European Environment Agency

Why did greenhouse gas emissions decrease in the EU in 2011?

EEA analysis

This paper briefly analyses the major factors that accounted for decreased greenhouse gas (GHG) emissions excluding land use, land use changes and forestry (LULUCF) in the EU-27 between 2010 and 2011. The paper commences with an overview of EU trends, followed by summaries of the contributions of individual Member States, greenhouse gas types, and main sectors. It then analyses the contribution of other factors such as population levels, economic output, renewable energy consumption, and energy and carbon intensity. It concludes with a brief overview of 2012 emissions under the EU Emissions Trading System and also from fossil fuel combustion.

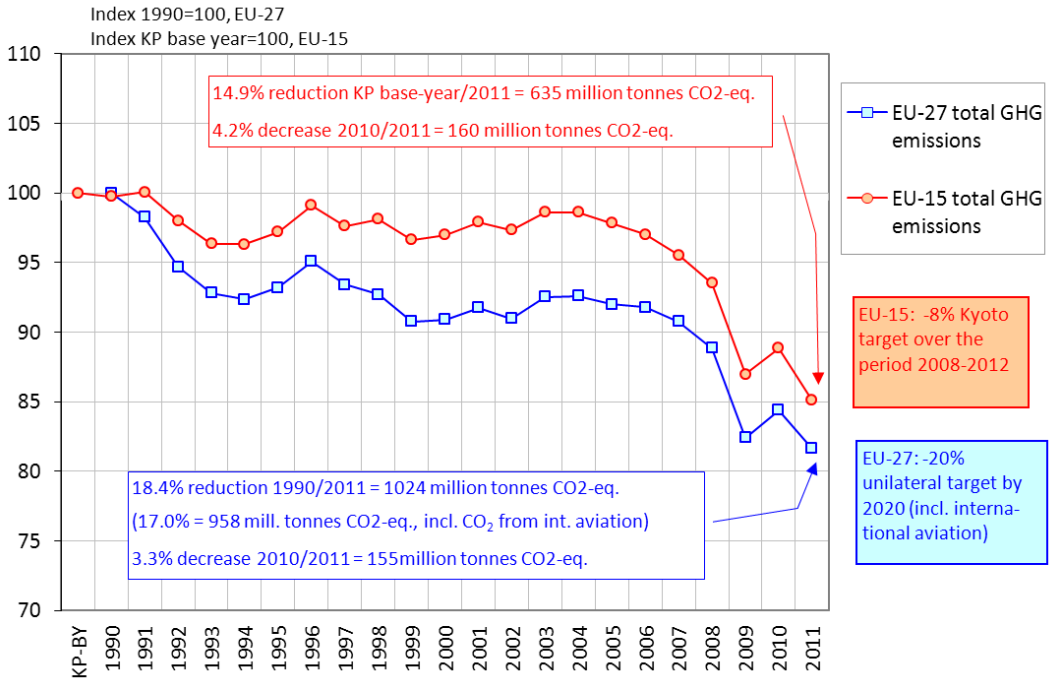
Contents

1 Summary of EU emissions

After the increase in 2010, total GHG emissions (excluding LULUCF) in the EU decreased again in 2011, reaching its lowest level since 1990. This continued the trend of emission reductions, which started in 2004. The annual percentage decrease in emissions in 2011 was also the third largest of the past 21 years of emissions reported to the UNFCCC.

GHG emissions between 2010 and 2011 decreased by 3.3 % and by 4.2 % in the EU-27 and EU-15, respectively[1]. Figure 1 shows total greenhouse gas emissions in the period 1990–2011, both in the EU-15 (which is collectively a party to the Kyoto Protocol) and in the EU-27.

Figure 1 EU greenhouse gas emissions relative to 1990 and the EU-15 base year



Source: EEA.

In 2011, EU-15 emissions were 14.9 % below the base year under the Kyoto Protocol ([2]). That constituted a net reduction of 635 million tonnes of CO_2-equivalents. Total greenhouse gas emissions in the EU-27 were 18.4 % below 1990 in 2011 — a net reduction of 1024 million tonnes of

(1) This reduction was significantly larger than predicted by the EEA last year. See Approximated EU GHG inventory: proxy estimates for 2011, EEA Technical report No 13/2012 (http://www.eea.europa.eu/publications/approximated-eu-ghg-inventory-2011). The main reason for the difference between actual and predicted values was the consumption of fuel for heating in the residential sector, as the full energy balances by final use are not available at the time of preparing the Approximated GHG inventory for the EU.

(2) Following the UNFCCC reviews of Member States' 'initial reports' during 2007 and 2008 and pursuant to Article 3, paragraphs 7 and 8 of the Kyoto Protocol, the base-year emissions for the EU-15 have been fixed at 4 265.5 Mt CO_2-equivalents.

CO_2-eq. If CO_2 emissions from international aviation are included, the overall reduction would be 17.0 % ([3]).

About 62 % of the EU net decrease in GHG emissions was accounted for by the United Kingdom, France and Germany. In percentage terms, emission reductions were highest in Finland, Belgium and Denmark.

For the EU as a whole, the 3.3 % decrease in GHG emissions in 2011 came amid positive economic growth in most EU member states. GDP increased by 1.6 %, although economic growth was lower than in 2010, when GDP increased by 2.1 %[4]. A milder 2011 winter compared to 2010 can, to a large extent, explain lower fossil fuel emissions. This is because, on average, the higher winter temperatures led to lower heating demand and lower emissions from the residential and commercial sectors.

The price of carbon fell markedly in 2011 compared to 2010. However, energy prices surged by over 11 % on average for the EU in 2011, clearly outpacing the increase in non-energy prices and the gross disposable income of households. Despite very low carbon prices, energy became relatively more expensive for the average household. The consumer price index for energy increased five times faster than the harmonised consumer price index (excluding energy). Although lower heat consumption seems to be the main reason for lower emissions in 2011, higher energy prices may have also contributed to this decline in some Member States.

GHG emissions decreased in the majority of key sectors in 2011, particularly those relying on fossil fuel combustion. On average, the total consumption of fossil fuels decreased by 5 % in the EU-27. The use of liquid fuels decreased by 4 %, whereas the consumption of natural gas fell starkly by almost 11 % in 2011. However, the use of solid fuels, such as hard coal and lignite, increased by about 2 %. Coal imports to the EU also increased significantly that year, particularly from Russia, the United States and Colombia, putting downward pressure on coal prices. This increase in coal use did not offset a much larger decrease in the consumption of natural gas, and GHG emissions fell as a result.

Final energy consumption from renewables witnessed the largest decline of the last 21 years in absolute terms, and the second largest in relative terms. Yet, the contribution of renewables to total final energy consumption increased because the consumption of fossil fuels decreased by an even greater amount. Biomass combustion increased by less than 1 % in the EU-27 in 2011, whereas, based on Eurostat data, hydroelectricity contracted by 16 % in 2011. However, energy production from wind and solar continued to increase strongly in 2011. Nuclear electricity consumption also declined in the EU-27 in 2011 compared to 2010, mainly due to a strong reduction in Germany.

The sector that contributed most to lower GHG emissions in the EU in 2011 was ‘residential and commercial’, which broadly falls outside the scope of the European Emissions Trading System (EU

(3) There is no Kyoto target for the EU-27 and therefore no applicable base year. The 20 % EU-27 target for 2020 is not directly comparable with the current accounting Kyoto rules due to the different scopes. When CO_2 emissions from international aviation are included (already part of the EU-ETS from 2012), the 18.4 % overall reduction between 1990 and 2011 would be equivalent to a 17.0 % reduction. If international shipping was included, the net emissions reduction between 1990 and 2011 would be 15.7 %.

(4) As will be shown later, other factors apart from GDP played a more important role in the decrease in GHG emissions in 2011 compared to 2010. However, GDP was one of the main factors underpinning lower and higher emissions in 2009 and 2010 for the EU, respectively. One should not therefore conclude that the link between GHG emissions from economic growth is broken by looking at the relationship between these two variables in one year only.

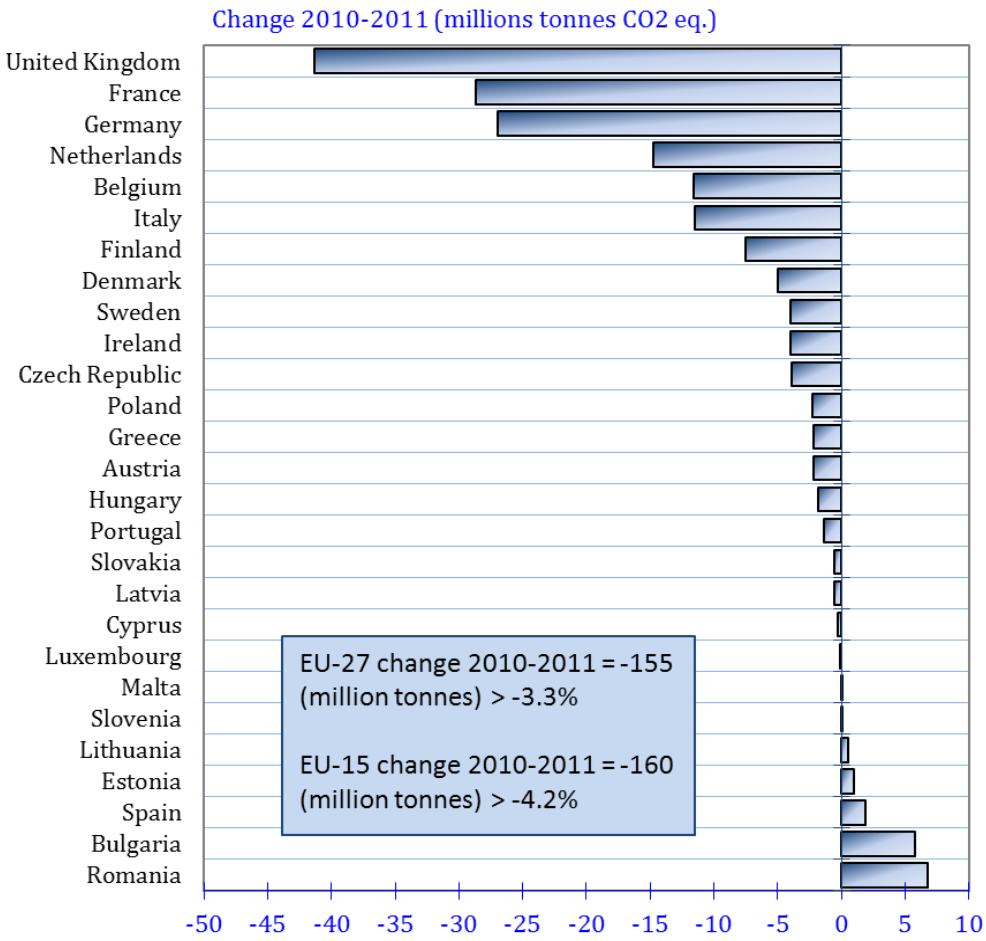
ETS). The key reason for the 104 million tonnes decrease in CO_2 emissions (83 of which from residential) in this sector was the mild winter in 2011, which decreased demand for heating, particularly by households. The second-largest decrease in emissions (20 million tonnes of CO_2) occurred in public electricity and heat production, which broadly falls within the scope of the EU ETS. The combined effect of these two sectors (residential/commercial and public heat and electricity) contributed to about 80 % of the total reduction in GHG emissions in the EU in 2011. EU emissions from transport fell for the fourth consecutive year.

Between 2010 and 2011 the emission reductions were larger in the non-ETS sectors (– 4.3 %) than in the installations covered by the ETS (– 1.8 %) for the EU as a whole. For the latter, combustion installations accounted for 99 % of the total reduction in emissions in 2011. Lower heat and electricity demand, particularly from the residential sector, appear to be the main contributing factor to lower ETS emissions in 2011.

2 Overview by Member State

At the Member State level, most EU countries reduced greenhouse gas emissions in 2011. The bars in Figure 2 depict the absolute emission increase or reduction by Member States between 2010 and 2011. The United Kingdom, France and Germany accounted for about 62 % of the total EU-27 net decrease. In percentage terms, emission reductions were highest in Finland, Belgium and Denmark. Contrastingly, Bulgaria, Romania and Spain increased GHG emissions in 2011.

Figure 2 Greenhouse gas emissions by EU Member State



Source: EEA.

The deep economic recession, which commenced at the end of 2008 and continued throughout 2009, was a key factor behind the strong decline in greenhouse gas emissions in 2009. Equally important, however, was the strong increase in the use of renewables in almost all EU countries. In 2010, by contrast, economic growth was positive in the EU as a whole, with GDP increasing by 2.1 % compared to 2009. This economic recovery in the majority of EU Member States in 2010 was a significant factor behind the growth in EU GHG emissions in 2010, albeit not the only one. In 2011, GDP growth was still positive (1.6%), although lower than in 2010, and with the prospect of a worsening of the economic situation in the EU in 2012.

In the United Kingdom, greenhouse gas emissions fell by 41 Mt of CO_2 equivalent in 2011 relative to 2010. This was the largest reduction of all EU Member States, and resulted primarily from a decrease in residential gas use due to a mild winter, combined with a reduction in demand for electricity. This was accompanied by lower use of gas and greater use of nuclear power for electricity generation after technical problems at some nuclear power stations in 2010 were resolved.

In France, the results indicate that greenhouse gas emissions declined by 29 Mt of CO_2 equivalent in 2011 compared to 2010. The drop in emissions was, on the one hand, caused by the mild winter leading to considerably reduced heating demand in the residential and services sectors. On the other hand, larger production of nuclear electricity in 2011 compared to the previous year resulted in a strong decrease in emissions from conventional electricity generation.

Germany, the largest EU economy and GHG emitter, showed an emission decrease of 27 Mt of CO_2 equivalent in 2011 compared to 2010. Lower consumption of gaseous and liquid fuels due to significantly lower heating demand in the residential sector accounted for the bulk of the net reduction in emissions in 2011. Lower emissions between 2010 and 2011 also occurred despite high economic growth and the shutdown of eight nuclear plants after the nuclear accident in Fukushima in 2011. The increasing use of renewable electricity also contributed to this reduction as well as to lower electricity exports.

In Spain, lower emissions from the residential sector resulting from a milder 2011 winter were more than offset by a switch from liquid and gaseous fuels to solid fuels for power generation. There was also a sharp contraction of electricity generated from hydroelectric facilities, and to a lesser extent from wind. However, energy use from solar and biomass increased strongly in 2011. The use of nuclear energy also decreased significantly. Low economic activity continued throughout 2011, and lower demand for construction also resulted in lower emissions from mineral products.

Romania and Bulgaria showed the strongest increase in emissions in 2011. Unlike in central Europe, the 2011 winter was colder than usual in these countries, leading to higher heating demand. As was the case in Spain, the emission increase is also due to a change in fuel use from liquid fuels to coal in conventional thermal power stations.

3 Overview by greenhouse gas type

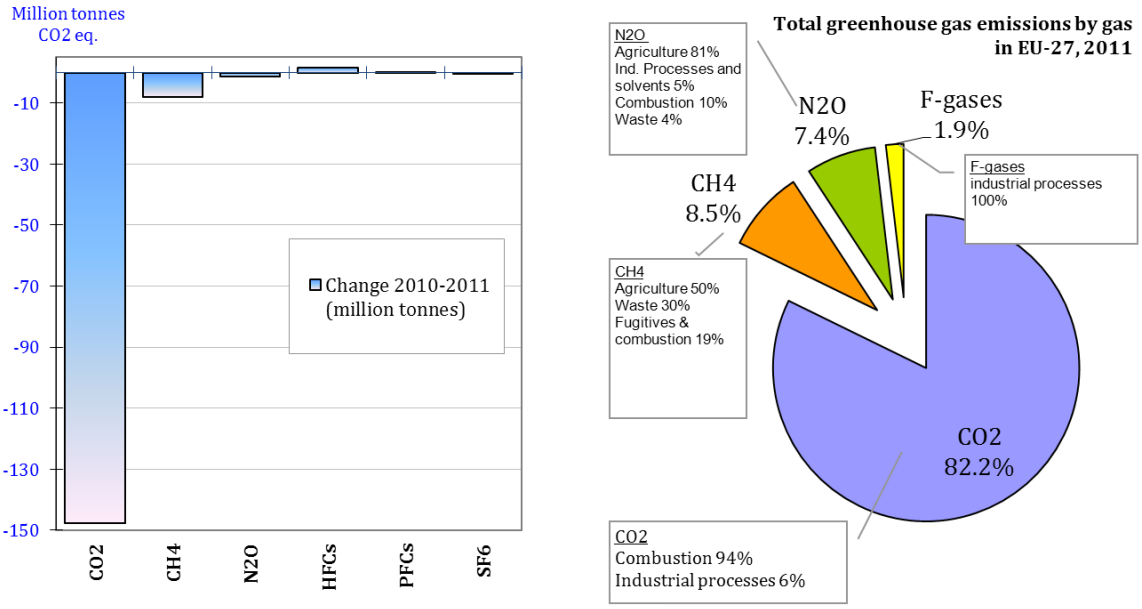
Of the Kyoto greenhouse gases, CO_2 accounted for the largest decrease in emissions in the EU-27 in 2011, with 148 million tonnes less (or 3.8 % reduction) than 2010 (Figure 3). About 82 % of all EU greenhouse gas emissions were CO_2 related. About 94 % of the CO_2 released to the atmosphere stemmed from combusting fossil fuels, while the remaining 6 % were released by industrial processes.

Hydrofluorocarbons (HFCs) from industrial processes increased again in 2011, continuing the long trend observed since 1990. HFCs are used in producing cooling devices such as air conditioning and refrigeration. The increase is consistent with both warmer climatic conditions in Europe and increased comfort standards (e.g. mobile air conditioning).

Emissions declined somewhat for nitrous oxide (N_2O), which accounted for 7.4 % of total EU greenhouse gas emissions in 2011. There were also small declines in emissions of methane (CH_4), which accounted for 8.5 % of the total 2011 GHG emissions. The reduction in N_2O emissions was mainly due to lower production of adipic acid — a precursor for nylon production. The small reduction in CH_4 emissions was due to lower emissions from enteric fermentation and manure management, and to less waste disposal on land.

Viewed over a longer timeframe, the decrease in methane emissions in the period 1990–2011 resulted from lower fugitive emissions from coal mining and post-mining activities, and lower emissions from managed waste disposal on land. Methane from enteric fermentation in the agricultural sector also fell significantly, partly due to reduced livestock numbers but also due to changes in the agricultural management of organic manures. Nitrous oxide emissions decreased strongly because of lower emissions from agricultural soils.

Figure 3 Greenhouse gas emissions by main gas in the EU-27



Source: EEA.

4 Overview by main sector

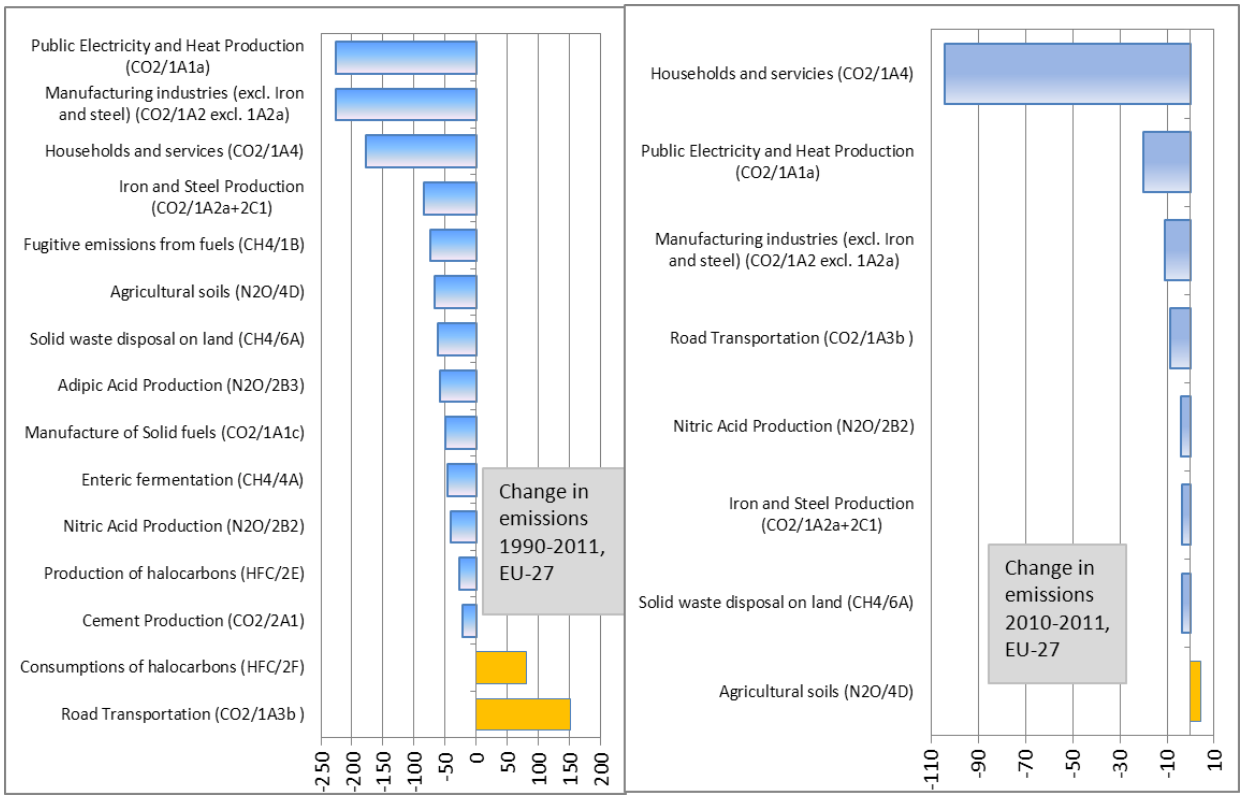
GHG emissions decreased in the majority of key sectors in 2011, particularly sectors relying on fossil fuel combustion. Figure 4 presents the most influential key emission sources (excluding bunkers, i.e. international transport) in the EU in the periods 1990–2011 and 2010–2011.

The sector that contributed most to lower GHG emissions in the EU in 2011 was 'residential and commercial', which broadly falls outside the scope of the EU ETS. The key reason for the 104 million-tonne decrease in CO_2 emissions (83 of which were from residential) in this sector was the mild winter in 2011, which decreased demand for heating, particularly by households. Around 70 % of the

decrease in emissions from households and services in 2011 was accounted for by lower use of natural gas. The second largest decrease in emissions (20 million tonnes of CO_2 equivalent) occurred in electricity and heat production from 'energy industries', which broadly falls within the scope of the EU ETS. The combined effect of these two sectors ('households and services' and 'public heat and electricity') contributed to about 80 % of the total reduction in GHG emissions in the EU in 2011. EU emissions from transport fell for the fourth consecutive year.

Overall, the sectors covered by the EU Emissions Trading System (EU ETS) contributed less to the overall reduction in 2011 GHG emissions than the non-trading sectors (i.e. those outside the EU ETS). Between 2010 and 2011, the emission reductions were larger in the non-ETS sectors (– 4.3 %) than in the installations covered by the European Emissions Trading System (– 1.8 %) for the EU as a whole. Combustion installations accounted for 99 % of the total net reduction in ETS emissions in 2011. Lower heat and electricity demand, particularly from the residential sector, appear to be the main contributing factor to lower ETS emissions in 2011.

Figure 4 **Overview of the EU-27 source categories recording the largest increases and decreases in the periods 1990–2011 and 2010–2011**

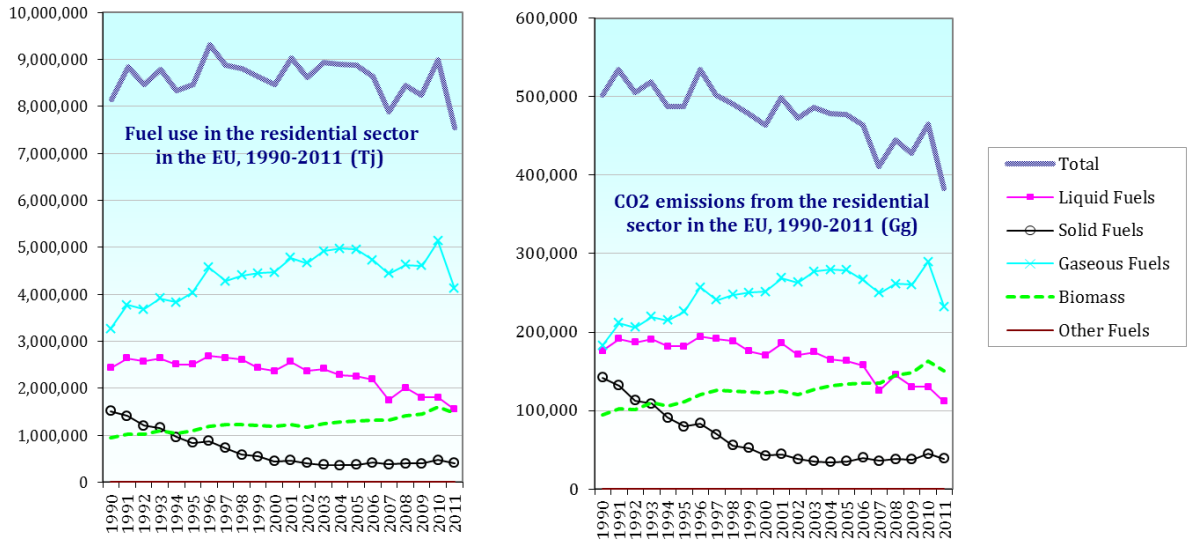


Source: EEA.

Viewed over a longer period, emission reductions from households (and services) are one of the key reasons for lower greenhouse gas emissions in the EU. One driver has been generally warmer winters in Europe and, correspondingly, less demand for heating. The winter in Europe in 2011 was

significantly warmer on average than in 2010, resulting in lower demand for heating[5] by households, and therefore lower GHG emissions. Fuel consumption in the residential sector reported in greenhouse gas inventories decreased by a staggering 16 % in 2011, making it the largest ever reduction since 1990. Also, final consumption of derived heat (e.g. from district heating and combined heat and power plants) reported to Eurostat under the EU Energy Statistics Regulation fell by as much as 10 % in 2011. Taken together, the overall reduction in heat-related GHG emissions from households of between 14-16 % in 2011 has been the largest of the past 21 years, particularly for gas (figure 5).

Figure 5 **Fuel use and CO_2 emissions from the EU's residential sector (excludes heat and electricity from distributed systems)**



Source: EEA

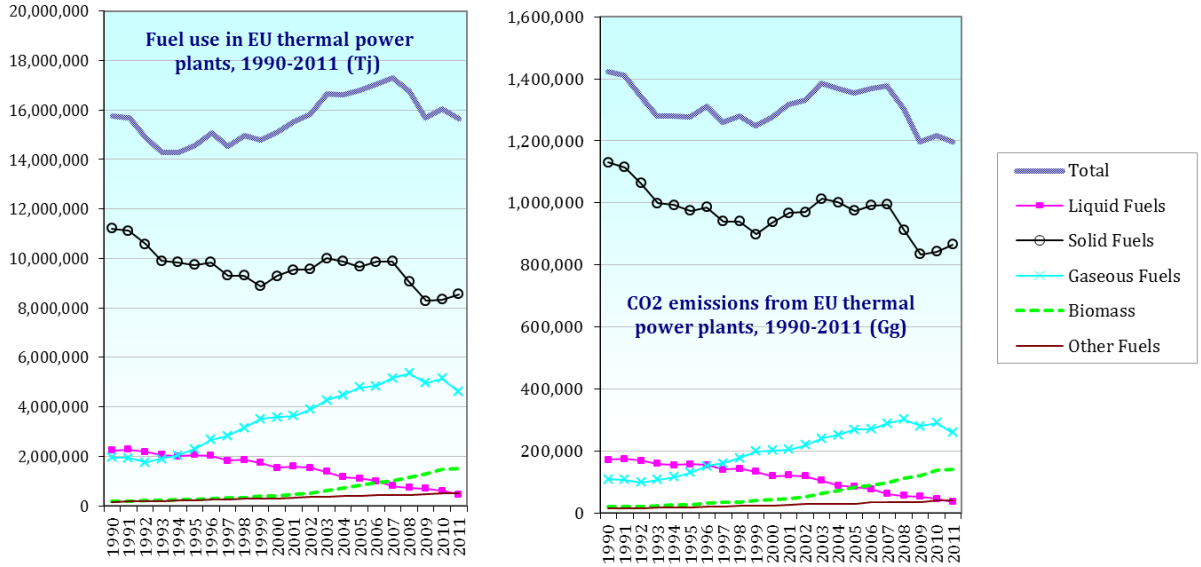
The second largest decrease in emissions (20 million tonnes of CO_2 equivalent) occurred in electricity and heat production. This was partly due to a decline in district heating, and partly due to lower electricity generation. However, this sector remains the largest contributor to GHG emissions in the EU, accounting for 27 % of total GHG emissions in 2011. Figure 6 shows that CO_2 emissions from heat and power in the EU have generally decreased since 1990, despite a significant increase in fuel

(5) Part of this heating is supplied via distributed systems from district heating and combined heat and power thermal stations. The primary energy to generate distributed heat (mainly from coal and gas) is reported under 'public electricity and heat production' in greenhouse gas inventories (by and large under the EU ETS). The other part of the heating consists of non-distributed heat, which is generated directly by households/services (mainly from gas and biomass) and is reported under 'residential and commercial' in greenhouse gas inventories. This includes emissions from fuel combustion in commercial and institutional buildings; all emissions from fuel combustion in households; and a smaller source category covering fuel combustion emissions from agriculture, forestry and fishing. Direct combustion emissions from households are by and large outside the EU ETS.

In 2012, the EEA published the technical report 'End-user GHG emissions from energy: Reallocation of emissions from energy industries to end users 2005–2010'. The report's objective was to help improve understanding of past greenhouse gas (GHG) emission trends in the energy sector from the demand or end-user side. To do this, the report developed a methodology to redistribute emissions from energy industries to the final users (by sector) of that energy. This reallocation is done on the basis of Eurostat's energy balances and GHG inventories for the energy sector, as reported to the United Nations Framework Convention on Climate Change (UNFCCC), for the period 2005–2010.

use in the sector. The implied emission factor for coal and lignite in the EU-27 in 2011 was on average 101 tonnes of CO_2 equivalent per terajoule in 2011. The emission factor for liquid fuels was 76 t CO_2 / Tj and for gaseous fuels it was 56 t CO_2/ Tj. This means that coal releases around 80 % more CO_2 than gas to deliver the same amount of energy. In 2011, the use of natural gas and liquid fuels in thermal stations decreased strongly whereas coal use increased, resulting in increased CO_2 emissions per unit of fossil energy generated. However, CO_2 emissions fell because the increase in coal use did not offset the much larger decrease in the use of natural gas, and to a lesser extent of liquid fuels. The steady increase in biomass use, although at a slower pace than in previous years, also served as a substitute for fossil fuels ([6]).

Figure 6 Fuel use and CO_2 emissions from EU-27 electricity and heat production



Source: EEA

Road transport emissions continued to decline in 2011 for the fourth consecutive year due to lower gasoline emissions. Automotive gasoline and diesel prices increased starkly in 2011 compared to 2010. Diesel price inflation has outpaced even the rapidly increasing gasoline prices for some years. Along with the start of economic recession in the second half of 2008 and the whole of 2009, this triggered a fall in freight transport demand, which was reversed in 2010. To a lesser extent, increased use of biofuels also contributed to the lower road transport emissions in 2011.

Emissions from international aviation and maritime transport are not relevant for Kyoto compliance. They are reported in greenhouse gas inventories as Memorandum items. International transport emissions increased constantly between 1992 and 2007. Emissions decreased between 2007 and 2010 in the EU-27, partly reflecting the economic recession, but have increased again in 2011. EU

(6) CO_2 emissions from the combustion of biomass (including biofuels in transport) are not included in national GHG emission totals according to UNFCCC Reporting Guidelines. They are reported separately in GHG inventories as a Memorandum item. The reason for this is mainly to avoid double counting emissions from a reporting perspective. It should not be linked to sustainability and/or to carbon neutrality. The assumption is that harvesting does not outpace annual regrowth, and that unsustainable biomass production would show as a loss of biomass stock in the LULUCF sector.

greenhouse gas emissions from international aviation are lower than for international maritime transport but have been growing more rapidly. Total GHG emissions from international transport altogether reached 299 million tonnes of CO_2 equivalent in 2011 for the EU as a whole.

5 Other factors explaining the change in greenhouse gas emissions in 2011

A number of factors outside formal GHG inventory reporting can help explain the decrease in greenhouse gas emissions in the EU in 2011. This section introduces additional socio-economic explanatory variables to provide a more complete picture of why emissions from fossil fuel combustion decreased in 2011. These additional variables include population, GDP, and the full energy balances of EU Member States reported to Eurostat.

Two approaches to understand emission drivers are presented below: a decomposition analysis based on an extension of the original Kaya identity, and the standard cross-sectional regression analysis.

5.1 Decomposition analysis

5.2.1 Key findings

EEA data show that CO_2 emissions from energy-related fossil fuel combustion (including transport) decreased by 4.1 % (148 million tonnes) in the EU-27 in 2011. The final energy intensity of the economy improved, as final energy demand decreased strongly (4.3 %) amid positive GDP growth (1.6 %). However, the carbon intensity of the EU economy deteriorated due to increased use of hard coal and lignite in the fossil-fuel mix. The contribution of the 'non-carbon fuels' effect was only positive because the consumption of renewables (and of nuclear) fell by less than the consumption of all fossil fuels as a whole. The energy efficiency effect was negative as lower heat production in 2011 meant a significant reduction in the average transformation efficiency from conventional thermal power stations. The sharp decrease in hydroelectricity production also meant a reduction in the ratio of final to primary energy. This is because there are no energy-transformation losses when converting mechanical energy to final energy, contrary to the combustion of fossil fuels.

5.2.2 Methodology

Decomposition analysis is often used to portray the primary forces driving emissions. The explanatory factors should not be seen as fundamental factors in themselves, however, nor should they be seen as independent of each other.

Energy combustion (i.e. the production and consumption of energy by all sectors, including transport) accounted for over 96 % of the net decrease in EU greenhouse gas emissions in 2011. Figure 7 shows a breakdown of the factors that help explain or illustrate year-on-year changes in CO_2 emissions (the largest GHG gas) from the combustion of fossil fuels. For definitions see Box 1.

Box 1 Factors used in the decomposition analysis

The chosen factors are an extension of the Kaya identity and should be seen as illustrative only since they represent an identity where the dependent variable is not determined stochastically.

The **equation** is:

(y) CO_2 = (x_1)POP * (x_2)GDP/POP * (x_3)FEC/GDP * (x_4)PEC/FEC * (x_5)FFC/PEC * (x_6) CO_2/FFC, where:

The **factors** are:

(y) CO_2: carbon dioxide emissions from energy combustion processes

(x_1) POP: population (population effect)

(x_2) GDP/POP: GDP per capita (affluence effect)

(x_3) FEC/GDP: final energy intensity of the economy (energy intensity effect)

(x_4) PEC/FEC: primary energy relative to final energy (energy efficiency effect)

(x_5) FFC/PEC: fossil fuel consumption in total primary energy (non-carbon fuels effect)

(x_6) CO_2/FFC: carbon dioxide emissions in fossil fuel consumption (carbon intensity effect)

CO_2 emissions from energy combustion decreased by 4.1 % (148 million tonnes) in the EU-27 in 2011. A growing population and GDP generally contribute to higher CO_2 emissions. The *population* increased by 0.3 % (1.3 million people) while GDP grew by 1.6 %, leading to a 1.3 % increase in *GDP per capita* in 2011. This positive affluence effect appears less dominant than in 2010, which is mainly due to the slowdown of the EU economy during 2011.

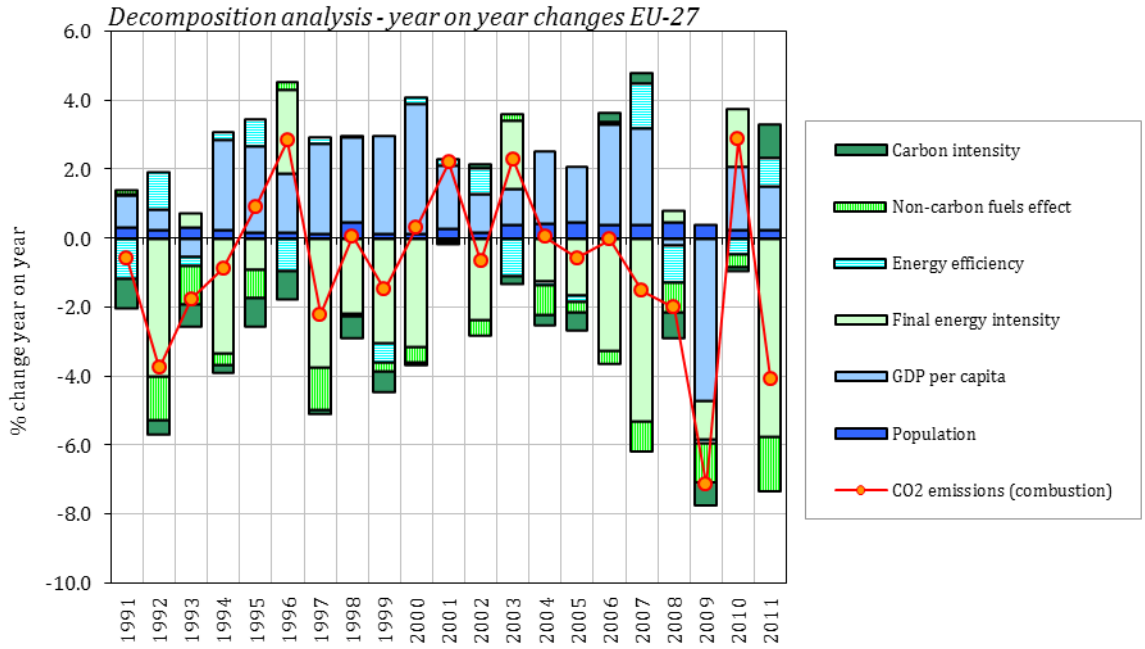
The *energy intensity* of the economy improved by 5.7 % in 2011 compared to 2010. This was mainly because the strong decrease in final energy demand in 2011 (4.3 %) outstripped the increase in GDP (1.6 %).

Eurostat's 2011 energy balances also point to a strong decrease in primary energy consumption (3.5 %). This rate was, however, lower than the decrease in final energy available to the end-use sectors ([7]), resulting in a worsening of the '*energy efficiency*' effect (as defined in Box 1) in 2011. At least two reasons can explain this deterioration. First, there was a significant decrease in renewables, some of which can produce electricity by means of mechanical energy without any combustion. The sharp decrease in hydroelectricity production, particularly, meant a reduction in the ratio of final to primary energy. This is because no energy-transformation loss is reported when converting mechanical energy to final energy, contrary to the combustion of fossil fuels. Second,

(7) It is worth noting that not all primary energy is available to the end users of energy such as industry, transport, households, services and agriculture. This is because various losses occur within the energy system to transform primary energy (e.g. coal and lignite, natural gas and crude oil) into useful energy (i.e. heat, electricity, gasoline etc.). In addition to transformation losses, there are additional losses related to energy distribution and consumption of energy by the energy-production sector itself. In the case of non-combustible renewables, such as wind or hydro (without pumping), mechanical energy is used to transform primary energy into useful energy.

there was also a 0.6 percentage point decrease in the transformation efficiency in conventional thermal power stations (including district heating) in the EU in 2011. This can be explained by lower heat production that year, as electricity generation is less efficient than heat generation. Viewed over a longer timeframe, the increased use of electricity from combined heat and power (cogeneration) and recovery of excess heat have contributed to higher energy efficiencies in the EU.

Figure 7 **Explanatory factors for CO_2 emissions from energy combustion in the EU-27, 1990–2011**



Note: The chart shows the estimated contributions of the various factors that have affected CO_2 emissions from energy production and consumption in the EU-27. This approach is often used to portray the primary forces driving emissions. The explanatory factors should not be seen as fundamental factors in themselves nor should they be seen as independent of each other.

Source: EEA (GHG emissions); Eurostat (population and energy balances); Eurostat and European Commission Ameco database (GDP).

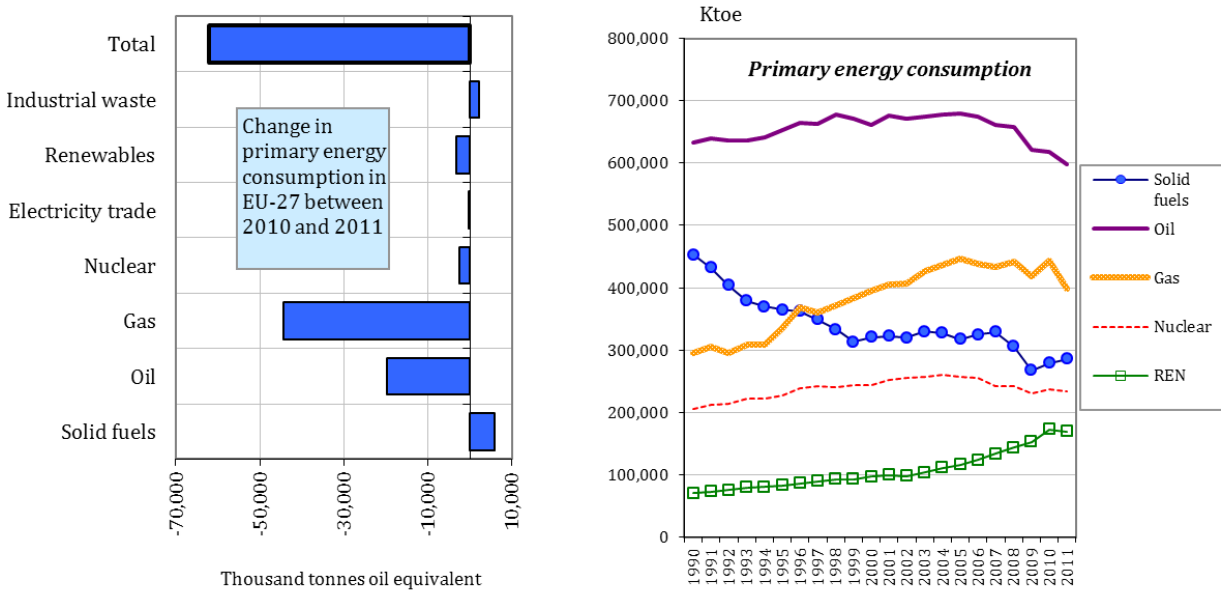
Figure 8 below shows that the consumption of solid fuels increased again in 2011 despite the overall decrease in primary consumption of fossil fuels, particularly of gas. Renewable energy use also dropped significantly in 2011. About 60% of the reduction in renewables was accounted for by lower hydro production. Consumption of solar and wind energy, however, continued to grow strongly in the EU in 2011. Consumption of nuclear-generated electricity also decreased in 2011. The '*non-carbon fuels*' effect (defined in Box 1 and shown in Figure 7) helped to lower emissions in 2011, as the reduction in fossil fuel use outpaced the reduction in renewable energy use.

Finally, the *carbon intensity* of the EU economy deteriorated due to increased use of hard coal and lignite in the fossil-fuel mix. As a result, CO_2 emissions decreased less than the primary fossil fuel input in 2011.

It should be noted that while decomposition analysis can be useful for describing some of the primary forces driving emissions, one should bear in mind its limitations. These limitations include the fact that the equation is an identity where the relationship between the variables is true by

definition, allowing no country-specific variation in the data . However, decomposition analysis can point to interesting findings, which can be explored further using other methods.

Figure 8 Primary energy consumption by main fuels in the EU-27, 1990–2011



Source: Eurostat energy balances.

5.2 Regression analysis

5.2.1 Key findings

The regression analysis outlined below indicates that lower final energy consumption, resulting from lower heat demand, lower energy efficiency and higher carbon intensity were the main (statistical) factors underpinning the change in greenhouse gas emissions in the EU in 2011. The latter two factors prevented GHG emissions from decreasing more in 2011.

In addition, the analysis suggests that the reduction in final energy consumption was the single most determinant factor of the three (higher beta coefficient) in explaining why EU emissions decreased by 3.3 % in 2011 compared to 2010. A milder 2011 winter compared to 2010 can to a large extent explain lower fossil fuel emissions, as higher winter temperatures, on average, led to lower heating demand and lower emissions from the residential and commercial sectors.

An extended regression model including 'heating degree days' (an indicator of demand for heating by households) confirms that lower heat consumption was the main reason for lower GHG emissions in the EU in 2011 compared to 2010.

5.2.2 Methodology

Basic model

This section presents a cross-sectional statistical analysis of greenhouse gas emission drivers in 2011. The variables have been selected from the decomposition analysis of the previous section so far as possible (Box 2).

The objective is to determine the statistical significance and importance of each of the predictors on the dependent variable. The variables are allowed to vary stochastically using data for 27 EU countries, and their significance is determined using standard and robust regression methods.

The basic model described in Box 2 takes into account the relative contributions of Member States in the regression coefficients, using greenhouse gas emissions as analytical weights. Thus, the model uses 'weighted least squares' (WLS), taking into account country-size effects on the dependent variable.

Box 2 Variables used in the regression analysis — basic model

The variables were derived from the previous decomposition analysis, transforming the deterministic relationship with no error into a stochastic relationship using data from 27 EU Member States.

The **equation** is:

(y) GHG = (x_1)GDP/POP + (x_2)FEC + (x_3)EFF + (x_4)REN + (x_5)CAR + μ, where:

The **variables** are, data source in brackets:

(y) GHG: % change in greenhouse gas emissions from energy combustion including fugitives (EEA).

(x_1) GDP/POP: % change in GDP at constant prices per head of population (European Commission, Ameco database)

(x_2) FEC: % change in final energy consumption (Eurostat's energy balances)

(x_3) EFF: percentage point change in transformation efficiency in main-activity thermal power stations and district heating plants (Eurostat's energy balances)

(x_4) REN: % change in final renewable energy consumption (Eurostat's energy balances)

(x_5) CAR: percentage point change in the average implied CO_2 emission factor of fossil fuel energy, excluding biomass (EEA)

μ: error term

The full regression model is highly significant (F-value), although some of the predictors have non-significant p-values (GDP, REN, CAR). The residuals are normally distributed. The Weighted Least Squares (WLS) coefficients in the full regression model could indeed suggest the presence of collinearity in the independent variables. However, all predictors show relatively low variance inflation factors and high tolerance values.

A closer inspection at the correlation matrix reveals very low correlation between GHG and GDP per capita. GDP/POP is discarded from the model because of its statistical insignificance (p-value of 0.425) and because of its very low correlation coefficient (0.13).

Final energy consumption of renewables (REN) in the reduced regression model remains statistically not significant (p-value of 0.148). The residuals are also normally distributed, and REN can therefore be discarded from the model. The remaining three predictors (FEC, EFF and CAR) are all significant at 95 % level and are retained in the final regression model.

Figure 9 shows the scatter diagrams of the dependent and explanatory variables, suggesting positive relationships between GHG and both FEC and CAR, and a negative relationship between GHG and EFF.

Figure 9 Relationship between GHG emissions and predictor variables, change 2010–2011

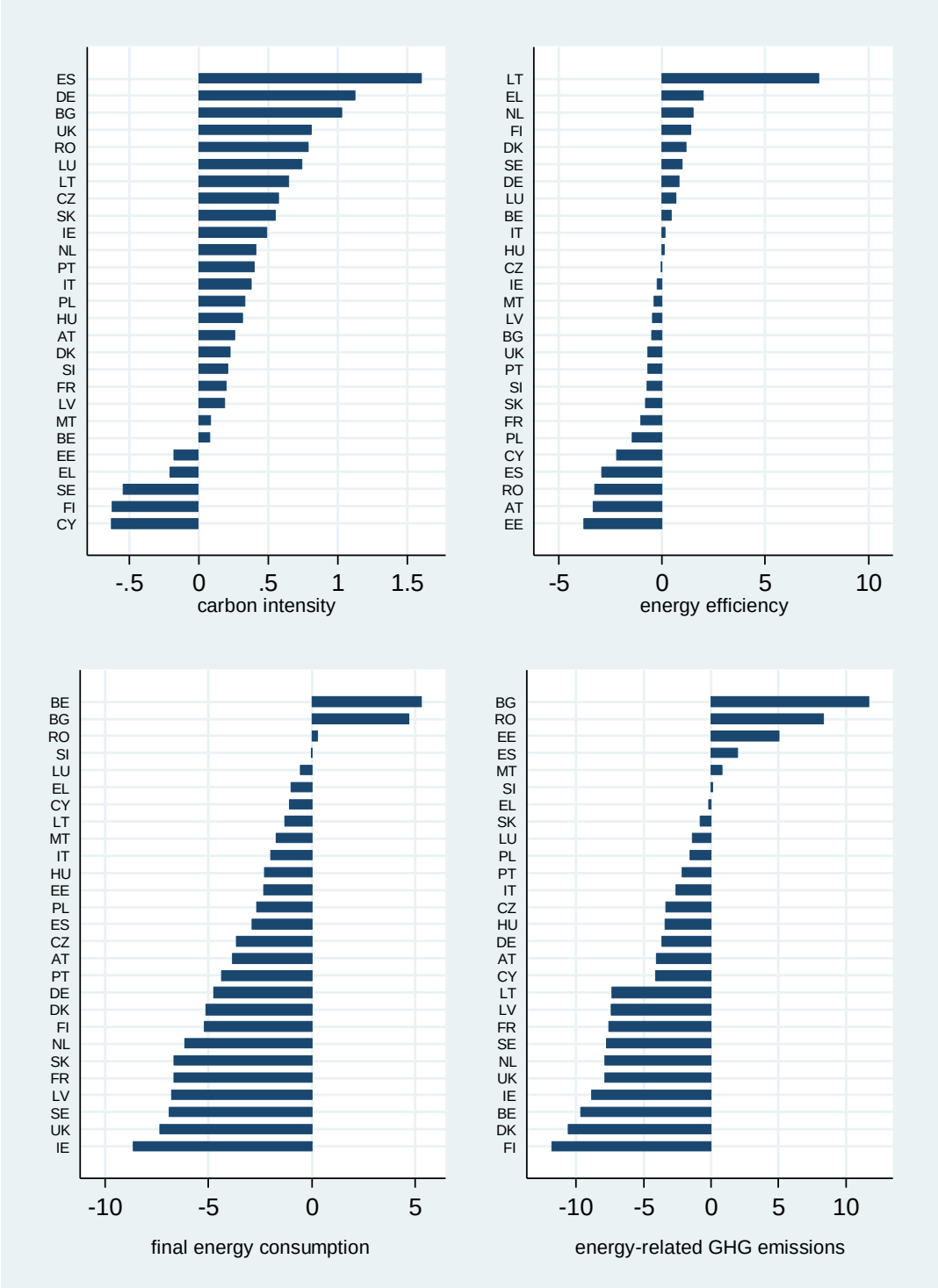
Final model

The coefficients from the reduced regression suggest that GHG is a function of FEC, EFF and CAR. The change in greenhouse gas emissions can therefore be written as a function of the individual and combined effects of growth in final energy consumption, the change in the efficiency of energy transformation, and the change in the CO_2 implied emission factor for fossil fuels in 2011. The WLS regression coefficients of GDP per capita and of renewable energy consumption are not significant at the 5 % level and are dropped from the regression model. The residuals from the final model are not normally distributed, probably due the presence of outlier/s. This will be analysed in the following section.

The final model consists of three independent variables (FEC, EFF and CAR). Based on this final model, the net decrease in greenhouse gas emissions in 2011 can be explained not only by the increase in final energy consumption but also by the reduction in energy efficiency and by a worsening of the carbon intensity in fossil fuel production. The latter two offset an otherwise larger decrease in GHG emissions.

The above conclusion takes into account all 27 EU Member States, and reflects positive and negative contributions for each explanatory (statistically significant) variable between 2010 and 2011 (see Figure 10).

Figure 10 **Growth in modelled dependent and explanatory variables in EU Member States, 2010–2011**



Final energy consumption fell in most EU countries in 2011. Emissions fell in all Member States where final energy consumption decreased, with the exception of Belgium. Energy use and energy-related emissions increased in Bulgaria and Romania.

The *energy efficiency* effect was negative, as lower heat production in 2011 meant a significant reduction in the average transformation efficiency from conventional thermal power stations. This is

not meant to imply that lower energy efficiency has resulted in lower GHG emissions. Rather, it confirms that lower final energy consumption from lower heat demand is a key explanatory factor underpinning lower GHG emissions in 2011.

Regarding *carbon intensity*, Member States vary in terms of changes in their CO_2 average emission factors from fossil fuel combustion. Changes in the average emission factor depend on several factors. At EU level, the implied emission factor (IEF) has generally decreased since 1990. In 2011, however, the use of natural gas and liquid fuels in conventional stations decreased strongly whereas coal use increased, resulting in increased CO_2 emissions per unit of fossil energy generated. However, CO_2 emissions fell because the increase in coal use did not offset the much larger decrease in the use of natural gas, and to a lesser extent of liquid fuels. The steady, although lower than in previous years, increase in biomass use also served as a substitute for fossil fuels. The average implied emission factor for CO_2 increased in 22 of 27 Member States in 2011. Overall, there is a significant positive correlation between GHG emissions and the IEFs, which also helps explain why the net decrease in GHG emissions was 3.3 % in EU-27 in 2011, and not larger.

Standard and robust regression analysis

All three predictors (FEC, EFF and CAR) played a role in the net decrease in GHG emissions in the EU in 2011. There is some evidence, however, that the variance of the residual errors is not constant and the errors are not distributed normally. This may be due to potential outliers or extreme observations in some countries, and could in turn lead to biased standard errors and inference ([8]).

A closer look at the influence of specific observations shows that Belgium in particular could be considered an statistical outlier because of its very large residual of more than two standard deviations from the mean of expected predicted values ('large residual effect').

In addition to the overall large residual effect, Spain and Lithuania have extreme values on at least one of the predictor variables ('high leverage effect'). Finally, Belgium, Bulgaria, Lithuania and Estonia have a significant effect on the regression coefficients of the model ('high influence effect'). In Belgium and Bulgaria, there is overall influence from final energy consumption and carbon intensity, whereas the influence in Lithuania and Estonia is mostly triggered by the energy efficiency effect. Finally, in Spain, the specific influence can be attributed to the relatively strong increase in carbon intensity in 2011.

None of the observations are removed from the model (model 1 of table 1) as they just represent the country-specific changes in the dependent variable (GHG) to changes in the three explanatory variables (FEC, EFF and CAR). However, removing Belgium would lead to a very large improvement of the model, with the adjusted R-squared increasing from 54 % to 88 %.

Robust specification of the standard errors from the WLS regression could help remove the bias in the variance of the residuals from the WLS regression. The approach only affects the confidence interval around the mean estimates, not influencing the regression coefficients ([9]).However, a robust

(8) The Breusch-Pagan / Cook-Weisberg test for heteroscedasticity rejects the null hypothesis of homoscedastic errors at the 5 % significance level. Thus, there is evidence of heteroscedasticity. Moreover, the kernel-density plot and the quantile and normal probability plots do not look normal. The Shapiro-Wilk W test, Jarque-Bera and the skewness/kurtosis tests reject the null hypothesis of normal residuals.

(9) The standard errors are estimated using Huber-White sandwich estimators and can deal with some minor problems of failure to meet the Gauss-Markov assumptions, in our case the lack of homoscedastic errors triggered by some

specification of the errors in the model would double the standard deviation of the coefficient for final energy consumption, while reducing the standard deviations of the two other explanatory variables (model 2 of table 1). This would make final energy statistically insignificant at 0.05 (p-value of 0.06). However, since the correlation between GHG and FEC is very high when considering 26 Member States (where the correlation reaches 85%) it does not seem appropriate removing this explanatory variable from the model in order to improve the heterocedasticity of the residuals. Thus, robust standard errors do not substantially improve the model.

To test whether heterocedasticity substantially affects the WLS estimates, we ran a robust regression[10] and compared the regression coefficients (model 3 of table 1). The coefficients of model 3 were different to models 1 and 2, suggesting a significant 'gain' from using robust regression compared to WLS regression. The explanatory power of the robust regression also increases with an adjusted R-squared of 0.75, compared to 0.54 when using WLS. However, this large improvement appears to be due to the exclusion of extreme observations (Cook's D is greater than 1), which is the case of Belgium in our sample[11]. While model 2 implied removing one explanatory variable, model 3 implies removing one observation. Therefore, robust regression does not substantially improve the model either. Figure 11[12] shows the partial regression plots for each explanatory variable for model 1.

To summarise, lower final energy consumption in 2011 is by and large the result of lower consumption of fossil fuels, particularly of gas in the residential sector. The statistical analysis also shows that energy efficiency is significant and suggests that lower efficiencies overall may be linked to lower heat production relative to electricity. These are clear indications that weather-related factors could be the main reason for lower GHG emissions in the EU in 2011. Rather than removing observations from the model to improve the explanatory power, it seems more appropriate to include an additional variable to model the weather effect directly. The starting point is therefore model 1.

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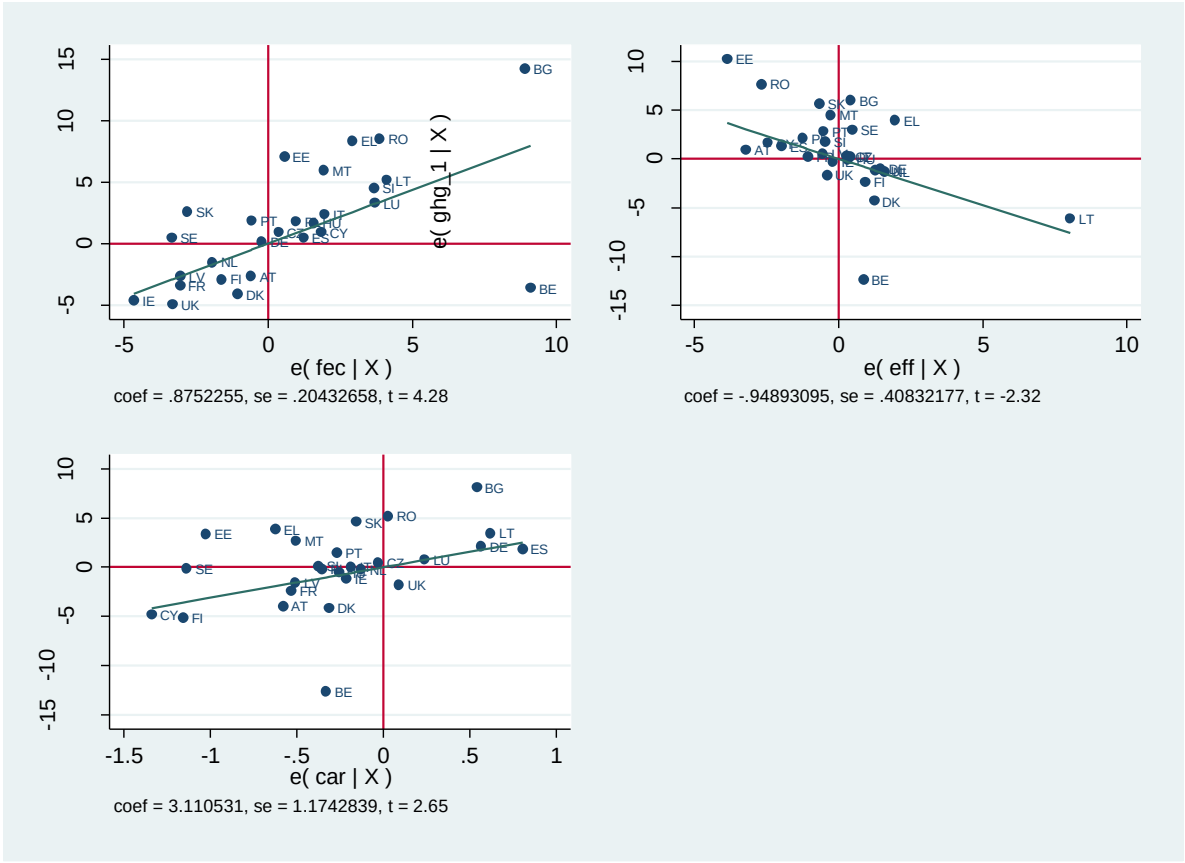
extreme observations. Belgium in particular causes the largest effect in the coefficients in the model. Removing this country from the regression would lead to an overall improvement of the model, with normally distributed errors and with a more homocedastic plot of residual versus fitted values.

(10) Robust regression basically uses iteratively re-weighted least squares by assigning a weight to each observation, with lower weights given to less well-behaved observations.

(11) Indeed, the coefficients from a standard Ordinary Least Squares (OLS) regression without Belgium match closely the results from the robust regression in model 3.

(12) Figure 8 showed the scatter plots of the response variable against each of the explanatory variables. However, this does not take into account the effect of the other explanatory variables in the final regression model.

Figure 11 Added-variable plots

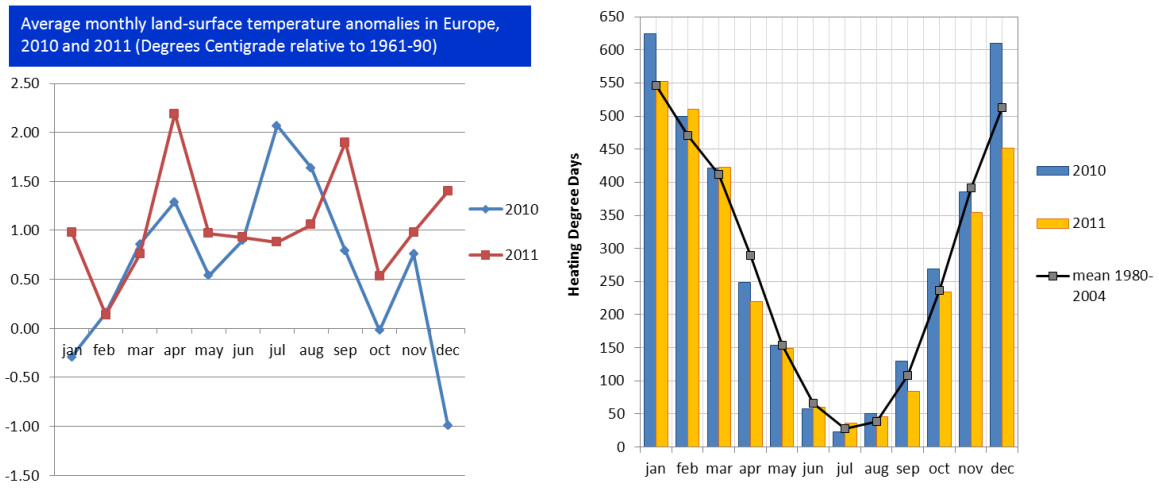


The weather effect

The results from model 1 suggest that lower heat consumption and heat demand are very likely the result of the warmer weather conditions in most parts of Europe during 2011 compared to 2010. This is also illustrated in figure 12. Based on data for Europe from the UK's Met Office Hadley Centre, the average monthly land-surface temperatures were higher in most winter-months of 2011 than 2010. Other international sources, such as the National Aeronautics and Space Administration Goddard Institute for Space Studies (NASA's GISS) and the National Oceanic and Atmospheric Administration's National Climatic Data Center (NOAA's NCDC), also confirm average warmer conditions in Europe in 2011 compared to 2010.

Furthermore, according to Eurostat, there was a 10 % decrease in the number of heating degree days (an indicator of household demand for heating) in the EU-27 in 2011 compared to 2010. Thus, mean temperatures for Europe as well as heating degree days strongly suggest that milder winter conditions in 2011 are responsible for the strong decrease in fuel use and emissions in the residential sector in 2011.

Figure 12 **Monthly mean land-surface temperatures and heating degree days in 2010 and 2011**



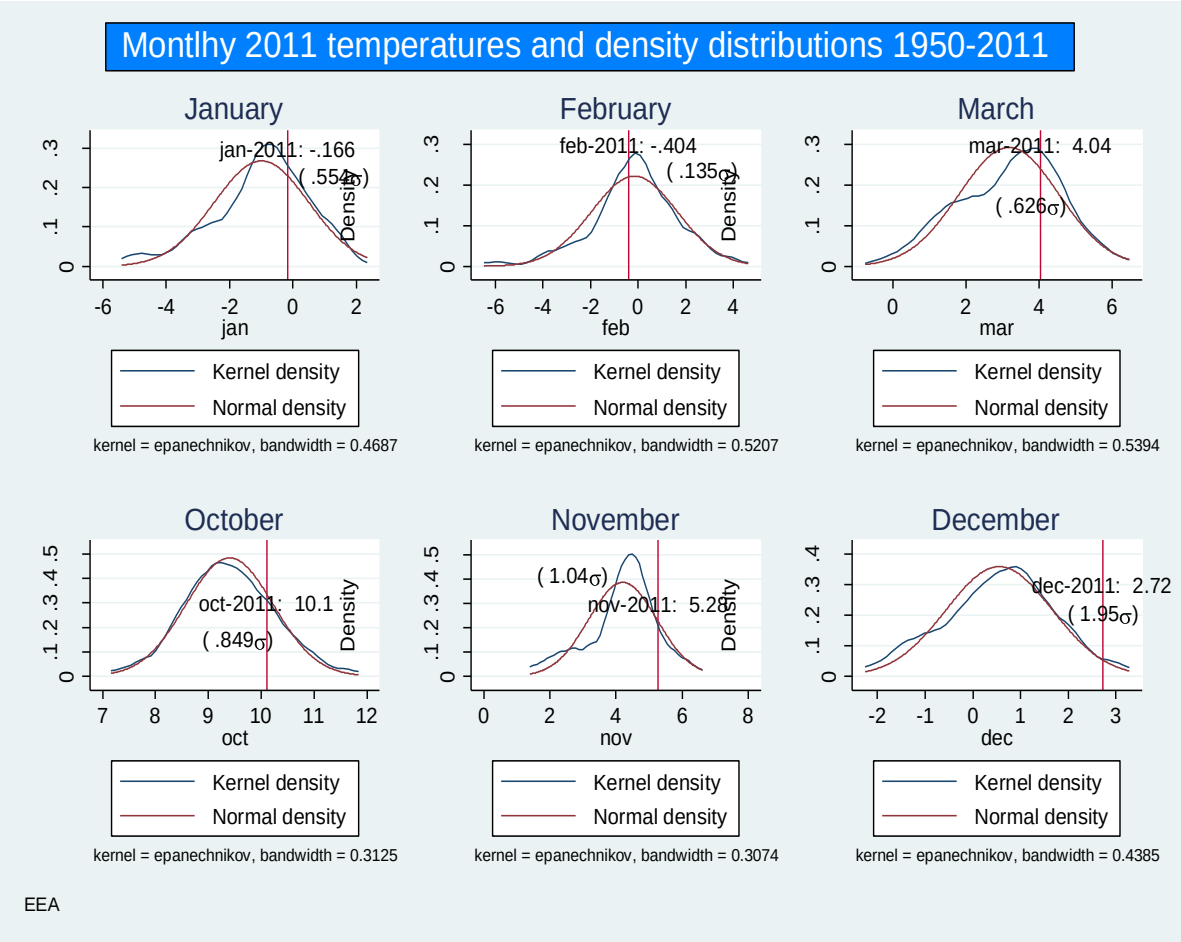
Note: Average monthly land-surface temperatures from the UK's Met Office Hadley Centre, HadCRUT3 dataset. Other international sources, such as NASA's GISS and NOAA's NCDC, also confirm average warmer conditions in Europe in 2011 compared to 2010.

Source: EEA. Data source for 'heating degree days' is Eurostat.

Other independent data sources confirm the above results. The European Climate Assessment & Dataset (ECA) contains series of daily observations at meteorological stations throughout Europe and the Mediterranean. Figure 13 below is based on daily maps of gridded data (E-OBS)[13] . It shows the distribution of monthly temperatures between 1950 and 2011 (Kernel densities), together with the normal densities (i.e. normal distributions), and the specific average temperatures for each month of 2011 (vertical line). In all months, except for February, the mean European temperature was significantly lower in 2011 than in 2010. This was particularly extreme in the month of December 2011, with temperatures almost outside the normal distribution: i.e. 2 standard deviations from the mean of December temperatures of the past 60 years.

(13) E-OBS dataset from the EU-FP6 project ENSEMBLES (http://ensembles-eu.metoffice.com) and the data providers in the ECA&D project (http://www.ecad.eu)"
"Haylock, M.R., N. Hofstra, A.M.G. Klein Tank, E.J. Klok, P.D. Jones, M. New. 2008: A European daily high-resolution gridded dataset of surface temperature and precipitation. J. Geophys. Res (Atmospheres), 113, D20119, doi:10.1029/2008JD10201

Figure 13 **Monthly 2011 temperatures and density probability distributions in Europe**



Source: EEA. Data source for the underpinning daily gridded temperatures, http://www.ecad.eu/ (see also footnote 13).

Including Heating Degree Days in the final model

Heating Degree Days (HDDs), compiled by Eurostat, are a measure of household demand for heating. HDDs decreased significantly in the majority of MS in the EU in 2011 and increased in Cyprus, Malta, Greece, Bulgaria and Romania. Clearly, including HDDs as an additional explanatory variable improves the model substantially without excluding any extreme observation. Although the new model (model 4 of table 1) is less parsimonious, all explanatory variables are significant at the 0.05 level. In addition, the adjusted R-squared increased from 0.54 in model 1 to 0.69 in model 4. Again, there is evidence that the residuals do not meet Gauss Markov conditions. In addition to Belgium, Cyprus has an extreme value on one of the predictor variables ('high leverage effect'). In particular, Cyprus' HDDs increased strongly whereas energy-related GHG emissions decreased in 2011([14]).

The WLS coefficients from model 4 indicate that when the final energy consumption increases by 1 percentage point greenhouse gas emissions are expected to increase by 0.6 % (holding EFF, CAR and HDD constant). Also, if the transformation efficiency increases by 1 %, greenhouse gas emissions are expected to increase by about 0.9 % (holding FEC, CAR and HDD constant)[15]. If the CO_2 implied emission factor for fossil fuels increases by 1 %, greenhouse gas emissions are expected to increase by about 4 % (holding FEC, EFF and HDD constant). Finally, if HDDs increase by 1 %, energy-related GHG emissions would be expected to increase by 0.2 %.

To conclude, the analysis indicates that lower final energy consumption, lower energy efficiency and higher carbon intensity were the main statistical factors underpinning the net decrease in greenhouse gas emissions in the EU in 2011. The latter two factors prevented GHG emissions from decreasing more in 2011 (i.e. offsetting factors). An extended regression model with heating degree days provided additional evidence to support the conclusion that lower heat consumption from lower heat demand was the main reason for lower GHG emissions in the EU in 2011. A milder 2011 winter compared to 2010 can to a large extent explain lower fossil fuel emissions, as higher winter temperatures, on average, led to lower heating demand and lower emissions from the residential and commercial sectors.

(14) As was the case with model 1, there is evidence of heterocedasticity and non-normality in the residuals of model 4. Cyprus in particular causes the largest effect in the coefficients in the model. Without Cyprus, the residuals would be homoscedastic, with zero mean and normally distributed. The residual v. fit plot would also suggest that the residuals have zero mean and constant variance. The errors are also independent. There is no misspecification of the model and there is no autocorrelation bias because of omitted variables. The kernel-density plot and the quantile and normal probability plots look normal. The Jarque-Bera and the skewness/kurtosis tests do not reject the null hypothesis of normal residuals.

(15) As mentioned earlier, there is a negative relationship between GHG emissions and energy efficiency in the model as lower heat production in 2011 meant a significant reduction in the average transformation efficiency from conventional thermal power stations. This is because electricity generation is less efficient than heat generation. Therefore, one should not extrapolate this negative correlation to conclude that energy efficiency improvements lead to higher GHG emissions, or the other way round. Rather, it can be seen as an additional indication to support the main conclusion that lower heat demand from the milder winter was the most important factor underpinning lower GHG emissions in 2011.

Table 1 Final model results

	(1) Weighted least squares	(2) WLS with robust standard errors	(3) Robust Regression	(4) Weighted least squares (with HDD)
Variables	ghg_1	ghg_1	ghg_1	ghg_1
Final energy consumption (FEC)	0.875***	0.875	1.350***	0.618**
	(0.204)	(0.444)	(0.191)	(0.183)
Beta coefficient	0.574	0.574		0.405
Energy efficiency (EFF)	-0.949*	-0.949**	-1.012***	-0.911*
	(0.408)	(0.334)	(0.256)	(0.335)
Beta coefficient	-0.316	-0.316		-0.303
Carbon intensity (CAR)	3.111*	3.111**	2.435*	4.142***
	(1.174)	(0.843)	(1.101)	(1.006)
Beta coefficient	0.361	0.361		0.480
Heating degree days (HDD)				0.160**
				(0.046)
Beta coefficient				0.438
Constant	-2.549*	-2.549	0.498	-1.900
	(1.192)	(2.510)	(0.987)	(0.993)
Observations	27	27	26	27
R-squared	0.59	0.59	0.78	0.74
Adj. R-squared	0.54	0.54	0.75	0.69
Mean square error	293.65	293.65	646.85	365.69
Residual square error	200.96	200.96	177.92	128.92
Root MSE	2.96	2.96	2.84	2.42

Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05

6 Early indications of 2012 figures

The most recent official data available for EU GHG emissions is the GHG inventory 1990-2011. Verified 2012 emissions from the EU ETS decreased by about 2 % compared to 2011. The EU ETS covers more than 12 000 power plants and manufacturing installations in the 27 EU member states, Norway and Liechtenstein. Emissions from the EU ETS represent approximately 40 % of total GHG emissions in the EU.

In addition, early Eurostat estimates of CO_2 from fossil fuel combustion also point to a 2.1 % decrease in emissions between 2011 and 2012. Eurostat's estimates are based on the IPCC Reference Approach. CO_2 emissions from fossil fuel combustion represent about 80 % of total GHG emissions in the EU.

In early autumn, the EEA will publish its annual Approximated GHG inventory for 2012. The EEA's Approximated GHG inventory covers all major sectors reported under the UNFCCC, and it is used to assess Member States' current progress towards GHG emission targets by the EEA and the European Commission. The Approximate GHG inventory is consistent with a full emissions inventory, therefore covering 100 % of total GHG emissions.

The final 2012 GHG emissions for the EU and its Member States will be submitted to the UNFCCC in the spring of 2014.

More information

The EU GHG inventory comprises the direct sum of the national inventories compiled by the EU Member States making up the EU-15 and the EU-27. The main institutions involved in compiling the EU GHG inventory are the Member States, the European Commission Directorate-General Climate Action (DG CLIMA), the European Environment Agency (EEA) and its European Topic Centre on Air Pollution and Climate Change Mitigation (ETC/ACM), Eurostat, and the Joint Research Centre (JRC).

Annual European Union greenhouse gas inventory 1990–2011 and inventory report 2013

Greenhouse gas data viewer

EU Emissions Trading System (ETS) data viewer

European Union Transaction Log

United Nations Framework Convention on Climate Change (UNFCCC)

Eurostat

Joint Research Centre
