1753/2000/EC established a scheme to monitor the average specific emissions of CO₂ from new passenger cars in the EU. Based on this Decision MS had to report average specific CO₂ emissions of new passenger cars to the EC on a yearly basis.


30 The policies identified are not mapped directly to the 2004 Cogeneration Directive.
Directive and the LCPD. The relative contribution of these PAMs is presented in Figure 3.7 below.

**Figure 3.7 Mitigation impact of the indirect PAMs linked to EU legislation**

![Figure 3.7](image)

*Source: ICF International*

- **Landfill Directive and other waste related policies**
  
  Nine MS listed the reduction of CH$_4$ emissions from landfills or other waste related policies as key mitigation policies during the study period. As illustrated in Figure 3.7, these policies proved to be effective; five of these had a medium mitigation impact and two had a high to very high mitigation impact.

- **Agricultural policies**
  
  The implementation of the CAP has led to a decoupling of subsidy payments from livestock numbers across the EU; which has contributed to a significant decrease in CH$_4$ and N$_2$O emissions in countries with strong agricultural sectors such as Austria, the Czech Republic, France, Ireland and Spain. Other CAP aspects such as stubble management and the promotion of organic farming are also linked to better emissions performance.

- **Nitrate Directive**
  
  The implementation of the Nitrate Directive has led to lower levels of N$_2$O in agriculture across the EU. In France and Spain this policy has had particularly high impacts and was therefore included among the key PAMs as part of the analysis.

- **LCPD**
  
  The implementation of the LCPD has led to significant changes in the operating hours of coal fired stations in Germany, Poland and the UK. The electricity generated by these plants was replaced by less carbon intensive producers.

**3.2.3.2 National policies**

28 national policies, which could not be linked to any EU legislation, were identified as important mitigation policies across the 15 MS analysed. Most of the national PAMs can be considered to be cross-cutting policies (Figure 3.8). These often take the form of subsidy schemes, investment programmes or fiscal measures designed to support investment in a

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31 This is one of the key emissions reductions reported in the selected PAMs that may be associated with a displacement of emissions in other MS due to potentially higher imports of meat into the EU.
variety of projects such as low-carbon investment in industries or energy transition projects at local level. This group also includes environmental taxes such as the carbon and energy taxes in place in Sweden, Ireland, the Netherlands and Lithuania. The effectiveness of these environmental taxes seemed to vary across MS but they can be very effective, as demonstrated by the energy and carbon tax in place in Sweden which had a particularly high mitigation impact (15% of the 2012 GHG emissions of Sweden).

The second group of national PAMs – representing 32% of the identified policies – relates to the transport sector. Within that sector, the PAMs identified include measures such as increased fuel taxation in Austria, Germany and Luxembourg; the promotion of modal shifts through various mechanisms in Belgium; and a number of support scheme in favour of sustainable mobility. As illustrated in Figure 3.9 the effectiveness of national PAMs linked to the transport sector varied considerably across the MS.

The third group of national PAMs cover policies targeting energy supply but not linked to RES. Three of the four PAMs in that group were identified in Bulgaria and are linked to the improvement of the energy distribution and transmission networks which are either under-developed or subject to import losses. These policies proved very effective as they had a high mitigation impact.

Two national PAMs were linked to industrial processes, specifically to the production of nitric acid in Belgium and the Netherlands. These two policies vary considerably in their design: the Belgian regions signed specific emission reduction agreements with the producers while the Netherlands opted in to integrate N₂O emissions from nitric acid plants within the EU ETS in phase two of the EU ETS. Both proved very effective and achieve a high mitigation impact during the studied period.

Two national PAMs linked to the energy consumption and waste sectors were identified in Spain and the UK.

**Figure 3.8 Key sectoral focus of national PAMs**

![Key sectoral focus of national PAMs](image)

*Source: ICF International*
3.2.4 Discussion on the results of the econometric and analysis of national PAMs

In Section 3.1, econometric methods are used to assess the role of the EU ETS, renewable energy generation and a sample of climate mitigation policies under the ESD that is narrower than the selection under the survey of national PAMs and consultation with MS representatives. The figure below illustrates the difference in the count of climate policies included in the econometric analysis as compared to the full list of policies included in the analysis of national PAMs.

**Figure 3.10** Comparison of the number of policies selected for the econometric analysis and the analysis of national PAMs per MS

**Source:** ICF International

Table 3.7 shows the relative contribution of different types of policy (within the total statistically identifiable effect) based on the econometric analysis.
Table 3.7  Contribution to CO₂ abatement by type of policy based on econometric results

<table>
<thead>
<tr>
<th>Policy and renewable energies</th>
<th>Abatement in % of total abatement (2012)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renewable Energy (total)</td>
<td>63%</td>
</tr>
<tr>
<td>EU ETS</td>
<td>17%</td>
</tr>
<tr>
<td>National Climate Policies (under the ESD)</td>
<td>13%</td>
</tr>
<tr>
<td>Energy Taxes</td>
<td>8%</td>
</tr>
<tr>
<td><strong>Total Policy/Renewable Effect</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Despite the significant differences in methodologies, the conclusions under the two approaches concur. RES promotion emerges as the most important climate mitigation mechanism during the study period. Both approaches also suggest that the large majority of PAMs put in place at national level impacted GHG emissions through the “intensity” and “fuel mix” effect, with no strong evidence of PAMs impacting economic activities.

A large number of relevant policies have not been included in the econometric analysis. The effect of the policies targeting CO₂ that were included may therefore have been over-estimated as the emission reduction effect is allocated to a subset of the policies in force rather than shared across all of them. As the econometric analysis only considers CO₂ emissions, the impact of RE policies on GHG emissions might be more important than shown here.

### 3.2.5  Conclusions

A total of 134 PAMs in 15 Member States were analysed. A large number of further policies were excluded due to relatively low emissions reduction impacts; lags in effects; dispersed effects across multiple MS; or inherent difficulties in quantifying emissions reductions impacts.

The analysis complemented and confirmed the findings of the econometric analysis. The key learning points from this section are that RES promotion, the EU ETS and energy efficiency policies emerged as the most important GHG reducing instruments across all Member States. Multiple national policies, such as the targeting of non-CO₂ gases, covenants with industry or incentives for modal shift in transport also feature across the MS considered. The implementation of policies that don’t target climate mitigation directly, such as the Landfill Directive, the LCP Directive, the CAP and the Nitrate Directive, play a significant role, including reducing non-CO₂ emissions.

The results of the analysis of national PAMs chime with those of the econometric analysis, but also suggest that the impact of national PAMs is likely to be considerably higher than what was suggested by the econometric estimation due to the econometric analysis covering only a fraction of the policies adopted.
4 Overview of the cost-effectiveness of specific policies

4.1 Objectives
The objective of this task is to examine the cost-effectiveness of the policies identified under task 3 above. Given the focus of this project and the data limitations that constrain analysis of the cost-effectiveness of climate and energy policies, this task seeks to illustrate which types of policies can be cost-effective rather than to provide a robust benchmarking analysis. This complements task 2 and 3 (which focus on the effectiveness of policies without consideration of cost). This task also inform future research needs.

4.2 Methodology
For each group of policies identified as having an impact on the different factors behind GHG emission reduction over the 1995-2012 period – as identified in task 3 – the existing cost data reported by the MS through the latest MMR report are presented and discussed. Given the scarcity of these data in the 2015 MMR reports, the results of other recent studies which analysed the cost-effectiveness of climate and energy policies within Europe are also presented. Two studies are taken as reference as they present very distinct approaches:

- The first one is a study on carbon pricing developed by the OECD in 2013\textsuperscript{32}. The estimate developed by the OECD is based on: “a partial equilibrium and comparative statistic approach that compares in the latest year for which data are available a snapshot of the post-policy situation to a counterfactual snapshot of no policy (…) The estimates presented [in the report] give an indication of relative shadow prices of carbon in 2010 within and across OECD countries. They do not necessarily properly reflect the long-term abatement incentives embedded in existing or planned policies in the countries concerned”\textsuperscript{33}. By looking at marginal abatement costs, the OECD takes a short term view reflecting the perception of most market actors.

- The second study covers the results of the project Sectoral Emission Reduction Potentials and Economic Costs for Climate Change (SERPECCC), published in 2009\textsuperscript{34}. The SERPECCC project used a social cost method and adopted a long term perspectives on abatement cost. It took account the costs of the capital investments – annualised over the technical lifetime of the measure – and operation and maintenance, over and above the reference technology, assuming a discount rate of 4%. The financial benefits of energy savings were accounted for, but taxes and subsidies excluded.

The objective is to put data reported in the 2015 Monitoring Mechanism Regulation reports in perspective and highlight the challenge of comparing cost-effectiveness data. Indeed, the benchmarking of PAMs faces important challenges and limitations in respect of data availability and methodology. These limitations relates to the difficulty of comparing ex ante and ex post analysis, the scarcity of cost-effectiveness assessment of PAMs, and the high level of caution needed when comparing existing cost-effectiveness data. These limitations are described in more detail in section 4.1.5.


\textsuperscript{33} For a full description of the methodology used in the OECD report, consult chapter 2 of the 2013 OECD report.

4.3 Key findings

4.3.1 Promotion of RES

As explained above, the majority of the PAMs supporting RES rely on economic incentives such as feed-in tariffs and other types of subsidies and investment programmes to achieve their objectives. As feed-in-tariff and investment programmes are two very different types of policies, their costs are considered separately in this section.

4.3.1.1 Feed-in tariffs

The only country which reported the costs associated with its feed-in tariff during the 2015 MMR reporting cycle is the Czech Republic. It reported a cost of € 340 per tonne of CO$_2$-eq for a measure which had a mitigation impact of 0.98 Mt CO$_2$-eq in 2010. This cost estimate is based on the extra payments of power distributors to electricity suppliers for electricity from RES. It therefore only represents the costs for power distributors and do not take into account any other cost or benefit components.

As stressed by the OECD in 2011, the marginal abatement costs associated with feed-in tariffs depend on two key parameters: the total amount of the feed-in tariff compared to the electricity market price and the carbon intensity of the power generation technology that is displaced by the subsidised technology. With a fixed feed-in tariff, the abatement cost will be lower if the carbon intensity of the displaced technology is high as a larger quantity of GHG is abated by the subsidised technology. This implies that the abatement costs of feed-in tariffs considerably vary across MS. The differences are exacerbated by the differentiation in feed-in tariffs across RES introduced by many governments to reflect the varying investment costs of RES. These differences across countries and energy sources are illustrated by Table 4.1. The marginal abatement costs of feed-in tariffs goes from negative costs for biomass in the UK (€ -115 per tonne of CO$_2$-eq) or for wind power in Portugal (€ -24 per tonne of CO$_2$-eq) to very low cost (e.g. € 5 per tonne of CO$_2$-eq for hydropower in Portugal) and more that € 1,500 per tonne of CO$_2$-eq for solar energy in Austria and France.

Table 4.1 GHG abatement costs implied by feed-in tariffs in Europe, 2009-2010 (€/tCO$_2$-eq reduced)

<table>
<thead>
<tr>
<th>Solar</th>
<th>Wind</th>
<th>Biogas</th>
<th>Biomass</th>
<th>Geothermal</th>
<th>Hydro</th>
<th>Wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>939-1,515</td>
<td>132</td>
<td>472</td>
<td>123</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BE</td>
<td>382-1,442</td>
<td>82-170</td>
<td>82-170</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CZ</td>
<td>689</td>
<td>71</td>
<td>94</td>
<td>96</td>
<td>179</td>
<td>65</td>
</tr>
<tr>
<td>DK</td>
<td>4-111</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FI</td>
<td>85</td>
<td>63-179</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FR</td>
<td>3,107-6,157</td>
<td>447-997</td>
<td>23-507</td>
<td>940-1,513</td>
<td>883-1,227</td>
<td>260-682</td>
</tr>
<tr>
<td>DE</td>
<td>487-655</td>
<td>89-153</td>
<td>65-130</td>
<td>65-130</td>
<td>111-343</td>
<td>63-147</td>
</tr>
<tr>
<td>EL</td>
<td>422-614</td>
<td>3-17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IR</td>
<td>28-165</td>
<td>50-246</td>
<td>132-165</td>
<td></td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>IT</td>
<td>495-718</td>
<td>412</td>
<td>496-412</td>
<td>268</td>
<td>232</td>
<td>484</td>
</tr>
<tr>
<td>NL</td>
<td>87</td>
<td>87</td>
<td>87</td>
<td></td>
<td>87</td>
<td></td>
</tr>
<tr>
<td>PT</td>
<td>587-1,154</td>
<td>-24</td>
<td></td>
<td></td>
<td>5</td>
<td>200</td>
</tr>
<tr>
<td>SK</td>
<td>1,524</td>
<td>166</td>
<td>344</td>
<td>293</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>528-772</td>
<td>24-634</td>
<td>44</td>
<td>-115</td>
<td>24-337</td>
<td></td>
</tr>
</tbody>
</table>

Decomposition analysis of the changes in GHG emissions in the EU and Member States


Note: Abatement costs are computed using the lower- and upper-bound feed-in tariffs in excess of market prices and the amount of avoided CO$_2$-eq emissions.

### 4.3.1.2 Investment programme supporting RES

As shown in Table 4.2 the abatement costs of investment programmes, as identified in the 2015 MMR, vary considerably across MS, from € 35 per tonne of CO$_2$-eq for the support programme in Estonia to € 709 per tonne of CO$_2$-eq for the Czech programme. These differences reflects the varying nature of these investment programmes and the technologies they target. These cost estimates also only consider the costs for the governments and do not include the benefits associated with electricity sales or other revenues.

**Table 4.2 Abatement costs associated with key investment programme supporting RES**

<table>
<thead>
<tr>
<th>National policies</th>
<th>GHG emissions reductions</th>
<th>€/tCO$_2$ eq reduced / sequestered</th>
<th>Absolute costs per year</th>
<th>Key assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE – Offshore wind energy</td>
<td>0.136 Mt CO$_2$ eq / yr over the 2008-2012 period</td>
<td>179 €</td>
<td>Projected costs: 700 million €</td>
<td>Cost is calculated over the entire investment lifetime (20 years). It includes capital and operational expenditures. Costs are discounted at 8%. Cost estimation does not include taxes, electricity sales or green certificates.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Price year: 2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Year for which calculated: 2008-2012</td>
</tr>
<tr>
<td>EE – Investment support for wind parks</td>
<td>0.066 MTCO$_2$-eq in 2020</td>
<td>35 €*</td>
<td>Projected costs: 23 million €</td>
<td>An investment of € 23 million was made in 2010.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Price year: 2010</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Year for which calculated: No information</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Source: EE MMR report 2015</td>
</tr>
<tr>
<td>CZ – State Programme for the Support of Energy Savings and the Usage of RES</td>
<td>0.055 MTCO$_2$-eq in 2020</td>
<td>709 €</td>
<td>Projected costs: 1 million €</td>
<td>Total budget of the programme and energy savings including the substitution of fossil fuels by RES. Expected share of subsidies is 35% for investment projects and 90% for non-investment projects.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Price year: No information</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Year for which calculated: No information</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Source: CZ MMR report 2015</td>
</tr>
</tbody>
</table>

**Source:** 2015 MMR reports.

**Note:** * Cost data computed by dividing the absolute cost per year by the yearly GHG emissions reductions.

As illustrated in Table 4.3, if a longer social cost perspective is taken into account, as was the case in the SERPECC project, then investments in RES turn to be cost-saving for almost all technologies. This means that from a social perspective there will be a net economic gain from taking these measures.
Table 4.3 Abatement costs associated with different policies supporting RES

<table>
<thead>
<tr>
<th>Measure</th>
<th>Specific abatement cost (2005-€ / tonne CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power: Hydropower</td>
<td>-72</td>
</tr>
<tr>
<td>Power: Geothermal</td>
<td>-51</td>
</tr>
<tr>
<td>Power: Concentrated solar</td>
<td>-35</td>
</tr>
<tr>
<td>Power: Wind Off Shore</td>
<td>-23</td>
</tr>
<tr>
<td>Power: Wind On Shore</td>
<td>-22</td>
</tr>
<tr>
<td>Power: Photovoltaic</td>
<td>-21</td>
</tr>
<tr>
<td>Power: Biomass electricity</td>
<td>-9</td>
</tr>
<tr>
<td>Power: Tidal and wave</td>
<td>58</td>
</tr>
</tbody>
</table>


4.3.2 EU ETS in the electricity sector

Table 4.4 provides an overview of the abatement costs associated with the EU ETS in the electricity sector as computed by the 2013 OECD report. These vary from €13.6 to €18 per tonne of CO₂-eq.

Table 4.4 Abatement costs associated with the EU ETS in the electricity sector

<table>
<thead>
<tr>
<th>National policies</th>
<th>GHG emissions reductions</th>
<th>€/tCO₂ eq reduced / sequestered</th>
<th>Absolute costs per year in €</th>
<th>Key assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE – EU ETS fuel switching</td>
<td>0.7 – 3.9 Mt CO₂-eq</td>
<td>14.2 €</td>
<td>10 – 56 million €</td>
<td>Source: OECD, 2013</td>
</tr>
<tr>
<td>DK – EU ETS coal-to-gas switching</td>
<td>0.13 Mt CO₂-eq</td>
<td>13.6 €</td>
<td>1.7 million €</td>
<td>Source: OECD, 2013</td>
</tr>
<tr>
<td>FR – EU ETS supply-side effect</td>
<td>0.6 – 2.1 Mt CO₂-eq</td>
<td>14.5 €</td>
<td>8.7 – 30.5 million €</td>
<td>Source: OECD, 2013</td>
</tr>
<tr>
<td>UK – EU ETS coal-to-gas substitution</td>
<td>4 – 14 Mt CO₂-eq</td>
<td>18 €</td>
<td>72 – 252 million €</td>
<td>Source: OECD, 2013</td>
</tr>
</tbody>
</table>


4.3.3 Energy efficiency in buildings

The costs of energy efficiency policies targeting buildings vary greatly depending on the assumptions taken. If one considers the societal costs and benefits associated with the implementation of the energy efficiency technologies on the long-term, these often turn into important benefits for the investors – as illustrated in Table 4.5 and the first line of Table 4.6. These PAMs can generate a benefit equivalent of up to €78 per tonne of CO₂-eq saved. These benefits are largely due to the energy savings associated with these measures.

If a shorter term perspective is taken – as illustrated by the cost reported by the Estonian authorities in their 2015 MMR report (Table 4.6) and the OECD report (Table 4.7) – then the abatement costs of these policies end up relatively high depending on the characteristics of the policies. This high cost is explained by the fact that most of these policies are pure subsidies for household’s renovation. The 2013 OECD report illustrates that if a short term
Decomposition analysis of the changes in GHG emissions in the EU and Member States

A perspective is taken into account tax schemes aiming to improve energy efficiency within buildings prove to be more cost-effective than subsidy schemes due to their larger abatement potential.

**Table 4.5 Abatement costs associated with different energy efficiency improvement measures within buildings**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Specific abatement cost (2005-€ / tonne CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Progressive renewal of electric appliances</td>
<td>-60</td>
</tr>
<tr>
<td>Energy conversion (heating /cooling systems) within buildings</td>
<td>-54</td>
</tr>
<tr>
<td>Improved energy efficiency through for example insulation of buildings</td>
<td>-12</td>
</tr>
<tr>
<td>Energy conversion (biomass) within buildings</td>
<td>80</td>
</tr>
</tbody>
</table>


**Table 4.6 Abatement costs associated with energy efficiency measures within buildings reported in the 2015 MMR reports**

<table>
<thead>
<tr>
<th>National policies</th>
<th>GHG emissions reductions</th>
<th>€/tCO₂ eq reduced / sequestered</th>
<th>Absolute costs per year in €</th>
<th>Key assumptions</th>
<th>Source</th>
</tr>
</thead>
</table>
| BE – Energy efficiency in residential buildings – covers multiple policies | 1.57 MTCO₂-eq / yr (2008-2012) | -78 €                          | Projected costs: -400 million € | ■ Cost is calculated over the entire life time of the investment (technology dependent) and includes capital and operational expenditures. A real discount rate of 8% is used.  
■ Price year: 2012  
| EE – Energy efficiency improvement in public buildings         | 0.027 MTCO₂-eq in 2020         | 1,533 €*                      | Realised costs: 41.4 million € | ■ The total investment was 165.6 million €. The investment was made between 2010 and 2013.  
■ Price year: 2010  
| EE – Energy efficiency improvement in residential buildings     | 0.028 Mt CO₂-eq in 2020         | 332 €*                        | Realised costs: 9.3 million €  | ■ The total investment was 28 million €. The investment was made between 2010 and 2012.  
■ Price year: 2010  

*Note:* * Cost data computed by dividing the absolute cost per year by the yearly GHG emissions reductions.
Decomposition analysis of the changes in GHG emissions in the EU and Member States

Table 4.7 Abatement costs associated with energy efficiency measures within buildings computed by the OECD

<table>
<thead>
<tr>
<th>National policies</th>
<th>GHG emissions reductions</th>
<th>€/tCO₂ eq reduced / sequestered</th>
<th>Absolute costs per year in €</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE – Support for household renovation</td>
<td>0.006 – 0.01 Mt CO₂-eq</td>
<td>32 – 53 €</td>
<td>0.34 million €</td>
</tr>
<tr>
<td>UK – Energy Assistance Package (Scotland)</td>
<td>0.3 Mt CO₂-eq</td>
<td>94 – 133 €</td>
<td>2.9 – 0.48 million €</td>
</tr>
<tr>
<td>UK – Home insulation scheme (Scotland)</td>
<td>0.003 Mt CO₂-eq</td>
<td>272 – 317 €</td>
<td>0.62 – 0.98 million €</td>
</tr>
</tbody>
</table>


4.3.4 Energy efficiency in industry

As presented in section 3.2.3, the PAMs tackling energy efficiency measures in industry often take the form of soft mechanisms such as voluntary agreements and covenants between industrial players and the authorities. This implies that although the effectiveness of these policies is not guaranteed, they have a relatively low cost for the authorities. As presented in Table 4.8, this costs even turn to a net gain for the investors if the full societal costs and benefits of key mitigation measures are considered over the lifetime of a specific measure.

Table 4.8 Abatement costs associated with different energy efficiency improvement measures within industries

<table>
<thead>
<tr>
<th>Measure</th>
<th>Specific abatement cost (2005-€ / tonne CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New BAT installations</td>
<td>-107</td>
</tr>
<tr>
<td>Process improvement within refineries</td>
<td>-78</td>
</tr>
<tr>
<td>Energy efficiency retrofit measures</td>
<td>-74</td>
</tr>
</tbody>
</table>


As demonstrated by the cost data submitted by the Czech government as part of its 2015 MMR report, the costs associated with investment programmes is considerably higher in views of the authorities than the costs of energy efficiency investments evaluated from the perspective of the investor.

Table 4.9 Abatement costs associated with energy efficiency measures within industrial sectors

<table>
<thead>
<tr>
<th>National policies</th>
<th>GHG emissions reductions</th>
<th>€/tCO₂ eq reduced / sequestered</th>
<th>Absolute costs per year in €</th>
<th>Key assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>CZ – Promotion of energy efficiency under the Operational Programme Enterprise and Innovation</td>
<td>3.2 Mt CO₂-eq in 2010</td>
<td>953 €</td>
<td>No data</td>
<td>• Calculated from budget allocated to the priority axe 3 - Effective energy. Both subsidies and own capital included.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Price year: No information</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Year for which calculated: No information</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Source: CZ MMR report 2015</td>
</tr>
</tbody>
</table>
4.3.5 Transport

Member States that reported the costs of policies they adopted to support use of biofuels in transport fuels used very different approaches, resulting in abatement costs that varied from € 40 per tonne of CO₂-equivalent to more than € 1,000 per tonne of CO₂-equivalent (Table 4.10).

Based on the data computed by the OECD in 2013 and presented in Table 4.11, fuel taxes seem to perform better in terms of both GHG abatement performance and abatement costs. These were however not picked up by many MS representatives during the consultation on the most relevant GHG mitigation policies during the 1995-2012 period. One reason for this might be that fuel taxes are often not considered to be a GHG mitigation measure.

Finally the OECD reports indicates that the cost-effectiveness of support schemes for electric vehicles is currently relatively low.

Table 4.10 Abatement costs associated with abatement measures in the transport sector

<table>
<thead>
<tr>
<th>National policies</th>
<th>GHG emissions reductions</th>
<th>€/tCO₂ eq reduced / sequestered</th>
<th>Absolute costs per year in €</th>
<th>Key assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biofuel mandate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| BE – Biofuels     | 0.921 Mt CO₂-eq / yr over the period 2008-2012 | 303 €                          | Projected costs: 600 million € | ■ Production costs of biofuels, taking into account capital expenditure and operational costs.  
      ■ Price year: 2012  
      ■ Year for which calculated: 2006-2020  
| CZ – Minimum share of biofuels | 0.82 Mt CO₂-eq in 2020 | 1,008 €                        | No data                     | ■ Estimates based on the difference between the price of biofuel and fossil fuel.  
      ■ Price year: No information  
      ■ Year for which calculated: No information  
      Source: CZ MMR report 2015 |
| FI – Promoting the use of biofuels in the transport sector | 0.83 Mt CO₂ eq / yr in 2012 | 40 €                           | No data                     | ■ The cost represents direct government cost occurring due to lower excise duty revenue from biofuels compared to corresponding fossil fuels.  
      ■ Price year: 2012  
      ■ Year for which calculated: 2012  
      Source: FI MMR report 2015 |

When taking a short term view on the cost and benefits of PAMs, the EU ETS is among the most cost-effective policies for GHG reduction. Fuel taxes also appear to be a cost-effective way to achieve GHG reduction, although these were not identified as an important mitigation policy by many stakeholders. The mandatory inclusion of biofuel into transport fuel seems to be one of the policy options with the highest abatement cost per tonne of CO\textsubscript{2}-eq within the European context.

Keeping a short term perspective, feed-in tariffs seem to be more cost-effective than direct infrastructure subsidies supporting RES. However, as discussed above, the cost-effectiveness of feed-in tariffs varies greatly across MS depending on their actual design and the country they apply to. If a long term “social cost method” is applied to renewable energy investments, these yield cost savings as they lead to important benefits.

The same logic applies to PAMs supporting energy efficiency measures. If a long term “social cost method” is applied, these PAMs lead to significant cost savings due to the energy savings they generate. However if a short term view is taken they suggest high abatement costs per tonne of CO\textsubscript{2}-eq as they involve important investment either within buildings or within industrial plants. It should be stressed, however, that measures targeting energy efficiency within buildings often have multiple purposes, i.e. not only supporting GHG mitigation objectives but also having important social objectives which are not considered in this cost-effectiveness analysis.
5 Discussion on the study approach and methodology

The objective of this study is to build on the methodology applied by the EEA in its 2014 study to further develop the analysis and expand its scope. As shown in Table 5.1, the two decomposition analysis approaches used (under task 2A and 2B) offer a series of improvements and enhancements when compared to the EEA methodology. The key improvements concern the breakdown of the analysis at MS and sectoral level; the consideration of additional factors and the inclusion of additional GHGs.

In addition to expanding the scope of the decomposition analysis, this study also goes one step further in analysing the causal links between the descriptive results of the decomposition analysis and specific GHG emission mitigation policies. This is done under task 3 through an econometric analysis focusing on the mitigation impact of the EU ETS, national policies under the ESD and renewable energy policies and an analysis of climate and energy PAMs at national level.

The objective of this section is to present the key advantages of each method used in this study and also to highlight weaknesses and limitations. The purpose is to identify recommendations for further studies.

Table 5.1 Improvements of decomposition analysis compared to the current EEA method

<table>
<thead>
<tr>
<th>Parameter / aspect</th>
<th>Details of EEA method</th>
<th>Details of improvements / enhancements in this project</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Approach A: Development of EEA approach</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Approach B: IDA with detailed sectoral resolution</td>
</tr>
<tr>
<td>Years covered</td>
<td>1990-2012</td>
<td>Choice of specific time frames necessary for specific policy assessment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EU level and MS where data availability allows</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Break down to level of individual MSs</td>
</tr>
<tr>
<td>MS breakdown</td>
<td>EU level only</td>
<td>EU only</td>
</tr>
<tr>
<td>Non EU countries</td>
<td>EU only</td>
<td>EU only</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EU plus 13 major economies outside EU (China, Russia, USA etc.) to enable comparison of EU performance to other major countries</td>
</tr>
<tr>
<td>Sectors</td>
<td>Limited number of sectors included</td>
<td>All Common Reporting Format (CRF) sectors and sub-sectors where decomposition is feasible and of relevance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>34 sectors (see listing below, and above table describing the advantages of detailed sectoral resolution)</td>
</tr>
<tr>
<td>Factors</td>
<td>Additional factors related to technology differentiation (e.g. renewables)</td>
<td></td>
</tr>
<tr>
<td>Econometric</td>
<td>Few variables in the empirical decomposition</td>
<td>As left</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Full-fledged empirical approach which uses results from the index decomposition and explains the different factors (recession analysis). Provides direct link to econometric analysis in task 3.</td>
</tr>
</tbody>
</table>
### 5.1 Key strengths, weaknesses and limitations of the study approach and methodology

#### 5.1.1 Updated EEA approach

The updated EEA decomposition analysis approach proved to be very useful for the identification of the factors shaping the evolution of GHG emissions at EU and Member State level, and within different sectors. The inclusion of specific factors for each sector under scrutiny allowed for a detailed sectoral analysis. The partition of the study period into different phases (e.g. pre-recession, during and post-recession) allowed analysis of the effects of the economic recession on GHG emissions and analyse of the effect of key drivers on emissions trends under different periods (pre-policy vs. post-policy).

As presented in A1.2, Eurostat and the MS GHG inventory submissions were the main data used for this decomposition analysis. The quality of these data is considered to be very high and hardly any gap-filling was needed. The main data limitations related to a delay in the submission of the latest MS GHG inventory submission due to a technical issue with the reporting process. This led the project team to use old CRF data in combination with data from PRIMES 2009.

Another issue linked to this approach is that it can only help researchers and policy makers understand the situation as it is. It doesn’t provide any insights on the links between the observed evolutions of the GHG emissions and the policies which might have caused these evolutions.

#### 5.1.2 Index decomposition analysis

The IDA applied under this study was a strong tool to describe the development of GHG emissions over time. By applying the three-factor and five-factor analysis at EU, MS and sectoral level a systematic comparative analysis was made possible. The inclusion of non-EU countries also allowed for cross-regional comparison. The detailed sectoral resolution of the IDA provided linked seamlessly to the econometric analysis applied under task 3B.

As described in detail in section A2.2, the main source of data for the IDA was the WIOD. The WIOD covers 40 countries (EU-27 and 13 other major economies) over the 1995-2009 period. It was complemented by additional data from Eurostat to cover the period 2009-2012. This led to a structural break due to switching from WIOD to Eurostat data. Unfortunately this coincided with the economic crisis, any conclusions therefore had to be developed with care and bearing this data limitation in mind. More resources could be spent harmonising the sectoral aggregation of Eurostat and WIOD data but the real added value of such aggregation needs to be considered as the available data already allowed for in-depth analysis.
Two additional shortcomings apply to the IDA:

- The WIOD data are only available for the EU-27 and do not cover Croatia. Efforts to identify suitable data were unsuccessful and so task 2B does not cover Croatia.
- A five-factor analysis was not possible for Belgium, Ireland, the UK and Portugal due to a lack of suitable data.

5.1.3 Econometric analysis

The econometric analysis and the different models used to assess the effects of the EU ETS, renewable energy policies and national policies under the ESD on CO₂ emissions abatement were a useful complement to the decomposition analyses:

- The dynamic model used to estimate the effect of the EU ETS counterfactual baseline scenario proved very successful. It allowed the research team to calculate the difference between this scenario and actually observed emissions.
- The standard dynamic model used to assess the impact of renewable energy policies also proved effective, although it implied important simplification as it only took into account a limited number of policies which were considered as equally stringent across MS. The estimated effects of the policies are limited in their validity as they represent short-run effects. National climate policies and renewable policies, research and development support and subsidy policies have been excluded from the analyses as these policies trigger technological improvements and the introduction of new technologies into the market which occurs over the long term. The effects of new technologies on emissions are without doubt substantial but are not accounted for directly in the econometric analysis. The numbers presented in section 3.1.2.2 are therefore very conservative and likely represent the lowermost estimate of the effect of climate policies on emissions.
- Finally, the model used to assess the impact of national climate mitigation policies proved very useful for assessing the causal relationship between policies and changes in emissions, although it was quite simplified as regulatory stringency was equated to the numbers of regulations that were in force in a certain year.

5.1.4 Analysis of national PAMs

The analysis of national PAMs realised under this project consisted used a survey of the key climate and energy PAMs in 15 MS, chosen to represent a balanced mix at EU level (see section 3.2). The approach offered a good level of complementarity to the econometric analysis and the validation of the analysis by MS representatives added value to its relevance. However it also has a few limitations, including:

- The method excludes a number of important policies such as the promotion of research and development of renewable energy and energy efficiency improvements. The impacts of these policies are either generally difficult to quantify, are not quantifiable at MS level, e.g. due to technology diffusion, or have long lead effects and will only be quantifiable after a longer period of time lapses from policy initiation. These policies are very important, however, as they have the potential to change the direction of major emissions drivers captured in the decomposition analysis.
- Data quality and quantification levels are variable across the 15 MS analysed.
- The methodologies used for the quantification of policy impacts vary across MS so direct comparison is difficult. Examples are: whether biofuels are believed to be 100% carbon free or not; the modelling of the BAU scenarios on basis of which emissions reductions are calculated; the way in which double counting issues are addressed, e.g. in quantifying the mitigation impact of different policies supporting a given objective such as RES or energy efficiency in buildings.
The analysis also highlighted the scarcity of \textit{ex post} estimates at MS level, with the quantified abatement levels in the fiches mostly presenting \textit{ex ante} evaluations that are subject to relatively high uncertainty levels. An example of the hydrochlorofluorocarbon regulation in the Netherlands suggests an \textit{ex post} result considerably higher than that of the \textit{ex ante} evaluation, although, anecdotal reports suggest many \textit{ex ante} estimates suffer from optimism bias.

5.1.5 Cost-effectiveness analysis

The comparative analysis of the cost-effectiveness of different climate and energy PAMs faces important challenges and limitations:

- The direct comparison of the mitigation impact and cost-effectiveness of single policies is difficult to realise given the numerous assumptions behind each evaluation, whether it is an \textit{ex ante} or \textit{ex post} evaluation. In addition, these evaluations face limitations that include:
  - The information reported by \textit{ex post} evaluations of climate mitigation PAMs – when they exist – is often limited to qualitative appraisals, and there is very limited analysis of the quantitative impacts;
  - \textit{Ex ante} and \textit{ex post} analysis are not conducted and reported in a consistent way by Member States; and
  - The indirect effects of policies, the overlaps between policies and rebound effects associated with policies are often neither recognised nor quantified in evaluations.

- In the evaluation of the costs of mitigation policies, the biggest challenge is to identify cost assessments as these are very sparse. A recent analysis of the 2015 MMR reports by the EEA\textsuperscript{36} found that only five Member States reported information on projected or realised costs of PAMs, namely:
  - Belgium: projected costs for five PAMs;
  - Czech Republic: projected costs for most of the 44 reported PAMs;
  - Estonia: projected costs for 34 PAMs and realized costs for four PAMs;
  - France: projected costs for four PAMs and realized and projected costs for one PAM; and
  - Finland: realized costs for one PAM.

- Even where cost data exists, a high level of caution is needed when attempting to benchmark them given the challenges associated with these cost assessments. Key issues are:
  - Determining the level at which the cost have been assessed: Policy costs may affect different economic agents: policy making institutions/regulating authorities, private sectors, individual consumers and, ultimately, the whole economy. A fiscal instrument can be seen as government spending/revenue, but at the same time it can entail macroeconomic costs as well. The level of the analysis chosen affects the type of cost the evaluation is able to account for. Moreover, the same policy can affect different agents in opposite ways, implying a revenue or a cost.
  - Identifying the type of costs estimated: The type of costs estimated - investment cost, operating cost, (cost saving), regulatory cost, macroeconomic cost - is often related to the type of policy under scrutiny.
  - Identifying the cost assessment method of each evaluation.

Despite these limitations the analysis of the existing data allowed the research team to draw general conclusions on the cost-effectiveness of the different policy groups identified in this study. The research also highlighted important needs for future research and analysis.

5.1.6 Complementarity and gaps between the different methods

The two decomposition analysis approaches were complementary and allowed expansion and refinement of the results of the 2014 EEA study by examination of more sectors and changes in emissions at both EU and MS level. By providing different sets of results (the updated EEA approach delivering detailed analysis of the different factors impacting GHG emissions at sectoral level, and the IDA approach delivering a more systematic analysis of different economic sectors and the EU as a whole) the two approaches complemented each other and reinforced the conclusions of the study.

The combination of these two DCA methodologies with the econometric analysis and the analysis of national PAMs used to assess the causal links between the outcomes of the DCA and specific policies reinforced the analysis. It demonstrated which types of policies impacted the intensity and fuel mix effect which were identified as the most important drivers behind the evolution of GHG emissions in Europe during the 1995-2012 period.

5.2 Key lessons learned for future studies and development areas

This project and the development of the methodologies it required provides points of learning that can inform the design of future studies. The key lessons learned and recommendations are:

■ The IDA approach could be further refined if more up-to-date data were available.
■ The causal link between the results of the decomposition analyses and specific policies should be studied in more detail in the future.
■ The econometric analysis applied for the ex post evaluation of renewable energy policies and national policies under the ESD could be refined to consider not only the number of policies but also their specificities as well as policies with longer term effects such as research and development policies.
■ Most of the evaluations of mitigation PAMs are ex ante and not easily compared. It would be useful to analyse how to standardise methods for BAU assessment, double counting avoidance (i.e. make sure that GHG abated in a particular sector are not attributed to different PAMs simultaneously), additionality (e.g. make sure that the mitigation impact attributed to a PAM was actually triggered by this PAM and not by other factors) and ultimately policy impact quantification for national climate policies. This would be particularly valuable for MMR reporting cycles as currently the reported data are difficult to combine and compare.
■ The analysis of national PAMs showed a significant impact of ‘other, non-climate’ policies such as the CAP and Landfill Directive on non-CO₂ GHGs. In the future, it would be useful to identify ways of integrating such policies in the quantitative analysis.
■ Information on the cost-effectiveness of climate and energy PAMs is very sparse. More studies are needed to first define a framework to develop cost-effectiveness assessments and, secondly, to apply this framework at different levels (sectoral, national and EU).
ANNEXES
Annex 1  Task 2A Methodology and data sources

A1.1 Definitions and conceptual model

This section describes the definitions and the conceptual model of the decomposition analysis. The first step for developing a decomposition analysis is the identification of possible factors and drivers that might have an influence on emissions. In this analysis the term ‘factor’ is used for the data set having a significant influence on GHG emissions. The term ‘driver’ is used for the data set actually used in the decomposition analysis; the driver is in many cases calculated by dividing one factor by a second factor (see example below). The following chart shows the drivers and factors used for the decomposition analysis of total GHG emissions, using seven selected factors/drivers.

Figure A1.1  Drivers and factors used for the decomposition analysis

<table>
<thead>
<tr>
<th>Driver name</th>
<th>Driver definition (input to decomposition analysis)</th>
<th>Factors used to calculate drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>Population</td>
<td>Population</td>
</tr>
<tr>
<td>GDP per capita</td>
<td>GDP/Population</td>
<td>GDP</td>
</tr>
<tr>
<td>Gross inland energy intensity</td>
<td>Gross inland energy consumption/GDP</td>
<td>Gross inland energy consumption</td>
</tr>
<tr>
<td>Gross final energy consumption</td>
<td>Gross final energy consumption/Gross inland energy consumption</td>
<td>Gross final energy consumption</td>
</tr>
<tr>
<td>Share of renewable energies</td>
<td>Gross final energy consumption from non-renewable energies / Gross final energy consumption = 1-share of renewable sources</td>
<td>Gross final energy consumption from non-renewable energies</td>
</tr>
<tr>
<td>Carbon intensity</td>
<td>CO2 emissions/Gross inland energy consumption from fossil</td>
<td>CO2 emissions</td>
</tr>
<tr>
<td>Share of combustion related CO2</td>
<td>Total GHG emissions/CO2 emissions = 1/Share of CO2</td>
<td>Total GHG emissions</td>
</tr>
</tbody>
</table>

The decomposition analysis is defined as follows:

\[
GHG = [\text{population}] \times [\text{GDP per capita}] \times [\text{gross inland energy consumption/GDP}] \times [\text{gross final energy consumption/gross inland energy consumption}] \times [\text{gross final energy consumption from non-renewable energies/gross final energy consumption}] \times [\text{CO}_2 \text{ emissions/gross inland energy consumption from fossil fuels}] \times [\frac{\text{Total GHG emissions}}{\text{CO}_2 \text{ emissions}}]
\]

The effect of the drivers is defined as follows:

Total GHG change = \( \Delta \) GHG due to change of population
+ \( \Delta \) GHG due to GDP per capita
+ \( \Delta \) GHG due to change in gross inland energy intensity
+ \( \Delta \) GHG due to change in gross final energy consumption efficiency
+ \( \Delta \) GHG due to change in share of renewable energies
+ \( \Delta \) GHG due to change in carbon intensity
+ \( \Delta \) GHG due to change in share of combustion related CO2

The following equations illustrate the conceptual model in general terms. The first step for developing a decomposition analysis is to identify possible factors “ai” that might have an influence on emissions. These factors are used to devise a multiplicative function for calculating the emission “C” during period “t”:
Decomposition analysis of the changes in GHG emissions in the EU and Member States

\[ C^t = \frac{a'_1}{a_1} \times \frac{a'_2}{a_2} \times \frac{a'_3}{a_3} \times \cdots \times \frac{a'_n}{a_{n-1}} \quad \text{with} \quad a'_n = C^i \]

Substituting

\[ a'_1 = D'_1, \quad \frac{a'_2}{a'_1} = D'_2, \quad \frac{a'_3}{a'_2} = D'_3, \quad \ldots, \quad \frac{a'_n}{a'_{n-1}} = D'_n \]

the expression changes to

\[ C^i = \prod_{i=1}^{n} D'_i = D'_1 \times D'_2 \times D'_3 \times \cdots \times D'_n \]

where “D^i” are the drivers, which are used for decomposition analysis.

To determine the influence of the drivers of emission changes between two periods we need the emission data at the beginning (e.g. emission during year “0”) and at the end (e.g. emission during year “T”):

\[ C^0 = \prod_{i=1}^{n} D^0_i = D^0_1 \times D^0_2 \times D^0_3 \times \cdots \times D^0_n \]

\[ C^T = \prod_{i=1}^{n} D^T_i = D^T_1 \times D^T_2 \times D^T_3 \times \cdots \times D^T_n \]

According to decomposition analysis (LMDI-I) the influence of the driver “D^i” during period [0;T] on GHG-emissions is calculated as follows

\[ \Delta C(D^i) = \frac{C^T - C^0}{\ln \left( \frac{C^T}{C^0} \right)} \left( \ln \left( \frac{D^T_i}{D^0_i} \right) \right) \]

“\( \Delta C(D^i) \)” represents the absolute contribution of driver D^i to the emission change during period [0;T]. Therefore the driver with the highest “\( \Delta C(D^i) \)”-value has the greatest effect on emission changes. The sum of all “\( \Delta C(D^i) \)” is equal to the total emission change during this period.

Due to the factor

\[ \ln \left( \frac{D^T_i}{D^0_i} \right) \]

this contribution depends on the relative change of the driver. The absolute change of the driver does not have any effect.

Since

\[ \ln \left( \frac{D^T_i}{D^0_i} \right) = \ln (D^T_i) - \ln (D^0_i) = (-1) \times \left[ \ln (D^0_i) - \ln (D^T_i) \right] = -\ln \left( \frac{D^0_i}{D^T_i} \right) \]

the function is symmetric, which means that the contribution of the driver only changes algebraic sign when the driver increases or decreases by the same amount.
A1.2 Data sources

This section describes the data sources, data quality, years covered, data gaps and gap filling techniques. Table A1.1 provides an overview of the relevant information for each decomposition analysis. It shows that the main data sources are Eurostat and the MS GHG inventory submissions (CRF). The quality of these data sets is very high: the data are officially reported by MS on an annual basis; the data are quality checked annually by Eurostat and through the UNFCCC review process (CRF). Hardly any gap filling is needed. Inventory data for 2013 are not included because of the delay in the UNFCCC reporting process. No gap-filling was made for 2013 inventory data. Therefore, the key findings presented below refer to 1990-2012.

Table A1.1 Overview of data sources used

<table>
<thead>
<tr>
<th>Data sources</th>
<th>Data quality</th>
<th>Years covered</th>
<th>Data gaps</th>
<th>Gap filling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General economy-wide analysis</strong></td>
<td>Eurostat CRF</td>
<td>High: data is reported and reviewed annually</td>
<td>2004-2012/2013</td>
<td>No data gaps</td>
</tr>
<tr>
<td><strong>Electricity production</strong></td>
<td>Eurostat CRF</td>
<td>High: data is reported and reviewed annually</td>
<td>1990-2012/2013</td>
<td>No data gaps</td>
</tr>
<tr>
<td><strong>Freight transport</strong></td>
<td>Eurostat CRF</td>
<td>High: except for PRIMES data is reported and reviewed annually; PRIMES is modelled data</td>
<td>1995-2012/2013</td>
<td>Split between freight and passenger transport not available in old CRF format; Croatia not covered by PRIMES; PRIMES data only available in five years intervals</td>
</tr>
<tr>
<td><strong>Passenger transport</strong></td>
<td>DG MOVE pocket book CRF PRIMES</td>
<td>High: except for PRIMES data is reported and reviewed annually; PRIMES is modelled data</td>
<td>1995-2012/2013</td>
<td>Split between freight and passenger transport not available in old CRF format; Croatia not covered by PRIMES; PRIMES data only available in five years intervals</td>
</tr>
<tr>
<td><strong>Iron and steel production</strong></td>
<td>World steel organisation Eurostat CRF</td>
<td>Medium: As MS use different methods to calculate emissions from iron and steel production it is</td>
<td>1990-2012/2013</td>
<td>No data gaps</td>
</tr>
<tr>
<td>Data sources</td>
<td>Data quality</td>
<td>Years covered</td>
<td>Data gaps</td>
<td>Gap filling</td>
</tr>
<tr>
<td>--------------</td>
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<td>-------------</td>
</tr>
<tr>
<td><strong>Households</strong></td>
<td>Eurostat CRF PRIMES</td>
<td>High: data is reported and reviewed annually; PRIMES is modelled data</td>
<td>2004-2012/2013 Eurostat Shares data on renewables is only available from 2004 onwards</td>
<td>PRIMES data only available in five years intervals; number of households not available for 1990-2004; heating shares not available for solar, geothermal, heat pumps and other fuels</td>
</tr>
<tr>
<td><strong>Fertiliser use</strong></td>
<td>CRF</td>
<td>High: data is reported and reviewed annually</td>
<td>1990-2012/2013</td>
<td>No data gaps</td>
</tr>
</tbody>
</table>
Annex 2  Task 2B methodology and data sources

A2.1  Methodology

This section explains the methodological background to the decomposition analysis. It starts with a three factor decomposition where an index is decomposed into its underlying parts. These underlying reasons for a change in the aggregate index are the activity effect, the structural effect, and the intensity effect. All decomposition methods presented here are multiplicative decompositions. This means that the product of the components equal the total effect, namely the index itself.

The three factor decomposition is applied for all non-\( \text{CO}_2 \) pollutants whereas the five-factor decomposition is applied to \( \text{CO}_2 \) emissions.

A2.1.1  Three-factor decomposition

Consider the following variables for a given country and \( i=1,\ldots,N \) (where there are 35 sectors in total for each country) sectors in years \( t=0,\ldots,T \).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Y_t )</td>
<td>Output in volume of the country in year ( t )</td>
</tr>
<tr>
<td>( Y_{t,i} )</td>
<td>Output of sector ( i ) in year ( t )</td>
</tr>
<tr>
<td>( E_t )</td>
<td>Total GHG emissions of a country in year ( t ) (( E_t = \sum_i S_{i,t} I_{i,t} Y_{t,i} ))</td>
</tr>
<tr>
<td>( E_{t,i} )</td>
<td>Emissions of sector ( i ) in year ( t )</td>
</tr>
<tr>
<td>( I_t = E_t / Y_t )</td>
<td>Emission intensity of the country in year ( t )</td>
</tr>
<tr>
<td>( I_{t,i} = E_{t,i} / Y_{t,i} )</td>
<td>Emission intensity of sector ( i ) in year ( t )</td>
</tr>
<tr>
<td>( S_{i,t} = Y_{t,i} / Y_t )</td>
<td>Share of sector ( i ) in the country’s output</td>
</tr>
</tbody>
</table>

The impact of economic growth on the index is called the "activity effect". Sometimes, this effect is referred to as the scale or growth effect. It describes how the index would have changed had there been no change in the other factors, meaning if they were held fixed (i.e. no structural and technical (intensity) change had taken place). The structural and intensity effects are defined in a similar way. The structural effect is often referred to as the composition effect as it addresses the effect on emissions due to a change in the composition of the countries’ sectors that differ in their GHG emission intensity. Some sectors such as the manufacturing or basic metals sectors need more energy and thus emit more GHGs per Euro value of output produced while other sectors such as the financial or insurance sector need much less energy. The structural effect thus reflects the impact of a change in the economic weight of these sectors output in a country’s total output on emissions holding all other factors (or effects) fixed at their initial values (1995 in this case). To put it in another way, the structural effect would increase if emission-intensive sectors such as the non-metallic minerals sectors (cement) would produce relatively more while other do not. This means their share in total output of the country increases and thus emissions.

Finally, the intensity effect measures the change in emissions that is due to technical change as it holds the economy’s structure (share of sectors in total output) and the scale of the economy at their initial levels. This effect is often referred to as the technique or technology effect. In a further subsection, another effect will be introduced — the fuel-mix effect. The rationale behind this additional effect is that the pure intensity effect does not allow concluding whether the change in intensity is due to technical change or due to a switch an energy source that leads to more emissions to another one that causes fewer emissions. An example is a switch from brown coal to hard coal or switch from oil to gas in power plants. The technology itself does not differ but the fuel used that differs in its emissions factor. The fuel-mix effect thus helps separate pure fuel switch effects from technical change.
Decomposition analysis of the changes in GHG emissions in the EU and Member States

For the moment, three factors (+ the total effect) are considered to easily introduce the methodology. Several indices can be used to perform a decomposition analysis. The most frequently used ones are the Laspeyres index and the Log Mean Divisia index. The Laspeyres index is often used because it is very easy to implement and allows readers not familiar with the concept of an index decomposition to understand how it works. For this reason, a very easy decomposition using the Laspeyres index is explained before the more appropriate Log Mean Divisia (which is used in this report’s analysis) is discussed.

In a simple Laspeyres index decomposition (e.g. Ang and Zhang, 2000): the activity effect can be obtained by holding fixed the sectoral GHG-intensities and output weights (\(I_{t,i}\) and \(S_{t,i}\) at the base year, 1995 in this case) of a country. The equation for the activity effects nicely shows this. Only the gross output of the total economy changes over the periods. The structural effect holds \(Y_t\) and \(I_{t,i}\) fixed in order to isolate the impact of the change in \(S_{t,i}\) (the weight of a sectors output in the total economy). Finally, intensity holds \(Y_t\) and \(S_{t,i}\) fixed, so that only the intensity of the different sectors are allowed to change. The three effects read as follows:

\[
\begin{align*}
\text{Activity} & = \frac{\sum_i S_{0,i} \cdot I_{0,i} \cdot Y_i}{\sum_i S_{0,i} \cdot I_{0,i} \cdot Y_0} \\
\text{Structure} & = \frac{\sum_i S_{i,i} \cdot I_{i,i} \cdot Y_0}{\sum_i S_{0,i} \cdot I_{0,i} \cdot Y_0} \\
\text{Intensity} & = \frac{\sum_i S_{0,i} \cdot I_{0,i} \cdot Y_0}{\sum_i S_{0,i} \cdot I_{0,i} \cdot Y_0} \\
\text{Total} & = \text{Activity} \cdot \text{Composition} \cdot \text{Intensity} + \text{RESIDUAL}
\end{align*}
\]

As the decomposition is a multiplicative one, the product of all three effects yields the total effect. The problem with this simple index decomposition is that it leaves a residual as already shown in the inception report. This problem does not appear in the Log Mean Divisia index (developed by Sato, 1976). The decomposition is very similar to the Laspeyres method although it looks way more complex. Instead of using the Laspeyres index as the underlying index, it relies on the use of a (logarithmic mean) weighting function of the GHGs emitted used. Let \(\omega_{t,i} = E_{t,i} / E_t\) be the share of a country’s total GHG emissions that is emitted by sector \(i\). The logarithmic mean of \(\omega_{t,i}\) is defined as:

\[
L(\omega_{0,i}, \omega_{t,i}) = \frac{\omega_{0,i} - \omega_{t,i}}{\ln \omega_{0,i} - \ln \omega_{t,i}}
\]

When \(\omega_{t,i} = \omega_{0,i}\) (i.e. if there is no change over time) the logarithmic mean is equal to \(\omega_{t,i}\) (including when \(\omega_{t,i} = \omega_{0,i} = 0\)). The resulting Log Mean Divisia index decomposition for CO\(_2\) emissions reads as follows (see Ang and Liu, 2001 for a detailed discussion of the properties of this decomposition):
Decomposition analysis of the changes in GHG emissions in the EU and Member States

\[
\text{Activity} = \exp \left( \sum_i \frac{L(\omega_{i,t}, \omega_{0,i})}{\sum_j L(\omega_{j,t}, \omega_{0,j})} \ln \frac{Y_i}{Y_0} \right)
\]

\[
\text{Structure} = \exp \left( \sum_i \frac{L(\omega_{i,t}, \omega_{0,i})}{\sum_j L(\omega_{j,t}, \omega_{0,j})} \ln \frac{S_{i,t}}{S_{0,j}} \right)
\]

\[
\text{Intensity} = \exp \left( \sum_i \frac{L(\omega_{i,t}, \omega_{0,i})}{\sum_j L(\omega_{j,t}, \omega_{0,j})} \ln \frac{I_{i,t}}{I_{0,i}} \right)
\]

\[
\text{Total} = \text{Activity} \cdot \text{Structure} \cdot \text{Intensity}
\]

These index values have to be calculated for all countries and for all years.

**A2.1.2 Five-factor decomposition**

The five factor decomposition goes further than the three factor decomposition. It includes, in addition to the effects outlined above, a fuel mix effect and an emission factor effect. The former describes changes in energy intensities driven by a modified composition of energy carriers. The latter effect describes the development of carbon intensity of energy broken down by fuel type. The intensity effect \(I_{t,i}\) now represents changes in energy intensity broken down by sector. Analogously to the explanations given in the previous section, we define total CO\(_2\) emissions as

\[
E_{t} = \sum_{i,k} S_{i,t} \cdot F_{t,i,k} \cdot EF_{t,i,k} \cdot Y_{t}
\]

The differences compared to the formula given in Table A2.1 in the previous subsection concern the inclusion of \(F_{t,i,k}\) and \(EF_{t,i,k}\) as well as the alternative definition of \(I_{t,i}\):

\[
I_{t,i} = EU_{t,i} / Y_{t,i}
\]

where \(EU_{t,i}\) describes energy use in sector \(i\) in year \(t\). Hence, \(I_{t,i}\) now is energy intensity in year \(t\).

\(F_{t,i,k}\) is defined as the share of energy use of each fuel type \(k\) in total sectoral energy use:

\[
F_{t,i,k} = EU_{t,i,k} / EU_{t,i}
\]

where \(EU_{t,i,k}\) describes energy use of fuel type \(k\) in sector \(i\) and year \(t\).

\(EF_{t,i,k}\) is defined as sector- and fuel-specific CO\(_2\) emissions per unit of energy of fuel type \(k\): the emission factor

\[
EF_{t,i,k} = E_{t,i,k} / EU_{t,i,k}
\]

where \(E_{t,i,k}\) describes emissions of fuel type \(k\) in sector \(i\) and year \(t\).

Analogously to the three factor decomposition, we use Log Mean Divisia index decomposition and have now five different effects (besides the total effect).

---

37 Note that due to the inclusion of an additional index \((k)\) the parameter \(\omega\) has to be modified and is now defined as \(\omega_{t,i,k} = E_{t,i,k} / E_t\). The logarithmic mean \(L(\omega_{t,i,k}, \omega_{0,i,k})\) changes analogously.
Decomposition analysis of the changes in GHG emissions in the EU and Member States

\[
\text{Activity} = \exp \left( \sum_{i,k} L(\omega_{i,k}, \omega_{0,i,k}) \cdot \ln \left( \frac{Y_i}{Y_0} \right) \right)
\]

\[
\text{Structure} = \exp \left( \sum_{i,k} L(\omega_{i,k}, \omega_{0,i,k}) \cdot \ln \left( \frac{S_{i,k}}{S_{0,k}} \right) \right)
\]

\[
\text{Intensity} = \exp \left( \sum_{i,k} L(\omega_{i,k}, \omega_{0,i,k}) \cdot \ln \left( \frac{I_{i,k}}{I_{0,i,k}} \right) \right)
\]

\[
\text{FuelMix} = \exp \left( \sum_{i,k} L(\omega_{i,k}, \omega_{0,i,k}) \cdot \ln \left( \frac{F_{i,k}}{F_{0,i,k}} \right) \right)
\]

\[
\text{EmFactor} = \exp \left( \sum_{i,k} L(\omega_{i,k}, \omega_{0,i,k}) \cdot \ln \left( \frac{EF_{i,k}}{EF_{0,i,k}} \right) \right)
\]

\[
\text{Total} = \text{Activity} \cdot \text{Structure} \cdot \text{Intensity} \cdot \text{FuelMix} \cdot \text{EmFactor}
\]

Hence, the effects in the five factor decomposition behave similar as in the three-factor decomposition. The differences are the introduction of the fuel mix effect and the emission factor effect and the alternative definition of the intensity effect. These are combined in the intensity effect in the three factor decomposition. Therefore, the intensity effect now describes the pure influence of energy efficiency improvements whereas in the three factor decomposition it also includes changes in the composition of energy carriers and carbon intensity changes of specific fuel types which are now taken up by the fuel mix and the emission factor effects.

A2.2 Data sources

The main source of data for task 2B is the WIOD. This database includes 40 countries; EU-27 and additional 13 major economies such as the United States, Canada, Japan, China, India and Brazil. These 40 countries contribute 85 percent to the world’s total production. This database has been collected by several institutions with the project also called WIOD, which has been funded by the EC within the 7th Framework program. The main responsible institution for the data collection is the University of Groningen (Netherlands) for the socio-economic data and the IPTS in Spain for the environmental satellite accounts, including CO₂ emissions from different fuel types. The WIOD database is a direct predecessor of the well-known and frequently used EU KLEMS database collected by the same institutions.

The database covers the years 1995 until 2009. For some countries where there was data from additional sources available, the WIOD database has been augmented by these data points in task 2B. Additional data points are taken from Eurostat. Information on gross output by sector is taken from the “National Accounts aggregates by industry” (nama_10_a64) table. Data on emissions to air stems from the “Air emissions accounts by industry and households (NACE Rev. 2)” (env_ac_aiah_r2) tables. Price deflators per sectors are also collected from Eurostat. If output price deflators are available, we use those to deflate gross output. If not, we revert to value added deflators. Both are taken from the “National Accounts aggregates by industry” (nama_10_a64) table. If neither output nor value added deflators are available, we use the Eurostat’s GDP deflator (nama_10_gdp). The latter case only occurs...
in the case of Cyprus, Luxembourg and Malta. Data gaps are presented in the country sheets for each MS separately.

From the WIOD database, three different variables are used. The gross output of each sector in each country in all years between 1995 and 2009, as well as gross output deflators to convert the current monetary values into constant ones. In addition, for the three-factor decomposition analysis, the total CO₂ emissions of the sectors are used, which are reported in the environmental satellite accounts. The underlying sources of the CO₂ data are in WIOD is the National Accounting Matrices including Environmental Accounts (in short NAMEAs) provided by the EEA. The source of the gross output data is OECD and the United Nations comtrade database. For the five factor decomposition, the total CO₂ emissions cannot be used. The reason is that the fourth factor (fuel mix effect) accounts for the impact of a change in fuels on emissions, so data on CO₂ emissions that are due to the use of different fuel types need to be used, which is provided in the WIOD environmental satellite accounts. The sum of the emissions due to the different fuel types does not equal the total emissions (those ones reported as totals that come from the NAMEAs).

In countries for which Eurostat data is available (i.e. all EU-27 MS\textsuperscript{38}), the Index Decomposition Analyses are extended up until 2012. The IDAs are conducted based on WIOD data for 1995 to 2008 and on Eurostat data from 2009 to 2012. There is a structural break due to switching from WIOD to Eurostat data. The WIOD data are compiled by using NACE 1.1 sector classification. Eurostat data are presented in NACE 2.0 classification. Correspondence tables between these classifications are available, but they do not allow for a unique correspondence for all sectors without further assumptions. Dashed horizontal lines in the graphs depict the structural break.

In total, 27 different fuel types are reported. These include hard coal, brown coal, jet fuel, diesel and crude oil. Neither fuel type data nor data on emission factors is available in Eurostat. Since this information is not available in the necessary sectoral classification, it is necessary to make assumptions on their development and extrapolate their development. As the emission factor effect is nearly constant at 1 for each country and for the entire sample period, we hold this effect constant at its 2008 level from 2009 onwards. Regarding the fuel mix effect we chose a different procedure as there is a certain movement in almost each country. From 2009 onwards, we assume a constant growth rate of the fuel mix effect which equals its average growth rate between 2004 and 2008. Since with Eurostat data we can easily compute the total, the activity and the structural effects until 2012, the intensity effect between 2009 and 2012 can then be determined by dividing the total effect by the other four effects.

\textsuperscript{38} For Portugal, no information for 2012 is available. Therefore, we extrapolated all effects based on the 2010-2011 growth rate.
Annex 3  Review of existing ex-post analyses of the impact of the EU ETS on emissions and innovation in Europe

Most of the literature studying the effects of European climate policy on emissions focuses almost exclusively on EU ETS. Among various climate policies, the scheme has the widest GHG coverage, affecting roughly 45%39 of total emissions. From an empirical research perspective, the EU ETS has the important advantage of a design that has led to variation across sectors, countries and time, thereby lending itself to statistical and econometric analysis. Other policies such as fuel efficiency regulations have a smaller coverage and suffer more from policy interactions, which makes it more difficult to disentangle their effects from those of overlapping instruments. For example, the EU has removed many conventional light bulbs from the market. The electricity supply sector is covered by the EU ETS so emissions generated here are regulated. The prohibition of conventional light bulbs would also affect the emissions generated by this sector, by lowering electricity demand. However, this may also lead to lower EU ETS allowance prices and therefore lead to higher emissions in other EU ETS sectors40.

This section provides a review of the existing economic ex post analysis of the effect of European climate policy on changes in emission levels and abatement. It follows the literature trends of focusing primarily on the EU ETS.

One of the first studies on the impacts of the EU ETS is offered by Ellerman and Buchner (2008). For the first trading period between 2005 and 2007, they find that considerable amounts of allowance over-allocation.41 However, they also find that over-allocation does not automatically mean lack of abatement, suggesting that in 2005 and 2006, emission abatement for the whole EU ranged between 50 and 100 million tons of CO$_2$42 per year. These results are obtained from non-parametric estimations, that is, they are based on the difference between the estimate of emissions that would have been observed had there been no ETS, BAU emissions with those that have been observed in reality43.

The study by Anderson and Di Maria (2011) used a similar approach, comparing estimated BAU and actual emissions. Their estimates covered the entire first trading period (2005-2007) and fall in the middle of the range provided by Ellerman and Buchner (2008), with an annual effect of the EU ETS of 82 million tons of CO$_2$.44

The study of Egenhofer et al. (2011) extends the previous analysis to the first two years of the second trading period (2008 and 2009) and identifies an emissions-intensity improvement due to the EU ETS that was considerably larger in 2008 and especially in 2009.

At the firm level45, a study by Petrick and Wagner (2014) finds for the second phase of the EU ETS that firms emitted, on average, between 25% and 28% fewer GHG emissions compared to almost identical

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40 This policy may have further effects such as increased household energy consumption from other appliances, the rebound effect as well as increased demand for the LED and other energy-saving light bulbs and further technological development in these sectors, leading to further emission reductions.

41 In Section 4, measures of over-allocation from CITL (Community Independent Transaction Log) are reproduced, similar as Ellerman and Buchner (2008) did it but for the first and the second trading period.

42 In 2005, the EU (EU-27 without Romania and Bulgaria as they were not under ETS) emitted 4.95 Billion tons of CO$_2$ equivalent GHGs so abatement according to the estimates of Ellerman and Buchner (2008) was 1-2% of total GHG emissions (or 2.48-4.97% of total ETS covered emissions), which is quite a lot in the first year of EU ETS.

43 Annex 4 sheds more light on technical, i.e. econometric details for estimating the effects of climate policy (especially EU ETS) on emission abatement. The focus here lies on the results.

44 In 2005, the EU (EU-27 without Romania and Bulgaria as they were not under ETS) emitted 4.95 Billion tons of CO$_2$ equivalent GHGs so abatement according to the estimates of Ellerman and Buchner (2008) was 1-2% of total GHG emissions (or 2.48-4.97% of total ETS covered emissions), which is quite a lot in the first year of EU ETS.

45 Micro-economic analysis at firm level is not within the scope of the current study.
firms not covered by the EU ETS. ‘Almost identical' means that firms are used as a reference which are slightly below the threshold of EU ETS regulation. The reduction was estimated to correspond to a reduction in the regulated firms’ CO₂-intensity between 18% and 30%. In the first phase, the authors did find strong consistent evidence of EU ETS effects.

The journal articles reviewed suggest that the EU ETS has brought about emissions reductions, compared to the counterfactual baseline scenario.

**A3.1 EU ETS and Innovation**

A number of studies analysed the impact of emissions trading on innovation, which is important for developing technologies that allow continued emissions abatement at decreased costs. This includes both empirical and theoretical studies covering various trading schemes addressing local and global pollutants in the US and Europe.

According to the theory, cap-and-trade systems provide clear innovation incentives because they “[…] define the potential payoffs for R&D investments by innovators through their allowance clearing prices, which set the bar for clean technology adoption by emission sources […]” (Taylor 2012, p. 4804). One of the first theoretical contributions by Downing and White (1986) identified that market based systems of tradable permits provide the highest innovation incentives while command-and-control regulations like efficiency standards perform worst. Milliman and Prince (1989) arrived at similar conclusions. Jaffe and Stavins (1995, p. S-45) summarized the existing theoretical literature on this issue as follows: “Theoretical economic analysis have generally supported the notion that market-based approaches provide the most effective long-term incentives for invention, innovation, and diffusion.”

Empirical studies also suggest the superiority of market based instruments over command and control. For example, Jaffe and Stavins (1995) did not find significant effects of command-and-control regulations on technology adoption in the buildings sector and Kerr and Newell (2003) who studied the post-invention adoption of innovations in the petroleum industry and found that market-based regulations provide larger incentives to adopt lead-reducing technologies compared to performance standards.

Taylor (2012) provides insights into the interaction between the efficiency of cap and trade programmes and innovation while studying the effect of two U.S. sulphur dioxide and N₂O cap-and-trade regulations. The study shows that the number of patents was stable during the implementation of command and control regulation as well as through the preparatory phase of the trading scheme. However, as trading started and revealed an average abatement cost that was lower than expected, new patent numbers decreased. These results are descriptive and their relevance to the EU ETS is only very indirect due to pollutant, cap level and geographic differences, among others.

The impact of the EU ETS itself on innovation was the focus of several strands of recent research. Martin et al. (2012) find the firms expecting to experience a reduction in freely allocated permits innovate significantly more. The authors relate this finding to EU ETS free allocation mechanisms that applied to firms producing trade and carbon intensive outputs. They conclude that free allocation therefore reduced innovation activities related to climate-friendly innovations. Similar conclusions are drawn from an econometric analysis based on interview data with managers of firms in different countries.

Another study by Calel and Dechezleprêtre (forthcoming) considers firm patents related to low carbon technologies. They find that firms under EU ETS regulation have significantly more low-carbon patents than comparable firms not affected by the EU ETS.

Additional evidence for the innovation-stimulating effect of the EU ETS is provided by Rogge et al. (2010), a study that includes expert interviews within company case studies in the German power sector.

**A3.2 Climate policy, EU ETS, competitiveness and structural change**

As with environmental regulation in general, there are concerns that climate policy can adversely affect the competitiveness of the European companies. However, the most important EU climate policy, the EU ETS is a market based instrument that both facilitates the identification of least cost abatement, thereby reducing costs, and allows firms decision making discretion with regards to operation. There
are a number of empirical studies focused on the impact of the EU ETS on several indicators of competitiveness. There is virtually no evidence available where more than one policy measure is considered.

One of the first empirical studies by Anger and Oberndorfer (2008) found that German firms affected by the EU ETS regulation in the first phase were not significantly affected in a negative way in terms of employment and economic activity accounted for by revenues. However, this finding is only relevant for the first trading period where there are well-grounded concerns of over-allocation and thus rather less strict EU ETS regulation.

Commins et al. (2011) do not provide clear cut empirical evidence for the impact of the EU ETS on economic activity. Using firm-level data, they find that EU ETS firms experience both a significantly lower growth in total factor productivity and a positive effect on employment. These contradictory findings do not merge into an unequivocal conclusion about the economic impact of the EU ETS. This view is backed up by the fact that the authors do not find a significant effect on investments.

The study by Bushnell et al. (2013) finds that some companies benefited from the EU ETS regulation. While the existence of a CO₂ price raised the cost of production, it also affected output prices, therefore leading to increased revenues. A drastic decline in prices, as observed in April 2006 (-50 percent), can thus increase revenues so that the revenue effect can dominate the cost effect of regulation. This view is supported using event studies using CO₂ market price data. A recent study by Petrick and Wagner (2014) does not find any adverse effect of the EU ETS for economic activities (production, employment, and trade) for a sample of German firms.

Another study by Martin et al. (2014) explicitly considered possible carbon leakage (or relocation) concerns for the case of the EU ETS. In particular, the authors investigated the approach to free allocation of permits to sectors exposed to the risk of carbon leakage. Based on extensive econometric analysis using data from telephone interviews with companies in six European countries, the study finds that compensation for regulation (in terms of free allocation of pollution permits) by sectors is not optimal with respect to carbon leakage and relocation risk. Instead, they argue in favour of free allocation of permits as compensation across firms based on observable firm-specific characteristics (such as firm size) to equalize the marginal expected risk of relocation across firms. In light of this recent contribution, studying the impact of the EU ETS on the change in emissions that is due to structural change — and thus likely accounting for relocation (but not necessarily) or downsizing of carbon-intensive production — seems to be of great interest.

46 Such a sector needs to have a trade intensity of more than 10% and a carbon intensity of more than 5% or either a trade intensity or a carbon intensity of more than 30%. 
Annex 4  Detailed description of the econometric models developed in task 3B

Please consult the separate annex document.

Annex 5  Description of Data Sources used in task 3B

Please consult the separate annex document.
Annex 6 References of task 3B


Decomposition analysis of the changes in GHG emissions in the EU and Member States


Annex 7  Analysis of the mitigation impact of key policies and measures within Member States: country fiches

Please consult the separate zip file.