Why did greenhouse gas emissions decrease in the EU in 2012?

EEA analysis

European Environment Agency

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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-28 between 2011 and 2012, which are the latest years for which official greenhouse gas inventory data are available[1]. 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 2013 emissions under the EU Emissions Trading System and also from fossil fuel combustion based on monthly energy statistics.

Contents

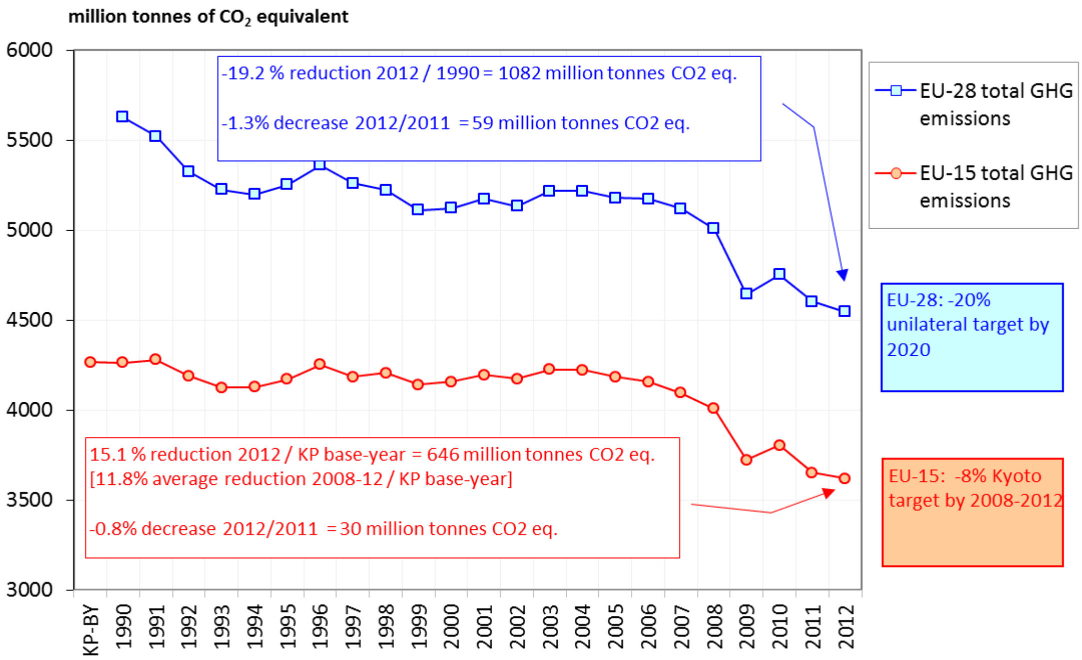
(1) For an overview of GHG emission trends in the EU between since 1990, see 'Why did GHG emissions decrease in the EU between 1990 and 2012', published alongside the current analysis on the EEA website http://www.eea.europa.eu/themes/climate

1 Summary of EU emissions

Total GHG emissions (excluding LULUCF) in the EU decreased again in 2012, reaching its lowest level since 1990. This continued the trend of emission reductions, which started in 2004.

In line with EEA predictions last year[2] GHG emissions between 2011 and 2012 decreased by 1.3 % in the EU28 and by 0.8 % in the EU-15. Figure 1 shows total greenhouse gas emissions in the period 1990–2012, both in the EU-15 (which has a collective target under Kyoto Protocol's first commitment period) and in the EU-28.

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



Source: EEA.

In 2012, EU-15 emissions were 15.1 % below the base year emission levels under the Kyoto Protocol's first commitment period ([3]). That constituted a net reduction of 646 million tonnes of CO_2-equivalents. The average reduction between 2008 and 2012 compared to base year emissions stands at 11.8 %. Total greenhouse gas emissions in the EU-28 were 19.2 % below 1990 in 2012 — a net reduction of 1082 million tonnes of CO_2-eq ([4]).

(2) Approximated EU GHG inventory for 2012, EEA Technical report No 14/2013 (http://www.eea.europa.eu/publications/approximated-eu-ghg-inventory-2012).

(3) 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.

(4) There is no Kyoto target for the EU-28 in the first commitment period and therefore no applicable base year. The 20 % EU 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 19.2 % overall

About two thirds of the EU net decrease in GHG emissions was accounted for by Italy, Poland and Finland. In percentage terms, emission reductions were highest in Finland, Denmark and Bulgaria.

The 1.3 % decrease in GHG emissions in EU-28 in 2012 came along with economic recession across the EU as a whole. Half the EU member states experienced negative economic growth in 2012. In the other half, positive economic growth in 2012 was lower than in 2011. Notwithstanding economic developments in specific sectors and countries, there was no apparent correlation between GDP and GHG emissions in the EU in 2012, although emissions did not increase in any MS where GDP was negative[5].

The winter in Europe was generally colder in 2012 than it was in 2011. Lower winter temperatures led to higher heating demand and higher emissions from the residential and commercial sectors. However, higher residential emissions did not offset much lower emissions in other combustion sectors, and as a result, total fossil fuel emissions decreased for the EU as a whole.

The price of carbon fell sharply in 2012 compared to 2011. However, energy prices increased by 7 % on average for the EU in 2012, clearly outpacing the increase in non-energy prices and the gross disposable income of households. Despite low carbon prices, energy became relatively more expensive for the average household. The consumer price index for energy increased three and half times faster than the harmonised consumer price index (excluding energy). This worsening of the relative purchasing power of families for energy products may have also contributed to the decline in GHG emissions in some Member States, particularly in road transportation.

GHG emissions decreased in the majority of key sectors in 2012. The exceptions were the residential and commercial sectors, where emissions increased due to the higher demand for heating. On average, the total consumption of fossil fuels decreased by 1.6 % in the EU-28 in 2012. The use of liquid and gaseous fuels decreased by 3.5 % and 2.7 % compared to 2011, respectively. However, the use of solid fuels, such as hard coal and lignite, increased by 3.7 %. Coal imports to the EU continued increasing quite significantly in 2012, particularly from Russia, Colombia and United States, putting downward pressure on coal prices. This increase in coal use did not offset a much larger decrease in the consumption of liquid fuels and natural gas, and GHG emissions fell as a result.

After the sharp decline in renewables witnessed in 2011, final energy consumption from renewables increased by 3.6 % in EU-28 in 2012. The contribution of renewables to the EU's overall energy mix improved quite significantly because of the lower use of fossil fuels in 2012. According to Eurostat, the share of renewable energy in gross final energy consumption reached 14.1 % in 2012, up from 12.9 % the year before. Approximately 50 % of the net increase in renewable energy in 2012 came from biomass (solid, biogas, biodiesel and renewable waste) and the other 50 % from wind, solar and hydro power. Nuclear electricity consumption also declined in the EU-28 in 2012 compared to 2011, mainly due to strong reductions in France, Germany and Belgium

reduction between 1990 and 2012 would be equivalent to a 17.9 % reduction. If international shipping was included, the net emissions reduction between 1990 and 2012 would be 16.9 %.

(5) The impact of the recession can go beyond the specific relationship between GHG emissions and GDP and affect energy consumption. Higher carbon intensity in the energy mix can indeed increase emissions despite lower or negative GDP growth. As will be shown later, other factors apart from GDP played a more important role in the decrease in GHG emissions in 2012 compared to 2011. 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.

In absolute terms, GHG emissions decreased by 59 million tonnes of CO2 eq. in the EU-28 in 2012. The only key sector where emissions at EU level increased in 2012 was 'residential and commercial', which broadly falls outside the scope of the European Emissions Trading System (EU ETS). The key reason for the 21 million tonnes increase in CO_2 emissions (16 of which from residential) in this sector was the colder winter in 2012, which increased demand for heating, particularly by households.

The largest decrease in emissions (32 million tonnes of CO_2) occurred in road transportation, which also falls outside the scope of the EU ETS. This was due to lower fuel sales of gasoline, mainly, and diesel for passenger cars as well as lower diesel sales for heavy duty and light commercial vehicles. To a lesser extent, increased use of biofuels and more efficient new vehicles also contributed to lower emissions in 2012. EU emissions from transport fell for the fifth consecutive year.

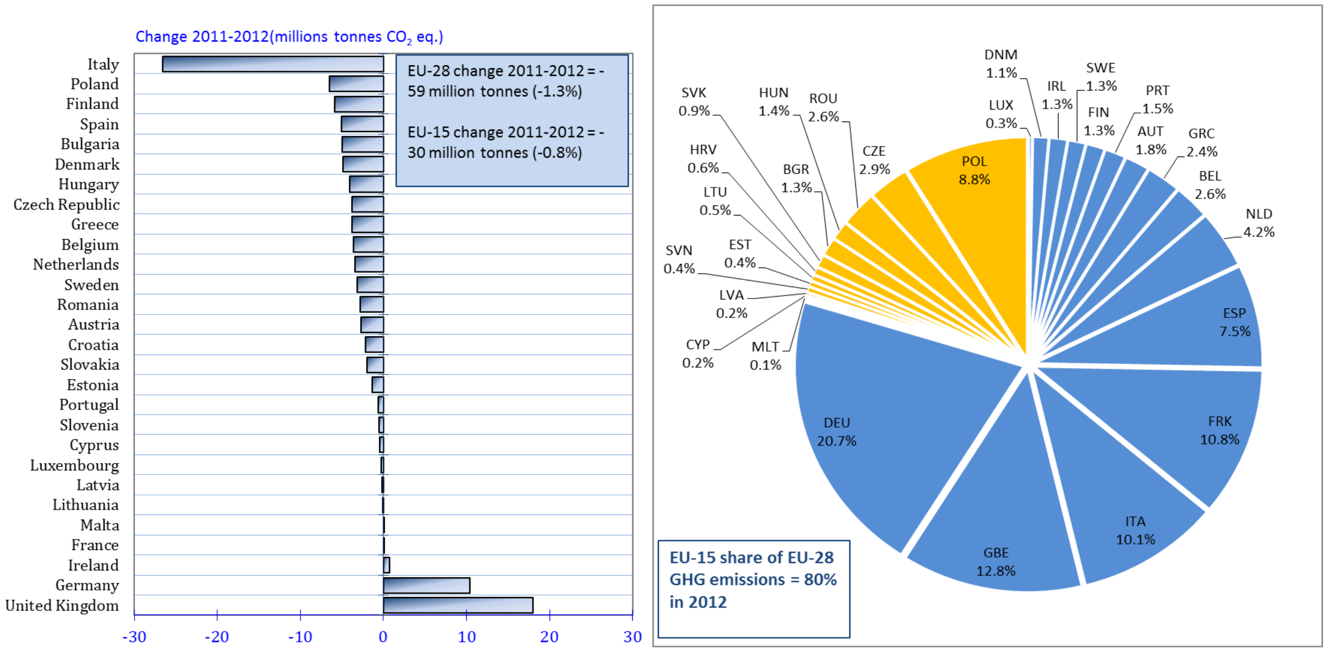
The sectors showing the second and third largest declines broadly fall within the scope of the EU ETS. The second-largest decrease was accounted for by manufacturing industries and construction, including iron and steel (23 million tonnes of CO_2). This reflects a decline in industrial production, particularly of cement and crude steel production. The third-largest decrease corresponded to the manufacture of other fuels (almost 10 million tonnes of CO_2), mainly linked to lower iron and steel production and the associated decline in coke production as well as the decline in oil and gas production.

Between 2011 and 2012 the emission reductions were larger in the installations covered by the ETS (– 2.0 %) than in the non-ETS sectors (– 0.8 %) for the EU as a whole. In the ETS sectors, lower output from combustion installations accounted for about one third of the total reduction in emissions in 2012. Industrial installations, particularly cement, refineries and iron and steel (including coke ovens), accounted for the remaining two thirds of the total reduction in ETS emissions. For the non-ETS sectors, CO_2 emissions from road transportation and N_2O emissions from agricultural soils accounted for most of the reduction in 2012.

2 Overview by Member State

At the Member State level, most EU countries reduced greenhouse gas emissions in 2012. The bars in Figure 2 depict the absolute emission increase or reduction by Member States between 2011 and 2012. Italy alone accounted for 45 % of the total EU-28 net reduction in emissions in 2012. This was particularly due to lower emissions from the transportation sector and from industry. The second largest reduction was in Poland and was mainly due to a substantial decrease in the consumption of solid fuels. In percentage terms, emission reductions were highest in Finland and Denmark, which benefited from high electricity imports from neighbouring countries. Contrastingly, United Kingdom and Germany increased GHG emissions significantly in 2012. In Germany, power production from coal increased mainly due to lower nuclear power production as well as higher electricity exports. Renewables increased strongly offsetting otherwise larger GHG emission increases. In the UK, there was a partial switch from gas to coal for power generation. In both the UK and Germany, the two largest GHG polluters in the EU, there was a substantial increase in the demand for heat from households due to a colder 2012 winter, with emissions from residential natural gas increasing significantly compared to 2011.

Figure 2 Greenhouse gas emissions by EU Member State



Source: EEA.

MS with the highest GHG emission reductions in the EU in 2012

Italy by far experienced the largest GHG emission reduction of all EU countries in 2012. Emissions decreased by 27 million tonnes (over 5 %) compared to 2011. This reduction reflects the effects of the economic recession with GDP down by 2.5 % compared to the previous year. There were significant emission reductions in manufacturing industries and construction, and related industrial emissions, such as those stemming from mineral products and iron and steel production (including coke production). Emissions also decreased quite significantly in the power sector, mainly due to lower gas consumption. Road transport emissions also fell substantially in 2012. Overall, fossil fuel consumption fell significantly, particularly of liquid fuels, whereas the consumption of renewables increased again in 2012. There was an increase in residential fuel consumption due to higher heating demand from the colder 2012 year. However, residential emissions decreased due to the substantial decrease in liquid fuels and a larger increase in the use of biomass.

For Poland there was a substantial decrease in the use of solid fuels in 2012 and GHG emissions decreased particularly for energy industries. Economic growth, albeit positive, was lower than in 2011. Lower winter temperatures and heating demand led to higher residential emissions. However, this did not offset lower emissions in other sectors and as a result total GHG emissions fell by almost 2 % in 2012.

Finland witnessed a significant decrease in fossil-fuel emissions in 2012. Although the economy contracted compared to 2011 lower GHG emissions in 2012 were the result of a very strong increase in electricity imports from favourable hydro conditions in the Nordic electricity market. The other main factor contributing to lower emissions was the strong increase in renewable energy consumption, particularly of wood, in 2012. The 2012 year was however colder, leading to higher heat demand and emissions from the residential sector.

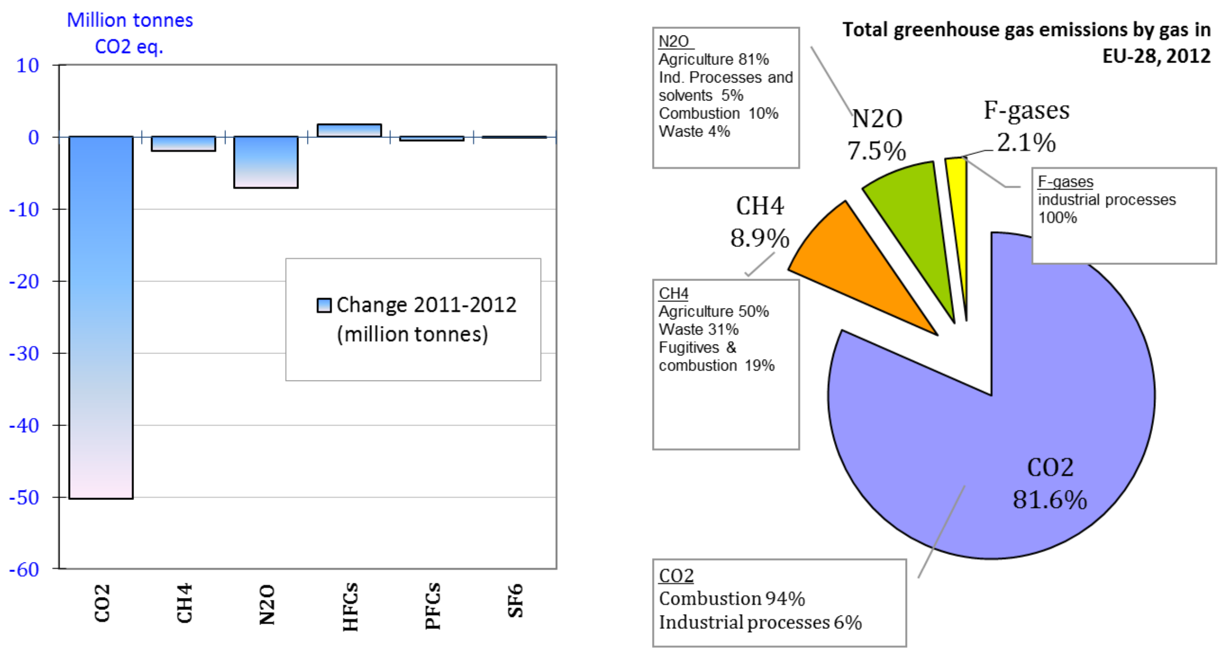
Denmark had a strong reduction in the consumption of solid fuels in 2012. Although the economy contracted compared to 2011, lower GHG emissions in 2012 were by and large due to the very strong increase of electricity imports from Norway and Sweden due to the favourable hydro conditions in these two countries. Despite a colder 2012 winter residential fuel consumption and emissions decreased compared to the previous year. Renewables continue growing strongly, particularly from wind power.

3 Overview by greenhouse gas type

Of the Kyoto greenhouse gases, CO_2 accounted for the largest decrease in emissions in the EU-28 in 2012, with 50 million tonnes less (or 1.3 % reduction) than 2011 (Figure 3). About 82 % of all EU GHG emissions in 2012 were CO_2 related. About 94 % of the CO_2 released to the atmosphere stemmed from combusting fossil fuels, while the remaining 6 % was released by industrial processes.

Emissions also declined for nitrous oxide (N_2O), which accounted for 7.5 % of total EU GHG emissions in 2012. There were also small declines in emissions of methane (CH_4), which accounted for 8.8 % of the total 2012 GHG emissions. The reduction in N_2O was mainly due to lower emissions from agriculture soils. The reduction in CH_4 emissions was due to lower waste disposal on land.

Figure 3 Greenhouse gas emissions by main gas in the EU-28



Source: EEA.

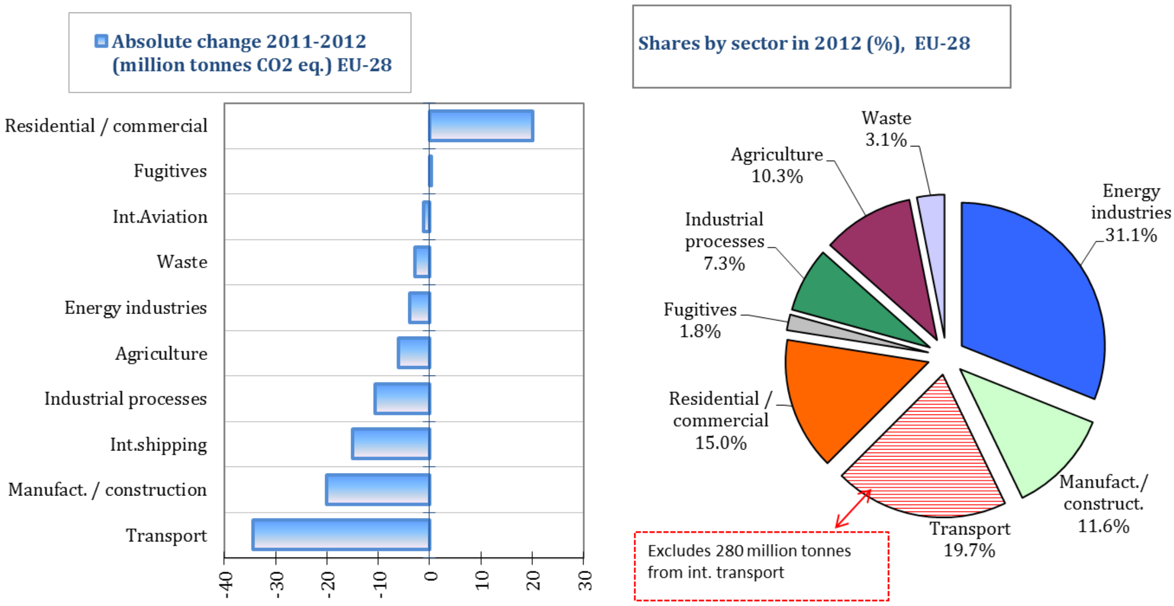
Viewed over a longer timeframe, the decrease in methane emissions in the period 1990–2012 resulted from lower fugitive emissions from coal mining and post-mining activities, and lower emissions from managed waste disposal on land. Methane from enteric fermentation in the agricultural sector also fell substantially, 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.

Hydrofluorocarbons (HFCs) from industrial processes increased again in 2012, 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).

4 Overview by main sector

GHG emissions decreased in the majority of key sectors in 2012, with the exception of residential and commercial (Figure 4)[6]. Table 1 presents the most influential key emission sources (excluding bunkers, i.e. international transport) in the EU in the periods 1990–2012 and 2011–2012.

Figure 4 Greenhouse gas emissions by main sector in the EU-28



Source: EEA.

The sector that contributed most to lower GHG emissions in the EU in 2012 was 'road transportation', which broadly falls outside the scope of the EU ETS. More than half of the EU net reduction in GHG emissions in 2012 (59 million tonnes of CO_2 eq.) was due to lower emissions from road transportation (32 million tonnes of CO_2 eq.). Figure 5 shows that road transport emissions continued to decline in 2012 for the fifth consecutive year due to both lower gasoline and diesel consumption.

(6) Emissions from electricity and heat production also increased in 2012 but are not visible from figure 4 because of a larger combined decrease in emissions from petroleum refining and the manufacture of solid fuels – which are also reported as part of 'energy industries'.

Table 1 **Overview of the EU-28 source categories recording the largest increases and decreases in the periods 1990–2012 and 2011–2012 (million tonnes CO_2 eq.)**

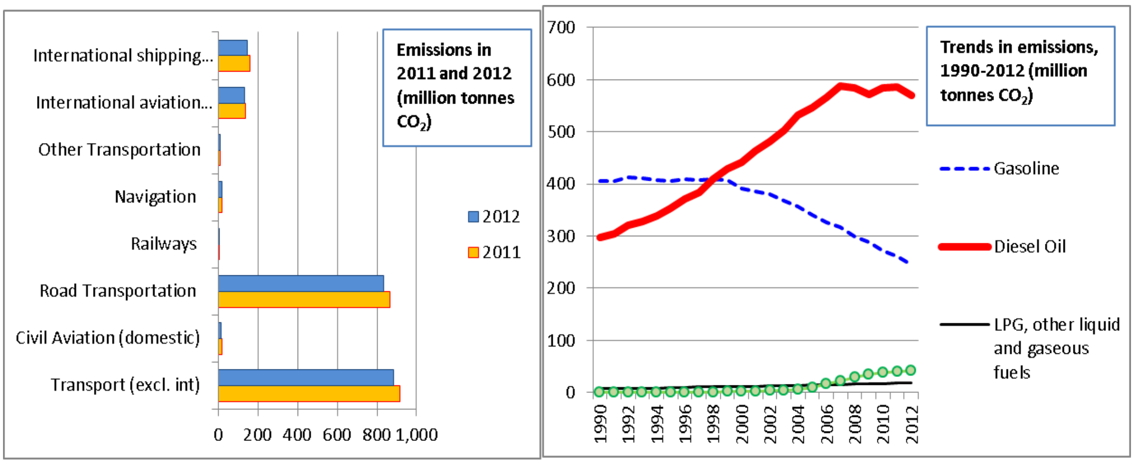
Emissions increased/decreased by > 20 million tonnes of CO2 eq. between 1990 & 2012	*Tg CO_2 eq.*	Emissions increased/decreased by > 3 million tonnes of CO2 eq. between 2011 & 2012	*Tg CO_2 eq.*
➢ Road Transportation (CO2 from 1A3b)	+123.1	➢ Households, services and other (CO2 from 1A4)	19.9
➢ Consumptions of halocarbons (HFC from 2F)	+84.9	➢ Electricity and Heat Production (CO2 from 1A1a)	9.6
➢ Production of halocarbons (HFC from 2E)	-26.9	➢ Refrigeration & air conditioning equipment (HFCs 2F1)	2.3
➢ Cement Production (CO2 from 2A1)	-28.0	➢ Solid waste disposal on land (CH4 from 6A)	-2.7
➢ Nitric Acid Production (N2O from 2B2)	-42.1	➢ Cement production (CO2 from 2A1)	-4.8
➢ Enteric fermentation (CH4 from 4A)	-48.2	➢ Agricultural soils (N2O from 4D)	-4.9
➢ Manufacture of Solid fuels (CO2 from 1A1c)	-59.2	➢ Refineries (CO2 from 1A1b)	-4.9
➢ Adipic Acid Production (N2O from 2B3)	-59.3	➢ Iron and Steel Production (CO2 from 1A2a +2C1)	-7.7
➢ Solid waste disposal on land (CH4 from 6A)	-61.3	➢ Manufacture of Solid fuels (CO2 from 1A1c)	-9.6
➢ Fugitive emissions from fuels (CH4 from 1B)	-72.5	➢ Manufacturing (excl. iron/steel) (CO2 1A2 excl. 1A2a)	-14.9
➢ Agricultural soils (N2O from 4D)	-74.1	➢ Road Transportation (CO2 from 1A3b)	-31.8
➢ Iron and Steel Production (CO2 from 1A2a +2C1)	-97.6		
➢ Households, services and other (CO2 from 1A4)	-137.2		
➢ Electricity and Heat Production (CO2 from 1A1a)	-214.0		
➢ Manufacturing (excl. iron/steel) (CO2 1A2 excl. 1A2a)	-258.5		
Total	**-1,082**	**Total**	**-59.0**

Source: EEA.

Automotive gasoline and diesel prices increased starkly in 2012 compared to 2011. Diesel and gasoline price increases have outpaced the increase in household disposable income in the last years. Along with the start of economic recession in the second half of 2008 and the whole of 2009, this appears to have triggered a fall in freight transport demand. In 2012, over 80 % of the decrease in emissions from diesel used in road transportation was due to lower transport demand for freight (light commercial vehicles and heavy duty) as compared to (diesel) passenger cars.

To a lesser extent, increased use of biofuels and energy efficiency improvements in new vehicles also contributed to the lower road transport emissions in 2012. Despite these improvements, road transport still represented about 19 % of total GHG emissions in the EU in 2012.

Figure 5 **CO_2 emissions from transport by mode and fuel in EU-28**



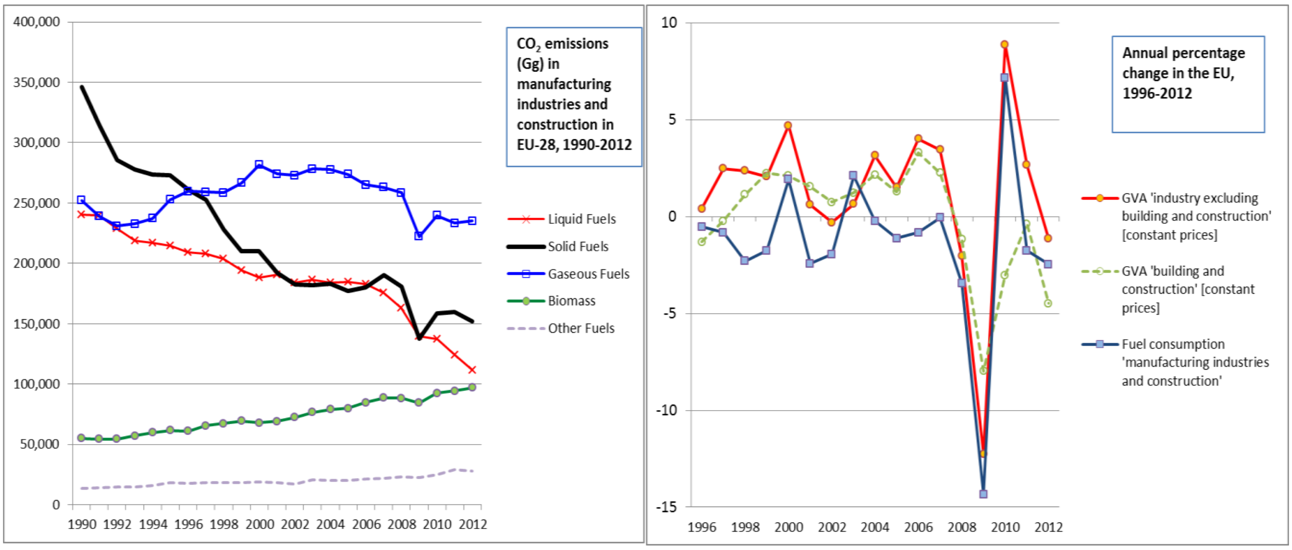
Source: EEA

The second sector that contributed most to lower GHG emissions in 2012 was 'manufacturing industries and construction'. Emissions in this sector (i.e. from combustion in iron and steel) are partly related to process emissions from iron and steel production and the manufacture of solid fuels (i.e. coke production). Taken together, they accounted for a reduction of 32 million tonnes in the EU in 2012. These sectors generally fall within the scope of the EU ETS.

Overall, the sectors covered by the EU Emissions Trading System (EU ETS) contributed more to the 2012 reduction in GHG emissions (-2.0 % decrease, or 62% of the total reduction) than the non-trading sectors (i.e. those outside the EU ETS, -0.8 % decrease, or 38% of the total reduction). Contrary to 2011, combustion installations accounted only for the smaller part of the whole reduction in ETS emissions in 2012. Lower emissions from industrial sectors such as cement clinker, iron and steel (including coke ovens) and oil refineries accounted for the major part of ETS emission reductions in 2012. The 2012 energy balances from Eurostat also confirm significantly lower energy use in most industrial sectors, particularly in non-metallic minerals, as well as much lower non-energy use in industry compared to 2011.

Figure 6 shows that emissions from manufacturing industries and construction decreased for liquid and solid fuels in 2012. Figure 6 also shows the evolution of GVA in industry alongside fuel consumption in the sector. Indeed, most of the biggest industrial installations are part of the EU ETS and the contraction in gross value added in industry during 2012 appears to have led to a significant reduction in final energy demand and emissions in the sector.

Figure 6 CO_2 emissions, fuel use, and GVA in manufacturing and construction in EU-28



Source: EEA

The top two sectors increasing emissions in 2012 were households and services and public electricity and heat production. The former broadly falls outside the scope of the EU ETS whereas the latter is by and large covered by the EU ETS. The combined effect of these two sectors in terms of emissions (almost 31 million tonnes) did offset a larger GHG emission reduction in the EU in 2012.

The main reason for the increase in emissions in public electricity and heat production was the substantial increase in the use of hard coal and lignite compared to 2011. The total fuel used in thermal power plants decreased in 2012 but the increase in solid-fuel used more than offset (in terms of emissions) the larger decrease in gaseous-fuel used[7]. In 2012, almost 60 % of the fuel used in thermal power stations came from hard coal and lignite. This sector remains the largest contributor to GHG emissions in the EU, accounting for 27 % of total GHG emissions in 2012. Over the long term, GHG emissions from heat and power in the EU have decreased since 1990. This is despite a significant increase in fuel use in the sector and has been due to the substantial increase of natural gas and a decrease in solid and 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 ([8]).

The main reason for the increase in emissions from households and services was the higher consumption of fuel for heating purposes. Fuel consumption in the residential sector increase in 2012 after the substantial decrease witnessed in 2011. A colder 2012 winter compared to 2011 can partly explain higher emissions, as lower winter temperatures, on average, led to higher heating demand and emissions from the residential and commercial sectors. 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.

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, partly reflecting the economic recession, but increased in 2011. In 2012, emissions from international transport decreased by over 6 %, mostly accounted for by maritime transport. EU 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 280 million tonnes of CO_2 equivalent in 2012 for the EU as a whole.

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(7) This is because the implied emission factor for coal and lignite in the EU-28 in 2012 was on average 101 tonnes of CO2 equivalent per terajoule in 2012, whereas the emission factor for gaseous fuels was 56 t CO2/ Tj. This means that coal releases around 80 % more CO2 than gas to deliver the same amount of energy.

(8) 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.

5 Other factors explaining the change in greenhouse gas emissions in 2012

A number of factors outside formal GHG inventory reporting can help explain the decrease in greenhouse gas emissions in the EU in 2012. This section introduces additional socio-economic explanatory variables to provide a more complete picture of why emissions from fossil fuel combustion decreased in 2012. 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 1.1 % (39 million tonnes) in the EU-28 in 2012. The final energy intensity of the economy remained somewhat stable compared to 2011, as final energy demand decreased by a degree similar to GDP. Primary energy decreased at a faster rate than final energy, resulting in a small improvement of the energy-transformation efficiency effect. This improvement was linked to the substantial increase in use of renewable energies from wind, hydro and solar. The carbon intensity of fossil fuels deteriorated again in 2012 due to increased use of hard coal and lignite combined with much lower use of gas and liquid fuels. There was a very strong increase in renewable energy use which is fully reflected in the positive contribution to the 'non-carbon fuels' effect, as nuclear electricity production also declined in 2012.

5.2.2 Methodology

Decomposition analysis is often used to portray the primary forces driving emissions[9]. 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 two thirds of the net decrease in EU greenhouse gas emissions in 2012. 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.

CO_2 emissions from energy combustion decreased by 1.1 % (39 million tonnes) in the EU-28 in 2012. A growing population and GDP generally contribute to higher CO_2 emissions. The *population* increased by 0.2 % (1.1 million people) while GDP contracted by 0.4 %, leading to a 0.6 % decrease in *GDP per capita* in 2012. As it happened in 1993 and 2009, the negative affluence effect resulted in lower GHG emissions in 2012, which would have been higher otherwise.

(9) For simplicity, the annual decomposition analysis shown in this paper is based on the Laspeyres multiplicative method. Similar results were obtained with the Logarithmic Mean Divisia Index (LMDI) method. The differences between both methods would be more significant in a cumulative decomposition analysis due to a larger residual, in which case the LMDI method would be preferred.

The *energy intensity* of the economy in 2012 remained somewhat stable compared to 2011. This was mainly because final energy demand decreased by a degree very similar to GDP.

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-transformation efficiency effect)

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

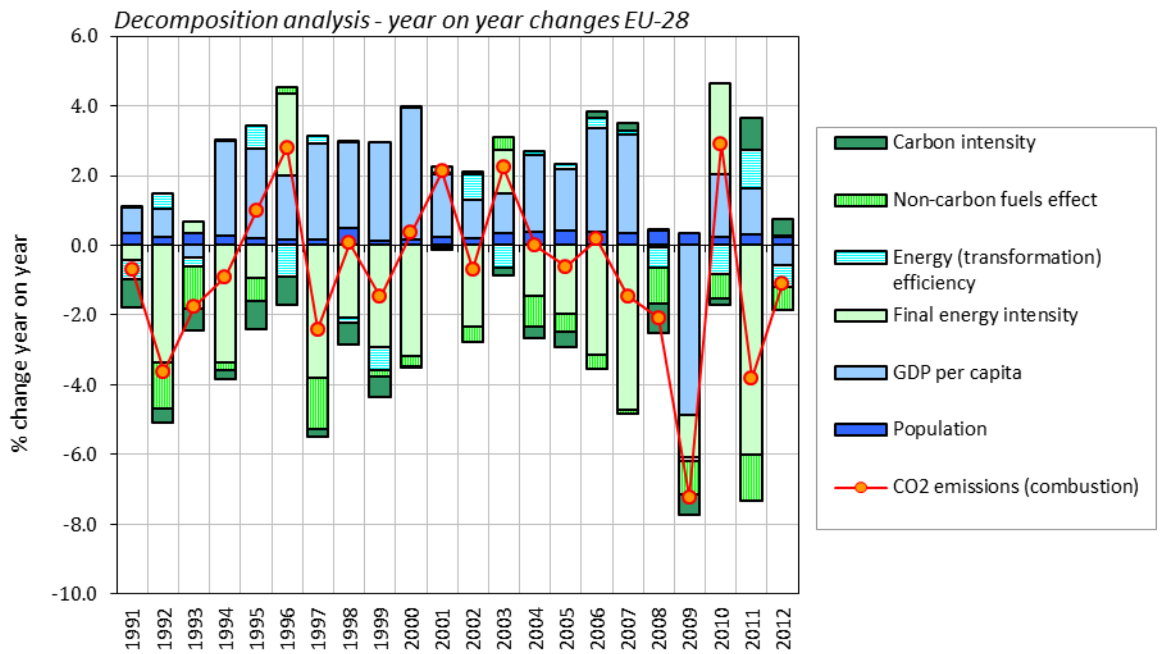
(x_6) CO_2/FFC: carbon dioxide emissions in fossil fuel consumption (carbon intensity effect)

Eurostat's 2012 energy balances point to a significant decrease in primary energy consumption (-1 %). This rate was higher than the decrease in final energy available to the end-use sectors ([10]), showing an improvement of the '*energy-transformation efficiency'* effect (as defined in Box 1) in 2012. One reason for this improvement was the significant increase in renewables, some of which can produce electricity by means of mechanical energy without any combustion. The increase in hydroelectricity, wind and solar energy meant a reduction in the ratio of primary to final energy. This is because no energy-transformation loss is reported when converting final energy to primary energy, contrary to the combustion of fossil fuels (or biomass). This improvement of the efficiency effect does not take into account a larger reduction in non-energy use by industry in 2012. Thus, the total energy available for final consumption (which includes non-energy use) decreased by more than primary energy. In addition, there was a worsening of the actual transformation efficiency in conventional thermal power stations (including district heating) in the EU in 2012. Therefore, although the decomposition analysis shows an improvement of the energy-transformation efficiency effect, one cannot conclude there was an increase in energy efficiency in 2012. Viewed over a longer

(10) 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.

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-28, 1990–2012

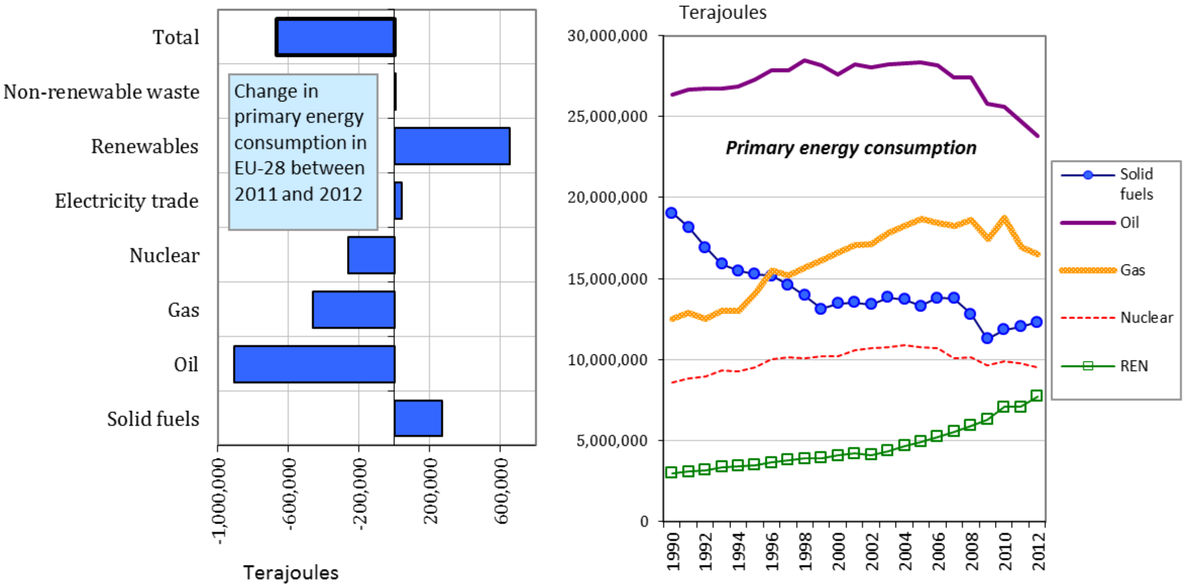


Note: The chart shows the estimated contributions of the various factors that have affected CO_2 emissions from energy production and consumption in the EU-28. This approach is often used to portray the primary forces driving emissions. The explanatory factors should not be seen as fundamental factors 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 2012 despite the overall decrease in primary consumption of fossil fuels, particularly of oil and gas. Actual (not-adjusted) renewable energy use increased very significantly in 2012 (+3.6 %) after the sharp decline witnessed in 2011. Thus, the contribution of renewables to the EU’s overall energy mix improved significantly in 2012. According to Eurostat, the share of renewable energy in gross final energy consumption (normalised to even out the annual variability in hydro & wind production) reached 14.1 % in 2012, up from 12.9 % the year before. Approximately 50 % of the net increase in renewable energy in 2012 came from biomass (solid, biogas, biodiesel and renewable waste) and the other 50 % from wind, solar and hydro power.

Figure 8 Primary energy consumption by main fuels in the EU-28, 1990–2012



Source: Eurostat energy balances.

The positive contribution of the '*non-carbon fuels*' effect (defined in Box 1 and shown in Figure 7) is fully accounted for by renewables as nuclear electricity production declined again in 2012, mainly in France, Germany and Belgium. Over the long term, the sustained growth in renewables since 1990 which was particularly strong after 2000 has clearly contributed to lower emissions in the EU.

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 2012.

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.

5.2 Regression analysis[11]

5.2.1 Key findings

The regression analysis outlined below indicates that lower final energy consumption and higher carbon intensity were the main (statistical) factors underpinning the change in greenhouse gas emissions in the EU in 2012.

Lower final energy consumption in 2012 was by and large the result of lower consumption of fossil fuels, particularly of liquid fuels in the transport sector and of gas in the power sector. Energy

(11) This section is based on the final GHG inventory submissions (15/03/2014) by Member States under the EU Monitoring Mechanism Regulation, and not on the final GHG inventory submissions to UNFCCC of 27 May.

consumption by industry, and industrial process emissions also decreased in 2012. As in 2011, the statistical analysis also shows that the increase in carbon intensity triggered by higher use of hard coal and lignite was an offsetting factor to an otherwise larger decrease in GHG emissions in 2012.

An extended regression model including 'heating degree days' (an indicator of demand for heating by households) confirmed that higher heat consumption by households due to a colder 2012 winter led to higher emissions from the residential sector and partly offset an otherwise higher decrease in GHG emissions in the EU in 2012 compared to 2011.

5.2.2 Methodology

Basic model

This section presents a cross-sectional statistical analysis of greenhouse gas emission drivers in 2012. 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 28 EU countries, and their significance is determined using standard and robust regression methods.

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 28 EU Member States.

The **equation** is:

$(y)\ GHG = (x_1)GDP/POP + (x_2)FEC + (x_3)EFF + (x_4)REN + (x_5)CAR + \mu$, 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 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.

The full regression model is highly significant (F-value), although some of the predictors have non-significant p-values (GDP/POP, REN, EFF). The residuals are normally distributed. The Weighted Least Squares (WLS) coefficients in the full regression model could 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/POP (0.29). This predictor is discarded from the full model because of its statistical insignificance (p-value of 0.333). Renewable energy consumption REN) also has a very low correlation coefficient (-0.19) and remains statistically insignificant in the first-reduced regression model (p-value of 0.376). The correlation coefficient for energy efficiency (EFF) in the second-reduced regression model is higher (-0.35) but still statistically insignificant (0.111). After checking the normality assumptions at each stage the last two predictors (FEC and CAR) are significant at 95 % level and are retained in the final regression model. There is a clear positive relationship between GHG and both FEC and CAR.

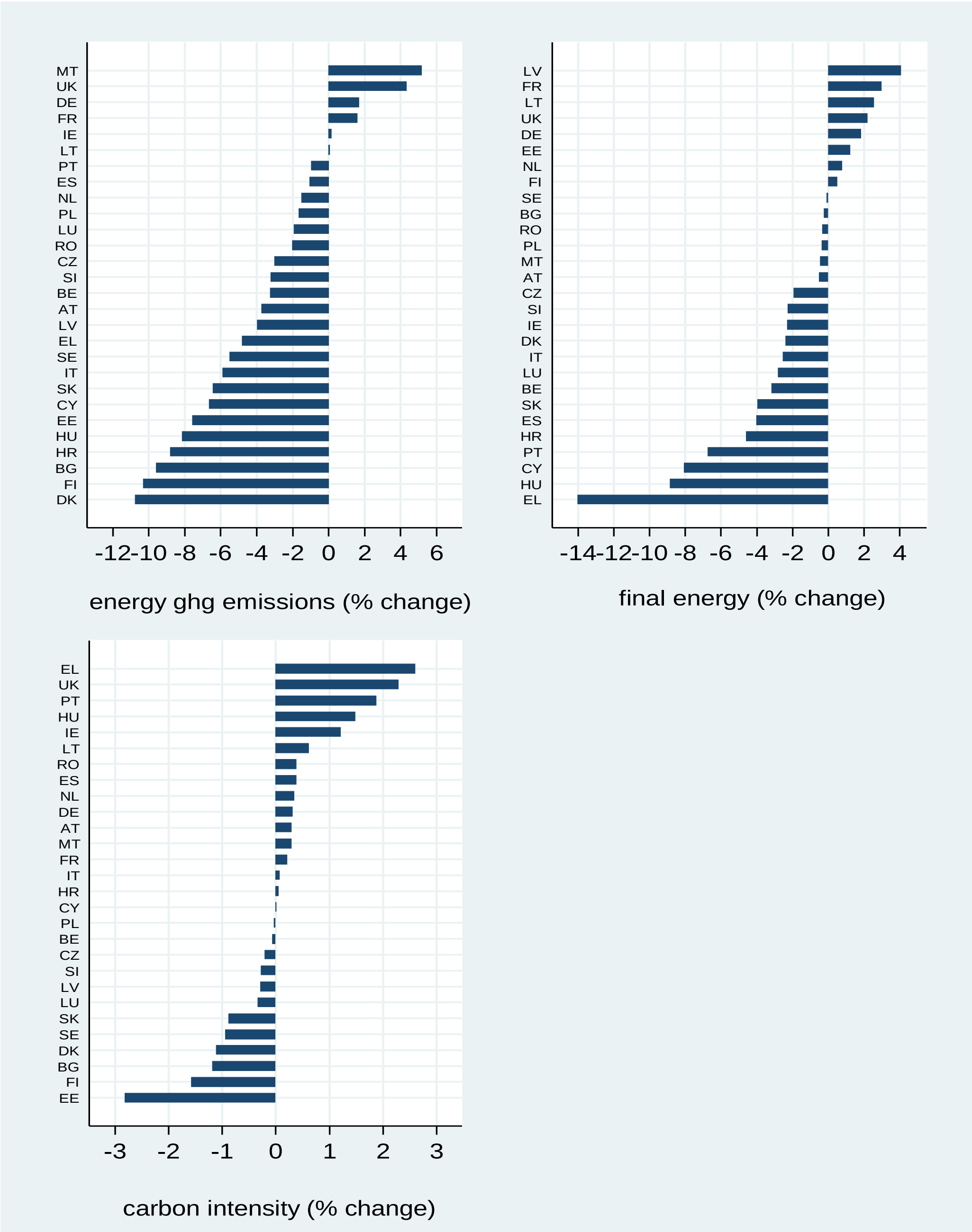
Final model

The coefficients from the reduced regression suggest that GHG is a function of FEC 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 and the change in the CO_2 implied emission factor for fossil fuels in 2012. The WLS regression coefficients of GDP per capita, of renewable energy consumption and of energy efficiency are not significant at the 5 % level and are dropped from the regression model. The residuals from the final model are normally distributed.

The final model consists of two independent variables (FEC and CAR). Based on this final model, the net decrease in greenhouse gas emissions in 2012 can be explained not only by the decrease in final energy consumption but also by a worsening of the carbon intensity in fossil fuel production. The latter factor has offset an otherwise larger decrease in GHG emissions.

The above conclusion takes into account all 28 EU Member States, and reflects positive and negative contributions for each explanatory (statistically significant) variable between 2011 and 2012 (see Figure 9).

Figure 9 **Growth in modelled dependent and explanatory variables in EU Member States, 2012/2011**



Source: EEA

Final energy consumption fell in many EU countries in 2012. Contrary to what happened in 2011, emissions in 2012 did not decrease in all Member States where final energy consumption decreased. Energy use and energy-related emissions increased in the UK, Germany and France.

Regarding *carbon intensity* of fossil fuels, 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. However, the CO_2 emissions per unit of fossil energy generated increased again in 2012 due to increased coal use. CO_2 emissions fell because the increase in coal use did not offset the much larger decrease in the use of natural gas and of liquid fuels. The average implied emission factor for CO_2 increased in 16 of 28 Member States in 2012. 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 1.3 % in EU-28 in 2012, and not larger.

Standard and robust regression analysis

The two predictors (FEC and CAR) played a role in the net decrease in GHG emissions in the EU in 2012. There is some evidence, however, that the variance of the residual errors is not constant. This may be due to potential outliers or extreme observations in some countries, and could in turn lead to biased standard errors and inference ([12]).

A closer look at the influence of specific observations shows that Malta in particular could be considered a 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, Greece, the UK and Estonia have extreme values on at least one of the predictor variables ('high leverage effect').

In terms of the overall effect on the regression coefficients of the model ('high influence effect'), Hungary, Estonia and Malta had the largest overall effect in 2012. In addition, Estonia and Finland had a specific influence from carbon intensity, whereas in Hungary and Latvia there was a specific influence from final energy consumption.

None of the observations are removed from the model (model 1 of table 2) as they just represent the country-specific changes in the dependent variable (GHG) to changes in the two explanatory variables (FEC and CAR).

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 ([13]).The robust specification of the errors in the model increases the standard deviations (and the confidence intervals) of the coefficients for final energy consumption and carbon intensity (model 2 of table 2).

To test whether heterocedasticity substantially affects the WLS estimates, we run a robust regression[14] and compare the regression coefficients (model 3 of table 2). The coefficients of model 3 are different to models 1 and 2, but the explanatory power of the robust regression is lower with an adjusted R-squared of 0.52, compared to 0.77 when using WLS. There is no significant *gain* from using robust regression compared to WLS regression. Thus, robust regression does not substantially

(12) 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. The Shapiro-Wilk W test, Jarque-Bera and the skewness/kurtosis tests fail to reject the null hypothesis of normal residuals.

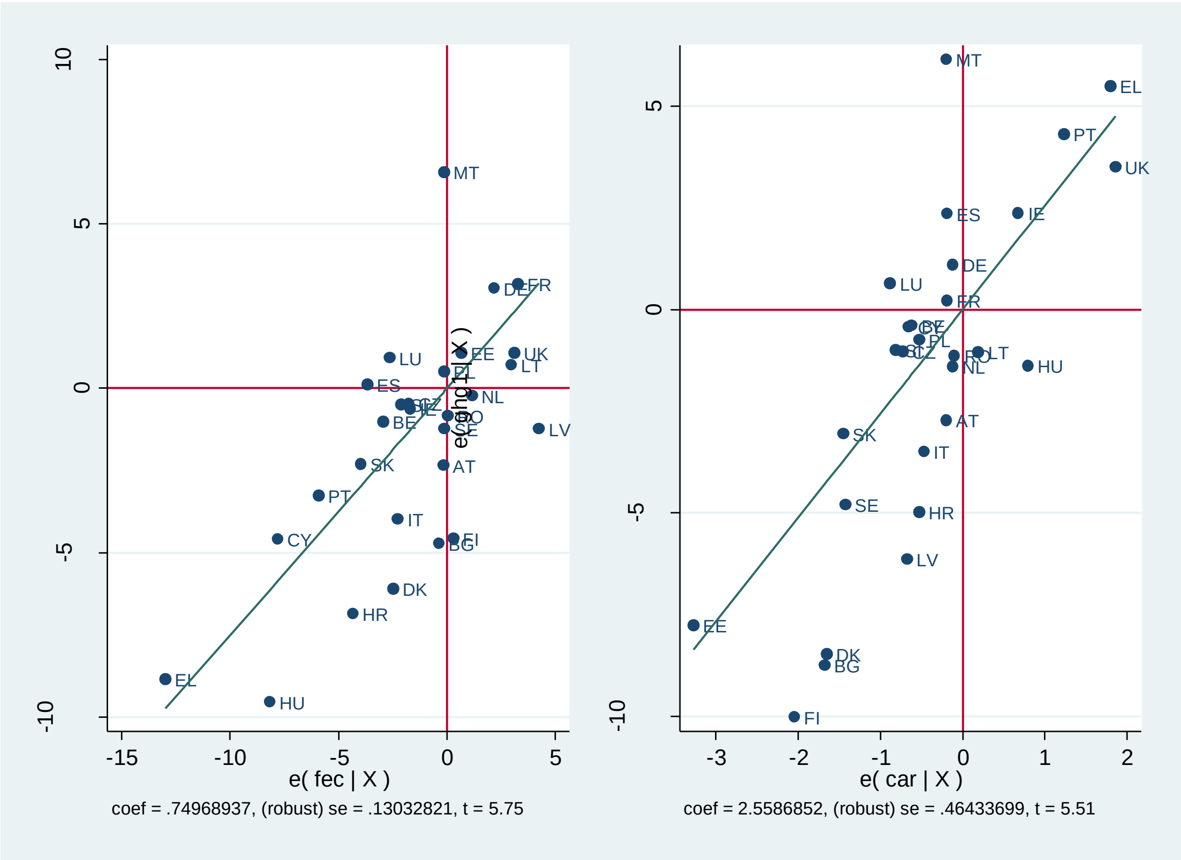
(13) The standard errors are estimated using Huber-White sandwich estimators and can deal with some minor problems of failure to meet the Gauss-Markov assumptions, in our case the lack of homoscedastic errors triggered by some extreme observations.

(14) 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.

improve the model. Figure 10[15] shows the partial regression plots for each explanatory variable for model 2.

To summarise, lower final energy consumption in 2012 is by and large the result of lower consumption of fossil fuels, particularly of liquid fuels in the transport sector, gas in the power sector and overall fuel consumption by industrial sectors. The statistical analysis also shows that carbon intensity is significant and has offset an otherwise higher decrease in GHG emissions in 2012. Although less clear than in 2011, there are also indications that weather-related factors could be a key factor underpinning the change in emissions in the residential sector. Therefore, it would seem appropriate to include an additional variable to model the weather effect directly. The starting point is therefore model 2.

Figure 10 Added-variable plots



Source: EEA

The weather effect

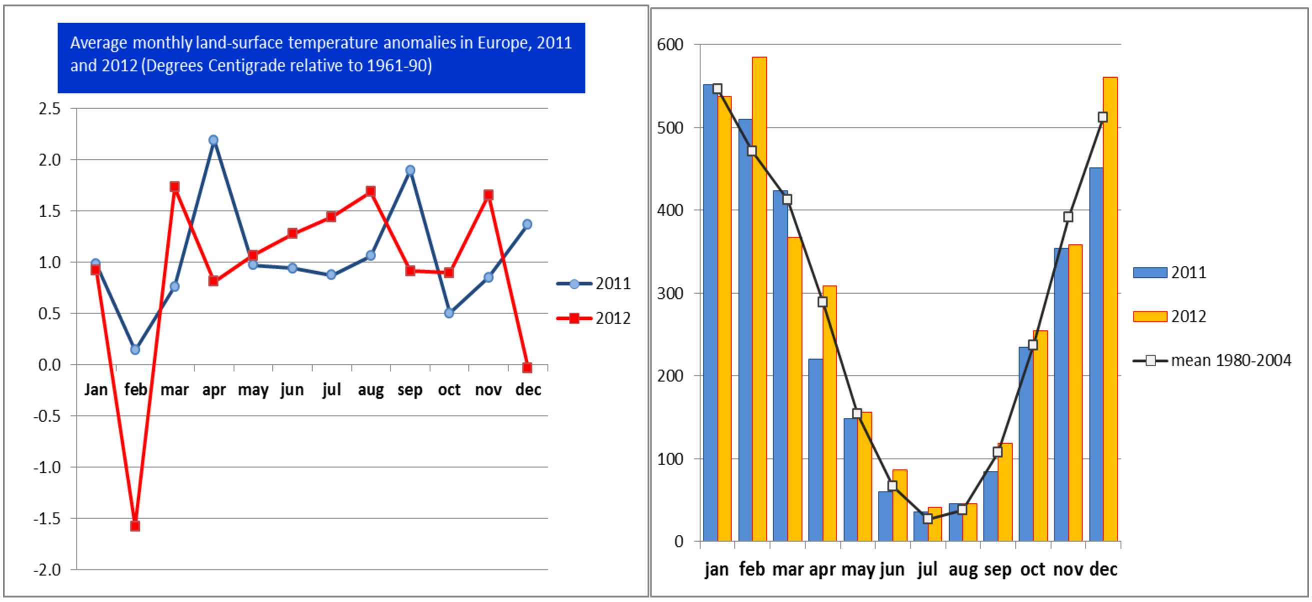
There is evidence of higher heat consumption and heat demand in the residential sector due to somewhat colder weather conditions in Europe during 2012 compared to 2011. This is also

(15) Simple scatter plots of the response variable against the individual explanatory variables do not take into account the effect of the other explanatory variables in the final regression model.

illustrated in figure 11. Based on data for Europe from the UK's Met Office Hadley Centre, the average monthly land-surface temperatures were substantially lower in December and February. 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 colder conditions in Europe in 2012 compared to 2011.

Furthermore, according to Eurostat, there was a 10 % increase in the number of heating degree days (an indicator of household demand for heating) in the EU in 2012 compared to 2011. Thus, mean temperatures for Europe as well as heating degree days strongly suggest that colder winter conditions in 2012 are responsible for the increase in fuel use and emissions in the residential sector in 2012.

Figure 11 Monthly mean land-surface temperatures and heating degree days in 2011 and 2012



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 colder conditions in Europe in 2012 compared to 2011.

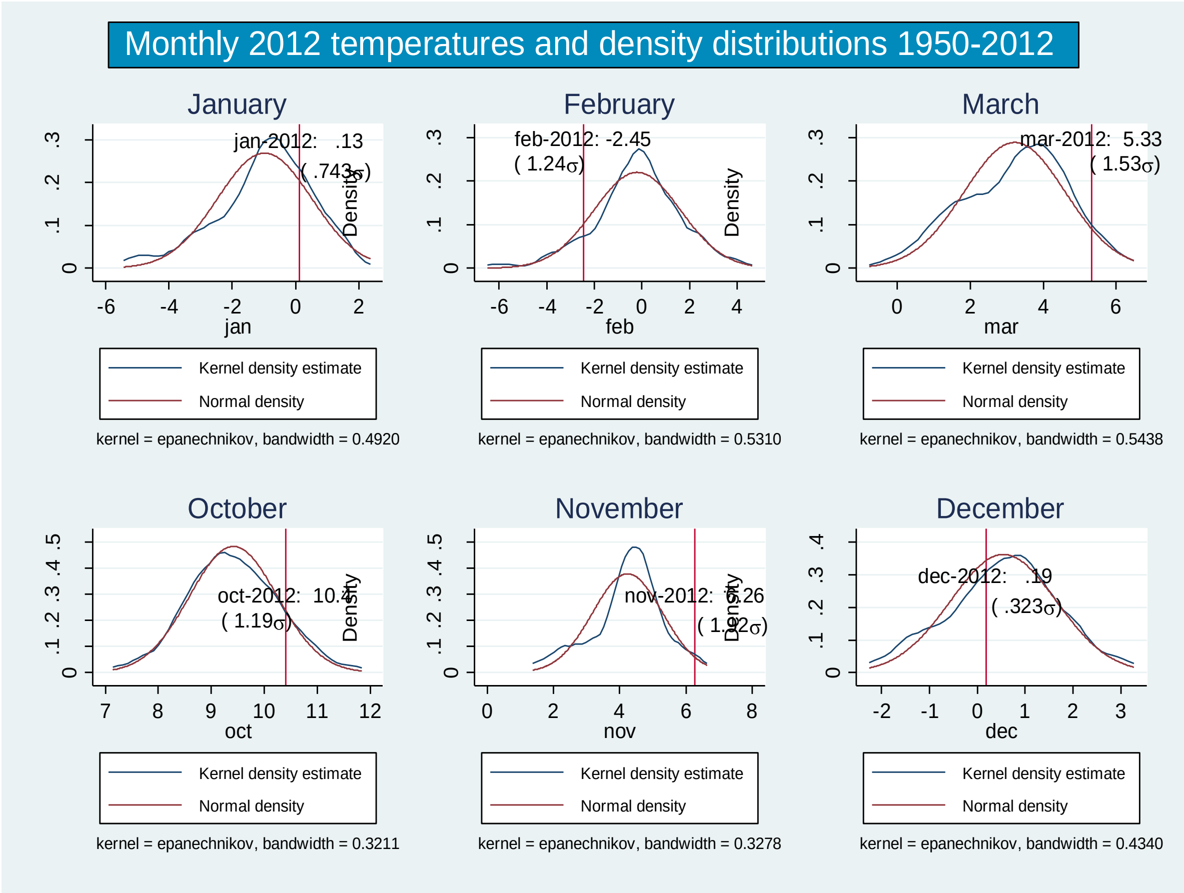
Source: EEA. Data source for 'heating degree days' is Eurostat.

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 12 below is based on daily maps of gridded data (E-OBS)[16] . It shows the distribution of monthly temperatures between 1950 and 2012 (Kernel densities), together with the normal densities (i.e. normal distributions), and the specific average temperatures for each month of 2012 (vertical line). Figure 11 had shown that the mean European temperatures were on average

(16) 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

lower in 2012 compared to 2011, particularly in February and December. Figure 12 confirms that temperatures in these months were significantly below the mean of the normal distribution of temperatures of the past 60 years.

Figure 12 Monthly 2012 temperatures and density probability distributions in Europe



Source: EEA. Data source for the underpinning daily gridded temperatures, http://www.ecad.eu/ (see also footnote 16).

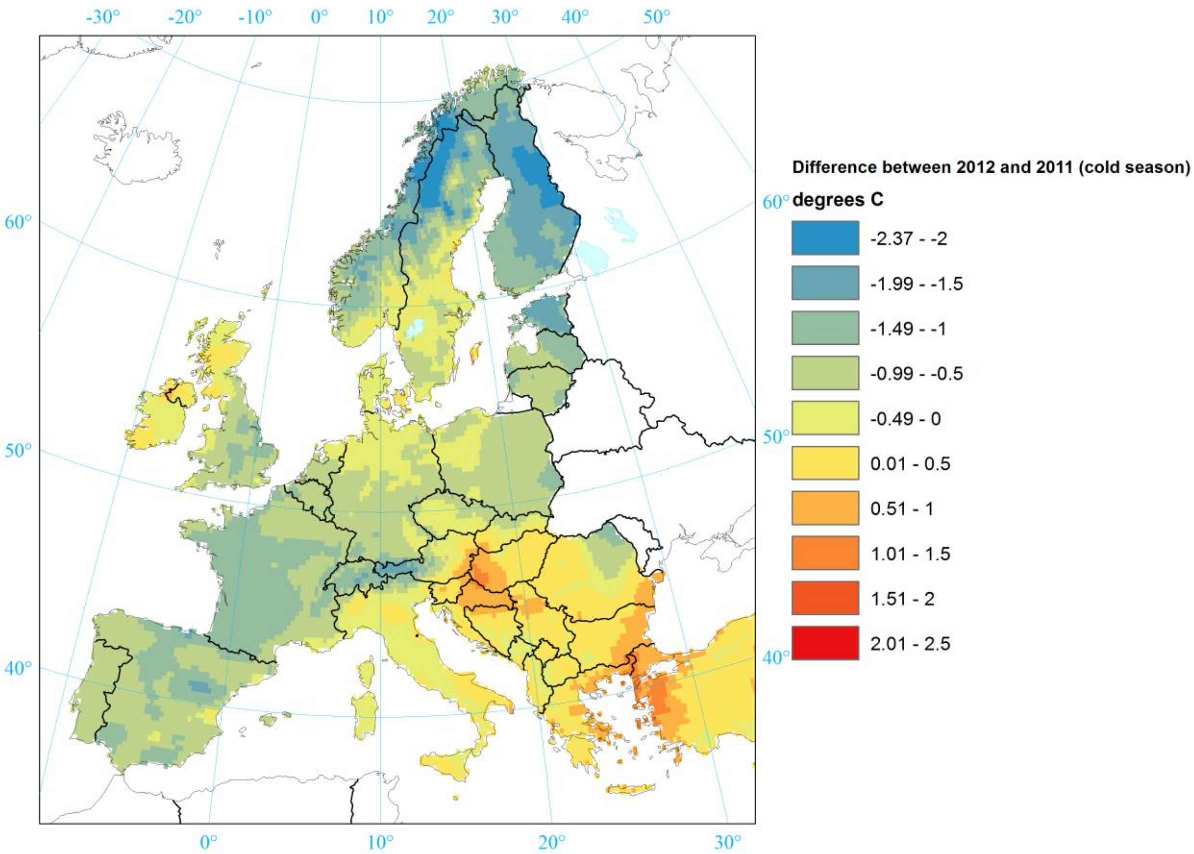
Figure 13 below illustrates the difference between average temperatures in 2012 and in 2011 in Europe. The map shows that, notwithstanding regional variability, mean temperatures in most parts of the continent were lower in 2012 compared to 2011. However, temperatures were above 2011 levels in many part of South Eastern Europe.

Including Heating Degree Days in the final model

Heating Degree Days (HDDs), compiled by Eurostat, are a measure of household demand for heating. HDDs increased significantly in the majority of MS in the EU in 2012 and decreased in Greece, Bulgaria, Romania, Hungary and Cyprus. Including HDDs as an additional explanatory variable improves the model (model 4 of table 2). Although model 4 is less parsimonious, all explanatory variables are significant at the 0.05 level. In addition, the adjusted R-squared increased from 0.77 in model 2 to 0.82 in model 4 ([17]).

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 0.7 % (holding CAR and HDD constant). If the CO_2 implied emission factor for fossil fuels increases by 1 %, greenhouse gas emissions are expected to increase by about 2.5 % (holding FEC and HDD constant). Finally, if HDDs increase by 1 %, energy-related GHG emissions would be expected to increase by 0.1 % (holding CAR and FEC constant).

Figure 13 Mean temperature change between 2011 and 2012 in Europe: average temperature of January, February, March, October, November and December



Source: EEA. Data source for the underpinning daily gridded temperatures, http://www.ecad.eu/ (see also footnote 16).

To conclude, the analysis indicates that lower final energy consumption and higher carbon intensity were the main statistical factors underpinning the net decrease in greenhouse gas emissions in the EU in 2012. The latter factor prevented GHG emissions from decreasing more in 2012 (i.e. offsetting factor). An extended regression model with heating degree days provided additional evidence to

(17) A robust regression removes the possible bias from the heterocedastic residuals. The residuals vs. fitted values plot suggests 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.

support the conclusion that higher heat consumption was a key factor for higher GHG emissions in the residential sector in the EU in 2012. A colder 2012 winter compared to 2011 can partly explain higher emissions, as lower winter temperatures, on average, led to higher heating demand and emissions from the residential and commercial sectors.

Table 2 Final model results

	(1)	(2)	(3)	(4)
	Weighted least squares	WLS with robust standard errors	Robust Regression	Weighted least squares (incl. HDD) with robust standard errors
Variables	ghg1	ghg1	ghg1	ghg1
Final energy consumption (FEC)	0.750***	0.750***	0.641***	0.656***
	(0.108)	(0.130)	(0.156)	(0.141)
Beta coefficient	0.664	0.664		0.581
Carbon intensity (CAR)	2.559***	2.559***	2.770***	2.507***
	(0.384)	(0.464)	(0.543)	(0.455)
Beta coefficient	0.635	0.635		0.622
Heating degree days (HDD)				0.131*
				(0.052)
Beta coefficient				0.224
Constant	-1.890***	-1.890**	-2.636***	-3.191**
	(0.407)	(0.587)	(0.618)	(0.947)
Observations	28	28	28	28
R-squared	0.77	0.77	0.55	0.82
Adj. R-squared	0.76	0.76	0.52	0.79
Mean square error	311.35	311.35	262.01	328.71
Residual square error	90.71	90.71	212.88	73.35
Root MSE	1.90	1.90	2.92	1.75

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

6 Early indications of 2013 figures

The most recent official data available for total EU GHG emissions is the GHG inventory 1990-2012. Verified 2013 emissions from the EU ETS decreased by 3 % compared to 2012. The EU ETS covers more than 12 000 power plants and industrial installations in the 28 EU member states plus Iceland, Norway and Liechtenstein. As from 2013, the scope of the ETS is being extended to include other sectors and greenhouse gases. Emissions from the EU ETS represent approximately 45 % of total GHG emissions in the EU.

In addition, early Eurostat estimates of CO_2 from fossil fuel combustion also point to a 2.5 % decrease in emissions between 2012 and 2013. 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.

By 30 of September, the EEA will publish its annual Approximated GHG inventory for 2013 (i.e. Proxy GHG inventory). The EEA's Approximated GHG inventory covers all major sectors reported under the UNFCCC and is consistent with a full emissions inventory, therefore covering 100 % of total GHG emissions. The Proxy estimates provided by Member States under the EU Monitoring Mechanism Regulation or, if not provided, the Proxy estimates produced by the EEA, will be used for tracking progress towards national and EU greenhouse gas emission targets.

The final 2013 GHG emissions for the EU and its Member States will be submitted to the UNFCCC in the spring of 2015 according to the new UNFCCC Reporting Guidelines and the 2006 IPCC Guidelines.

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-28. 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 1990–2012 and inventory report 2014

Greenhouse gas data viewer

EU Emissions Trading System (ETS) data viewer

Union Registry and European Union Transaction Log

United Nations Framework Convention on Climate Change (UNFCCC)

Eurostat

Joint Research Centre

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