European Environment Agency

Why did greenhouse gas emissions increase in the EU in 2010?

EEA analysis in brief

This paper briefly analyses the major factors that accounted for increased greenhouse gas emissions in the EU-27 between 2009 and 2010. 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 2011 emissions under the EU Emissions Trading System.

Contents

1 Summary of EU emissions

Total greenhouse gas emissions (excluding LULUCF) in the EU increased in 2010 after five consecutive years of emission reductions, starting in 2004. The annual percentage increase in emissions in 2010 was also the largest of the past 20 years of emissions reported to the UNFCCC.

In line with EEA predictions last year ([1]), GHG emissions between 2009 and 2010 increased by 2.4 % in the EU-27 and by 2.1 % in the EU-15. Figure 1 shows total greenhouse gas emissions in the period 1990–2010, both in the EU-15, as a party to the Kyoto Protocol, and in the EU-27.

In 2010, EU-15 emissions were 11.0 % below the base year under the Kyoto Protocol ([2]). That constituted a net reduction of 468 million tonnes of CO_2-equivalents, despite the 78.5 million increase compared to 2009.

Total greenhouse gas emissions in the EU-27 were 15.4 % below 1990 in 2010 — a net reduction of 862 million tonnes of CO_2-eq., despite the 111 million increase compared to 2009. If CO_2 emissions from international aviation are included, the overall reduction would be 14.1 % ([3]).

About 56 % of the EU increase in GHG emissions was accounted for by Germany, Poland and the United Kingdom. In percentage terms, growth in emissions was highest in Estonia, Finland, Sweden and Latvia. Contrastingly, Spain, Greece and Portugal continued reducing GHG emissions in 2010.

The increase in emissions in 2010 was partly driven by the economic recovery from the 2009 recession in many European countries, which had itself caused substantial emission reductions in 2008 and 2009 in all Member States. Final energy demand increased by 3.7 % in 2010, outpacing the increase in economic output (2.0 %).

In 2010 the winter was also colder than in the previous year, leading to increased demand for heating and higher emissions from the residential and commercial sectors. The continued strong increase in renewable energy use and the improved carbon intensity of fossil fuels — underpinned by strong gas consumption — prevented the increase in GHG emissions from being higher.

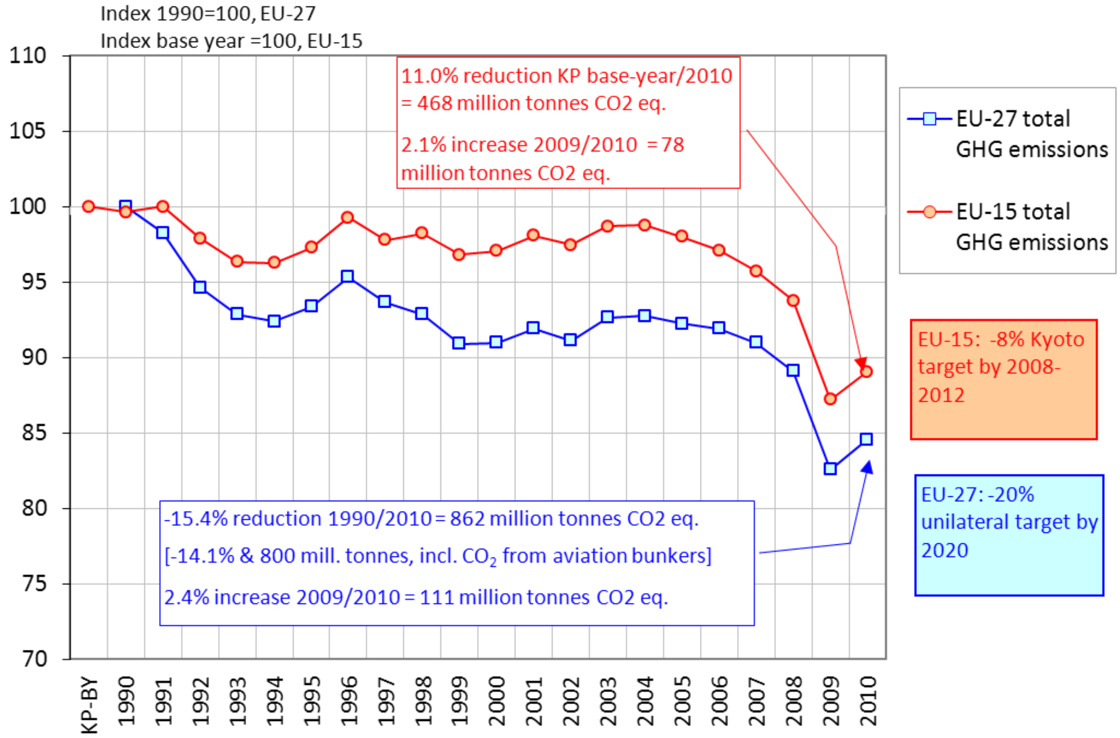
([1]) *Approximated EU GHG inventory: early estimates for 2010*, EEA Technical report No 11/2011 (http://www.eea.europa.eu/publications/approximated-eu-ghg-inventory-2010).

([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 EU15 have been fixed at 4 265.5 Mt CO2-equivalents.

([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 15.4 % overall reduction between 1990 and 2010 would be equivalent to a 14.1 % reduction. If international shipping is included, the net emissions reduction between 1990 and 2010 would be 13.2 %.

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



Source: EEA.

Overall the sectors covered by the EU Emissions Trading System (EU ETS) increased their emissions more in 2010 than the non-trading sectors (i.e. those outside the EU ETS). The 2010 verified emissions from EU-27 installations in EU EU-ETS sectors increased by 2.5 %, with emissions from industrial sectors rising by 5.2 %. The increase in EU ETS emissions in 2010 was nevertheless lower than the real growth in industrial gross value added that year.

Among the EU ETS sectors, the largest combined increase stemmed from manufacturing industries and construction (including iron and steel process emissions) and from public heat and electricity production. Higher industrial activity during 2010, after the strong contraction in 2009, appears to have led to a sharper increase in final energy demand and emissions in these sectors.

The sector that contributed most to higher emissions in the EU in 2010 was, however, 'residential and commercial', which broadly falls outside the scope of the EU ETS. The key reason for the 43 million tonnes increase in emissions there was the cold winter in 2010, which increased demand for heating, particularly by households.

In general, GHG emissions increased in the majority of key sectors in 2010, particularly sectors relying on fossil fuel combustion. CO_2 emissions from combusting fossil fuels increased by 2.8 % in the EU-27 in 2010 compared to 2009. This was driven by strong growth in emissions from natural gas (7.4 %), underpinned by significantly lower gas prices ([4]), and higher emissions from solid fuels

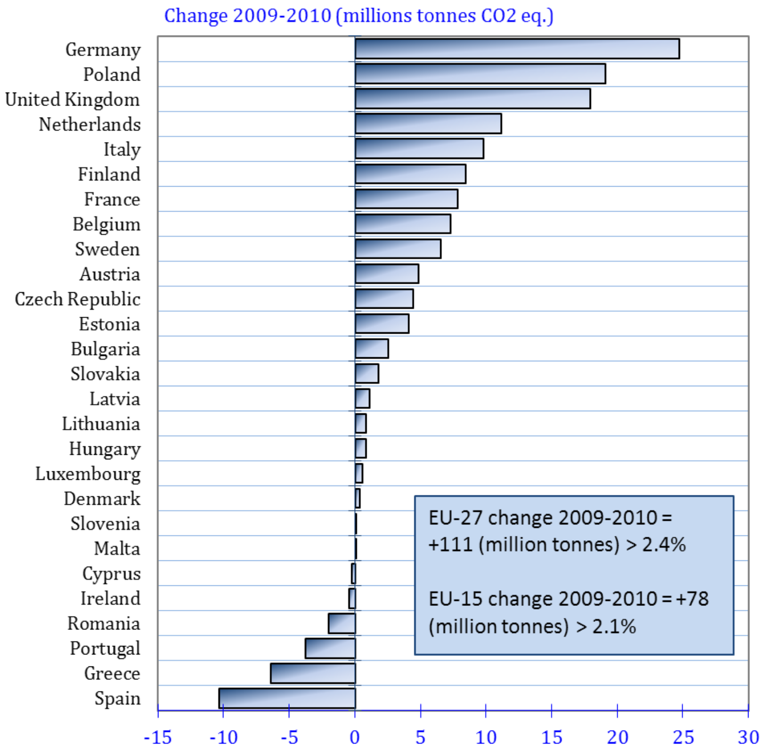
([4]) Despite the economic recovery in most EU Member States in 2010 (compared to 2009) the price of carbon remained relatively stable. This year, energy prices increased particularly for coal and oil products. Gas prices fell markedly in 2010 in the EU as a whole, which partly explains the stronger increase of gas consumption compared to other fossil fuels.

(4.1 %), partly offset by lower emissions from the combustion of liquid fuels (–1.3 %). The use of nuclear power also increased in 2010 (2.5 %). As in previous years, strong growth in the use of renewables (12.7 %) continued in 2010, offsetting the increase in GHG emissions in the EU in 2010.

2 Overview by Member State

At the Member State level, most EU countries increased greenhouse gas emissions in 2010. The bars in Figure 2 depict the absolute emission increase or reduction by Member States between 2009 and 2010. Germany, Poland and the United Kingdom accounted for about 56 % of the total EU-27 net increase. In percentage terms, growth in emissions was highest in Estonia, Finland, Sweden and Latvia. Contrastingly, Spain, Greece and Portugal continued reducing GHG emissions in 2010.

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 about 2 % compared to 2009. As will be explained later, 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.

This led to an improvement of the carbon intensity of fossil fuel consumption in many Member States, which partly offset the increase in GHG emissions in 2010.

3 Overview by greenhouse gas type

Of the Kyoto greenhouse gases, CO_2 accounted for the largest increase in emissions in 2010 (Figure 3). This was mainly due to the improved economic situation and higher industrial activity in most Member States, increased use of fossil fuels (particularly gas and coal), and a colder winter. As in previous years, renewable energy consumption continued to grow strongly in 2010, offsetting an otherwise steeper increase in EU emissions.

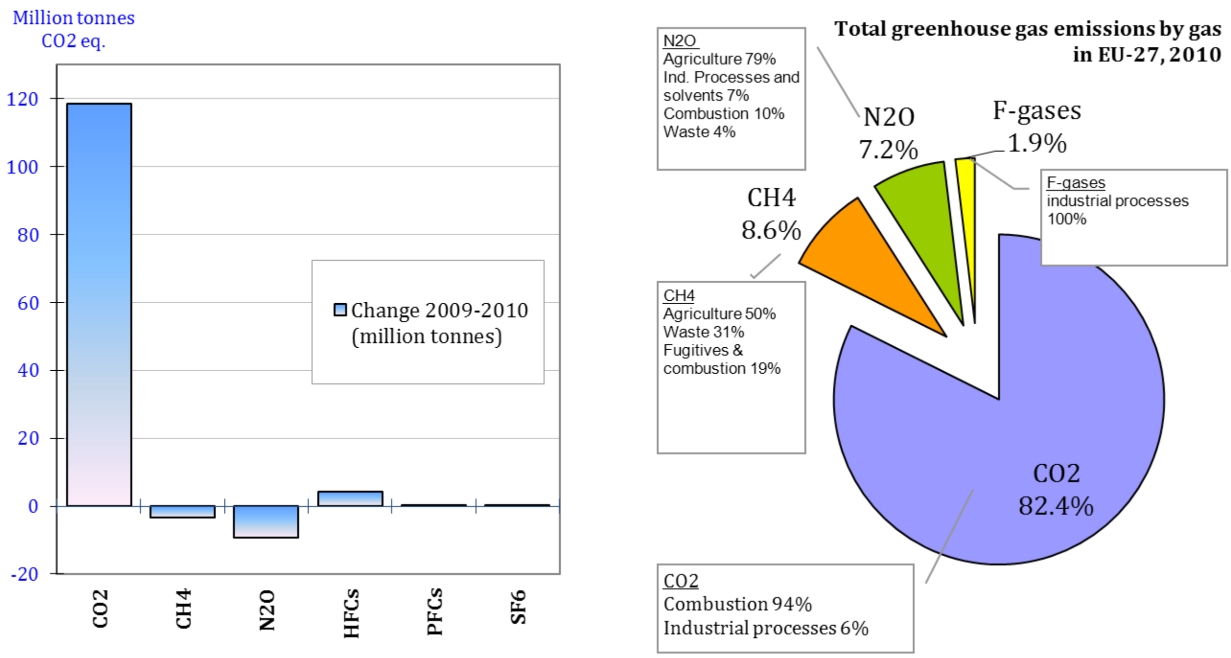
In 2010, 82 % of all EU greenhouse gas emissions were CO_2 related. About 94 % of the CO_2 released to the atmosphere stemmed from combusting fossil fuels and the remaining 6 % from industrial processes.

Hydrofluorocarbons (HFCs) from industrial processes were the other group of greenhouse gases that increased significantly in 2010, 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 for nitrous oxide (N_2O), which accounted for 7.2 % of total EU greenhouse gas emissions in 2010, and for methane (CH_4), which accounted for 8.6 % of the total. 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 less waste disposal on land.

Viewed over a longer timeframe, the decrease in methane emissions in the period 1990–2010 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.

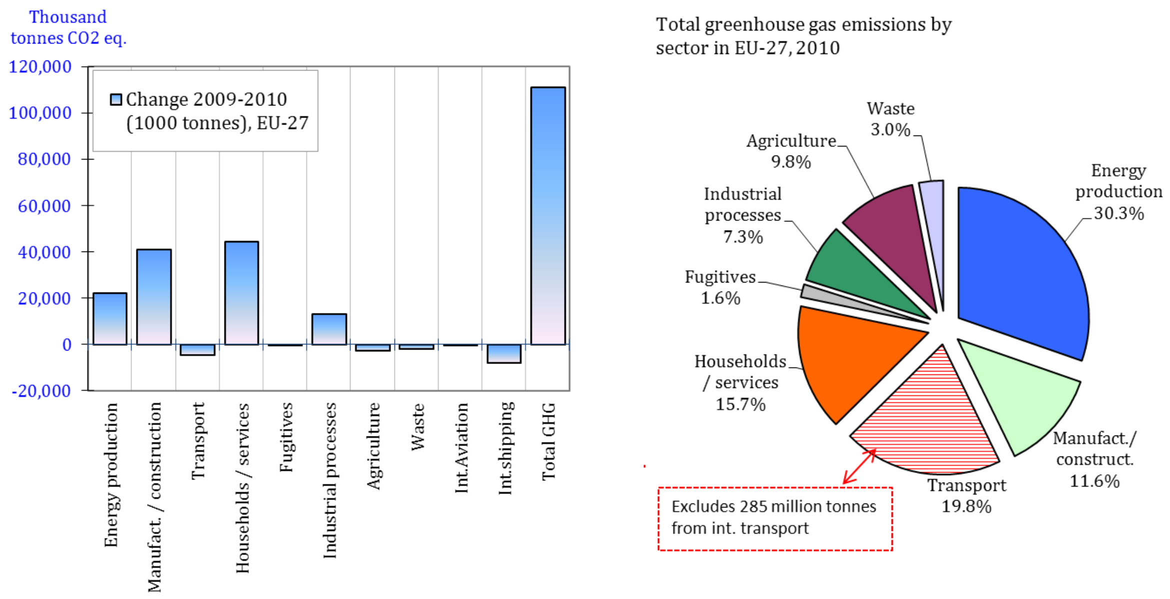
4 Overview by main sector

GHG emissions increased in the majority of key sectors in 2010, particularly sectors relying on fossil fuel combustion (Figure 4).

Emissions from EU ETS sectors increased more than non-trading sectors in 2010. Most of the biggest industrial installations operate within the EU ETS and higher industrial activity during 2010, after the huge contraction in 2009, appears to have led to a sharper increase in final energy demand and emissions in that sector. However, whereas total EU GHG emissions increased by more than total GDP, ETS emissions increased by less than the industrial gross value added, suggesting some efficiency improvements in the ETS sector.

The EU-wide emission sources that increased most in 2010 were: CO_2 emissions from residential and commercial sectors; CO_2 emissions from manufacturing industries and construction (including iron and steel process emissions); and CO_2 emissions from public heat and electricity production. Notwithstanding specific differences between Member States, the latter two sectors are largely part of the EU ETS, while emissions from the residential and commercial sectors broadly fall outside the EU ETS.

Figure 4 Greenhouse gas emissions by main sector in the EU-27



Source: EEA.

The largest contributor to higher emissions in the EU in 2010 was the households and services sector, whose emissions increased by 43 million tonnes CO_2-eq. compared to 2009. The winter in Europe in 2010 was colder than in 2009 ([5]), resulting in greater household (and services) demand for heating and higher GHG emissions. 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

([5]) In addition, there was an 8 % increase in the number of heating degree days (an indicator of household demand for heating) in the EU-27, on average, during the first five months of 2010 compared to the same period of the previous year. More up-to-date heating degree days information is not available from Eurostat heat (mainly from coal and gas) is reported under ‘public electricity and heat production’ in greenhouse gas inventories. Eurostat’s energy balances confirm a very significant increase in derived heat in EU-27 households during 2010.

The other part of the heating consists of non-distributed heat ([6]), which is generated directly by households and services. Non-distributed heat (mainly from gas and biomass) is reported under the residential/commercial sector in greenhouse gas inventories and it is as large as distributed heat at the EU level ([7]). More than two thirds of the increase in emissions from households and services in 2010 was accounted for by higher gas use.

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. Even though 2009 was colder than 2008, and 2010 colder than 2009, the last two years were still among the warmest years since 1850.

The second largest contributor to higher EU emissions in 2010 was the coal-dominated iron and steel sector, and other key manufacturing industries. CO_2 combustion emissions in manufacturing industries (excluding steel) increased by 20 million tonnes in 2010. CO_2 emissions in the iron and steel sector (combustion and processes) increased by 33 million, driven by higher industrial activity and an increase in crude steel production. Greenhouse gas inventories for 2010, the 2010 energy balances and the verified 2010 emissions from the EU ETS published last year all confirm significantly higher energy use and emissions in industry — predominantly in iron and steel.

The third largest contributor to higher emissions in 2010 was electricity and heat production, with 14 million additional tonnes of CO_2 compared to 2009. Emissions from gas and coal more than offset lower emissions from liquid fuels in the sector. The use of biomass for heat and power also increased strongly in 2010 and continued the upward trend observed since 1990 ([8]).

Heat and electricity production remains the largest contributor to GHG emissions in the EU, accounting for 26 % of total GHG emissions in 2010. Figure 5 shows that CO_2 emissions from heat and power in the EU have generally decreased since 1990, despite a significant increase in fuel use in the sector. The implied emission factor for coal and lignite in the EU-27 was on average 101 tonnes of CO_2 per Terajoule in 2010. The emission factor for liquid fuels was 77 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 2010, gas use increased by more than coal use while oil consumption fell, resulting in reduced CO_2 emissions per unit of fossil energy generated. The steady increase in biomass use also served as a substitute for fossil fuels.

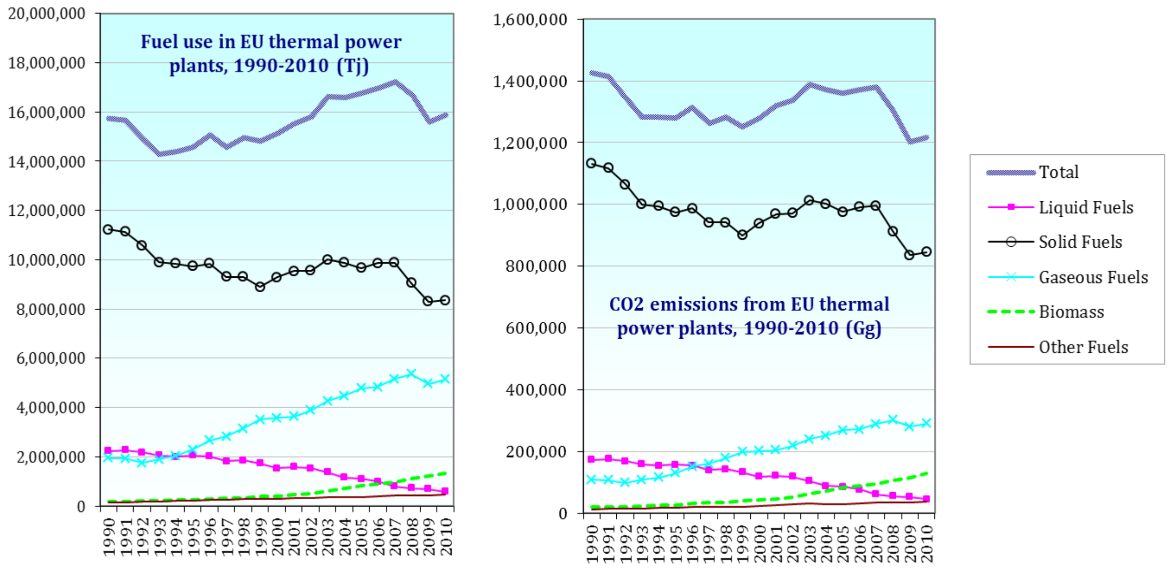
([6]) This includes emissions from fuel combustion in commercial and institutional buildings; all emissions from fuel combustion in households; and a smaller source category covering fuel combustion emissions from agriculture, forestry and fishing. Direct combustion emissions from households are by and large outside the EU ETS. It should be noted, however, that greenhouse gas emissions from households and services do not include indirect/distributed emissions. That is, greenhouse gas emissions resulting from the production of heat and electricity supplied to households and services are included under ‘public electricity and heat production’.

([7]) In 2011, the EEA published the technical report ‘End-user GHG emissions from energy: Reallocation of emissions from energy industries to end users 2005–2009’. 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 2005–2009.

([8]) CO_2 emissions from the combustion of biomass (including biofuels in transport) are considered neutral for IPCC/UNFCCC reporting purposes. 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.

In contrast to the favourable long-term emissions trend, emissions from EU heat and power production increased in 2010. Greater use of fossil fuels, particularly gas and coal, explain the increase of 14 million tonnes of CO_2 compared to 2009.

Figure 5 Fuel use and CO_2 emissions from EU-27 electricity and heat production



Source: EEA

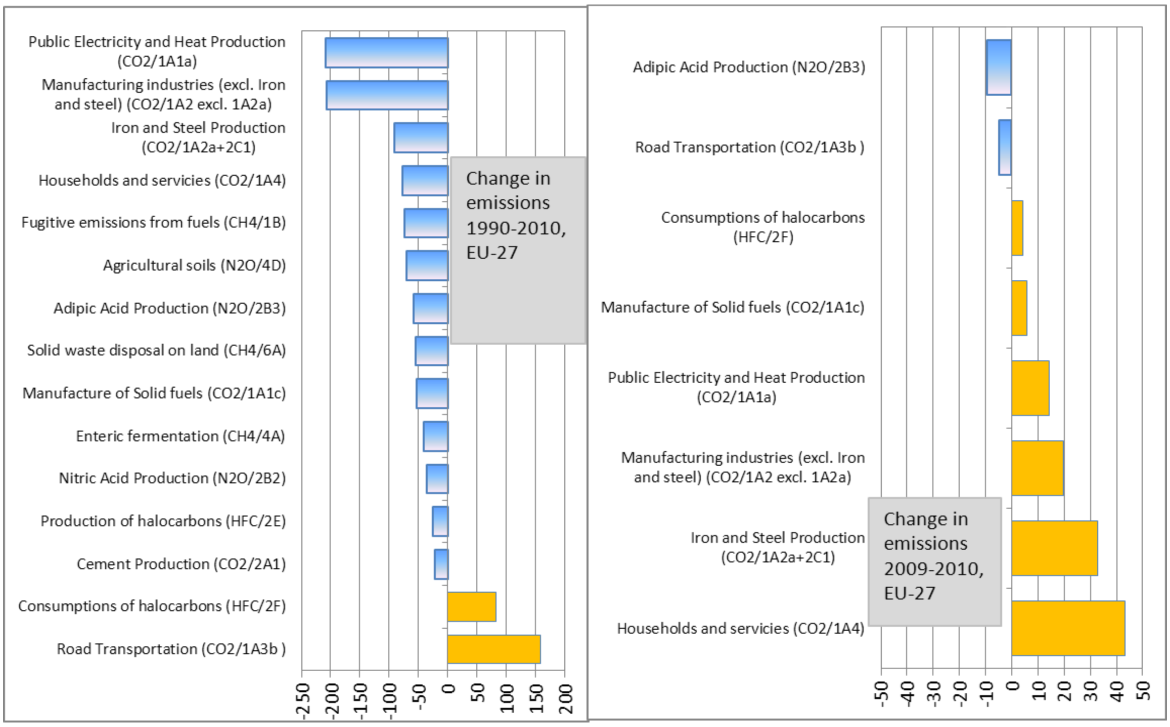
GHG emissions did fall in some sectors between 2009 and 2010. Road transport emissions continued to decline in 2010 due to lower gasoline emissions. This was despite the recovery in diesel emissions after two consecutive years of decline. Diesel price inflation has outpaced the rapidly increasing gasoline 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 2010.

Emissions from international aviation and maritime transport also fell for the third consecutive year. The decline in emissions from international shipping was much stronger, reflecting the severity of the economic recession and lower freight transport. Since 1990, however, international transport emissions have grown very rapidly, reaching 6 % of total EU greenhouse gas emissions.

Emissions from international aviation and maritime transport are not relevant for Kyoto compliance. They are reported in the greenhouse gas inventory as memorandum items, representing 285 million tonnes of CO_2-equivalents in 2010 for the EU as a whole.

Figure 6 presents the most influential key emission sources (excluding bunkers) in the EU in the periods 1990–2010 and 2009–2010.

Figure 6 Overview of the EU-27 source categories recording the largest increases and decreases in the periods 1990–2010 and 2009–2010



Source: EEA

5 Other factors explaining the change in greenhouse gas emissions in 2010

A number of factors outside formal GHG inventory reporting can help explain the increase in greenhouse gas emissions in the EU in 2010. This section introduces additional socio-economic explanatory variables to provide a more complete picture of why emissions from fossil fuel combustion increased in 2010. 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 a regression analysis using both standard and robust methods.

5.1 Decomposition analysis

5.1.1 Key findings

EEA data show that CO_2 emissions from energy-related fossil fuel combustion (including transport) increased by 2.8 % (100 million tonnes) in the EU-27 in 2010. The average fossil fuel CO_2 emission factor continued its downward trend in 2010, although at a slower pace. Eurostat data for 2010 show that the EU population increased by 0.3 % (1.4 million people) and GDP increased by 2.0 %. The final energy intensity of the economy grew by 1.6 % in 2010 compared to 2009, as increased final energy demand in 2010 (3.7 %) outpaced GDP growth (2.0 %).

Energy balances also point to a strong increase in primary energy consumption in the EU (3.2 %) but a stronger increase in renewable energy (12.7 %), particularly from wind, solar and hydro for electricity generation. As discussed in Section 5.2, the overall increase in GHG emissions in the EU would have been worse if renewable energy use had not continued to expand.

5.1.2 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 90 % of the net increase in EU greenhouse gas emissions in 2010. 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)

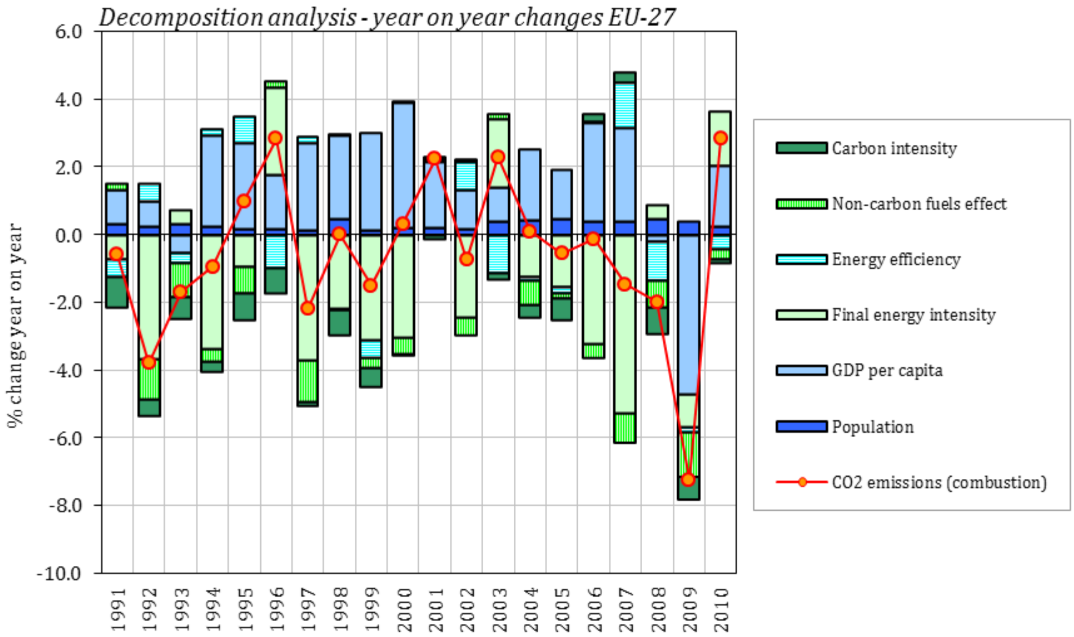
(x_5) FFC/PEC: fossil fuel consumption in total primary energy (non-carbon fuels effect)

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

CO_2 emissions from energy combustion increased by 2.8 % (100 million tonnes) in the EU-27 in 2010. A growing population and GDP generally contribute to higher CO_2 emissions. The population increased by 0.3 % (1.4 million people) while GDP grew by 2.0 %, leading to a 1.7 % increase in GDP per capita in 2010. This positive affluence effect appears quite dominant in 2010 (as it did in 2009, but on the negative side).

The energy intensity of the economy deteriorated by 1.6 % in 2010 compared to 2009. This was mainly because the strong increase in final energy demand in 2010 (3.7 %) outpaced the increase in GDP (2.0 %).

Figure 7 Explanatory factors for CO_2 emissions from energy combustion in the EU-27, 1990–2010



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).

Eurostat's 2010 energy balances also point to a strong increase in primary energy consumption (3.2 %). This rate was, however, lower than the increase in final energy available to the end-use sectors ([9]), resulting in an improvement of the 'energy efficiency effect' in 2010. At least two reasons can explain this improvement. First, there was a strong increase in renewables, some of which can produce electricity by means of mechanical energy without any combustion. The avoided transformation losses in thermal power stations that resulted partly explain why emissions did not increase more. Second, there was also a half percentage point increase in the transformation efficiency in conventional thermal power stations (including district heating) in the EU, to 50.4 % in 2010. Viewed over a longer timeframe, the increased use of electricity from combined heat and power (cogeneration) and recovery of excess heat have also contributed to higher energy efficiencies in the EU.

Along with the strong increase in primary consumption of fossil fuels (gas, coal, oil) the energy balances show a very strong relative increase in renewable energy, particularly of wind, solar and hydro for electricity generation. In absolute terms, however, biomass still represented about 70 % of

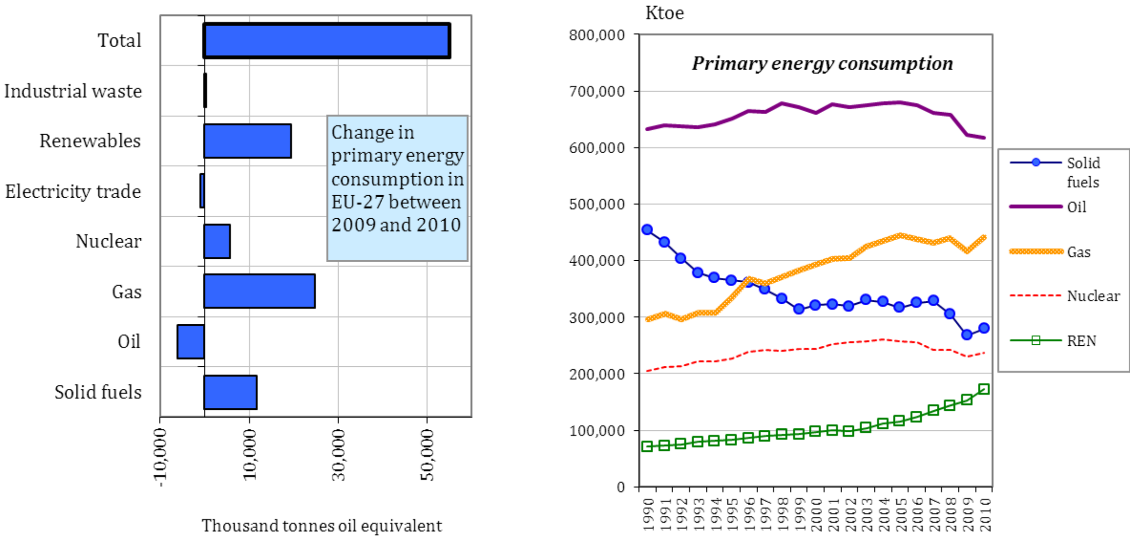
([9]) It is worth noting that not all primary energy is available to the end users of energy such as industry, transport, households, services and agriculture. This is because various losses occur within the energy system to transform primary energy (e.g. coal and lignite, natural gas and crude oil) 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, hydro (without pumping) or photovoltaics, mechanical energy is used to transform primary energy into useful energy.

the increase in renewables in 2010. Nuclear electricity production also increased in 2010 but much less than renewables (Figure 8). Thus, the 'non-carbon fuels effect' (defined in Box 1) was largely the result of increased renewable energy.

Finally, the average fossil fuel CO_2 emission factor continued its downward trend in 2010, although at a slower pace. The emission factor for gaseous and liquid fuels remained stable whereas that of solid fuels increased in 2010. Yet the stronger polluting effect from coal was more than offset by a large increase in gas consumption in the EU.

The 'carbon intensity effect' (defined in Box 1) improved only slightly compared to 2009 because CO_2 emissions increased as fast as the primary fossil fuel input.

Figure 8 Primary energy consumption by main fuels in the EU-27, 1990–2009



Source: Eurostat energy balances.

5.2 Regression analysis

5.2.1 Key findings

The regression analysis outlined below indicates that the economic recovery and higher industrial output, more renewable energy in final energy consumption, and slightly improved carbon intensity were the main (statistical) factors underpinning the change in greenhouse gas emissions in the EU in 2010. The latter two factors prevented GHG emissions from increasing more in 2010.

In addition, the analysis suggests that all three factors were roughly equally important (having similar beta coefficients) in explaining why average EU emissions increased by 2.4 %. The higher heating demand from the colder 2010 winter ([10]) was an additional factor, largely met using natural gas.

([10]) The winter effect factor could not be tested statistically due to the unavailability of complete heating degree days data by Member State in 2010 from Eurostat.

5.2.2 *Methodology*

Basic model

This section presents a cross-sectional statistical analysis of greenhouse gas emission drivers in 2010. 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.

Building on last year's analysis of the factors ([11]) accounting for EU GHG emission trends, 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 used '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)POP + (x_2)GDP + (x_3)GDP*POP + (x_4)EFF + (x_5)REN + (x_6)CAR + μ, where:

The **variables** are:

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

(x_1) POP: % change in population

(x_2) GDP: % change in GDP at constant prices

(x_3) GDP*POP: interaction between GDP and POP

(x_4) EFF: percentage point change in transformation efficiency in public thermal power stations and district heating plants

(x_5) REN: percentage point change in the share of renewable energy in final energy consumption, taking into account distribution losses and own energy consumption (no hydro/wind normalisations)

(x_6) CAR: percentage point change in the average implied CO_2 emission factor of fossil fuel energy (excludes biomass)

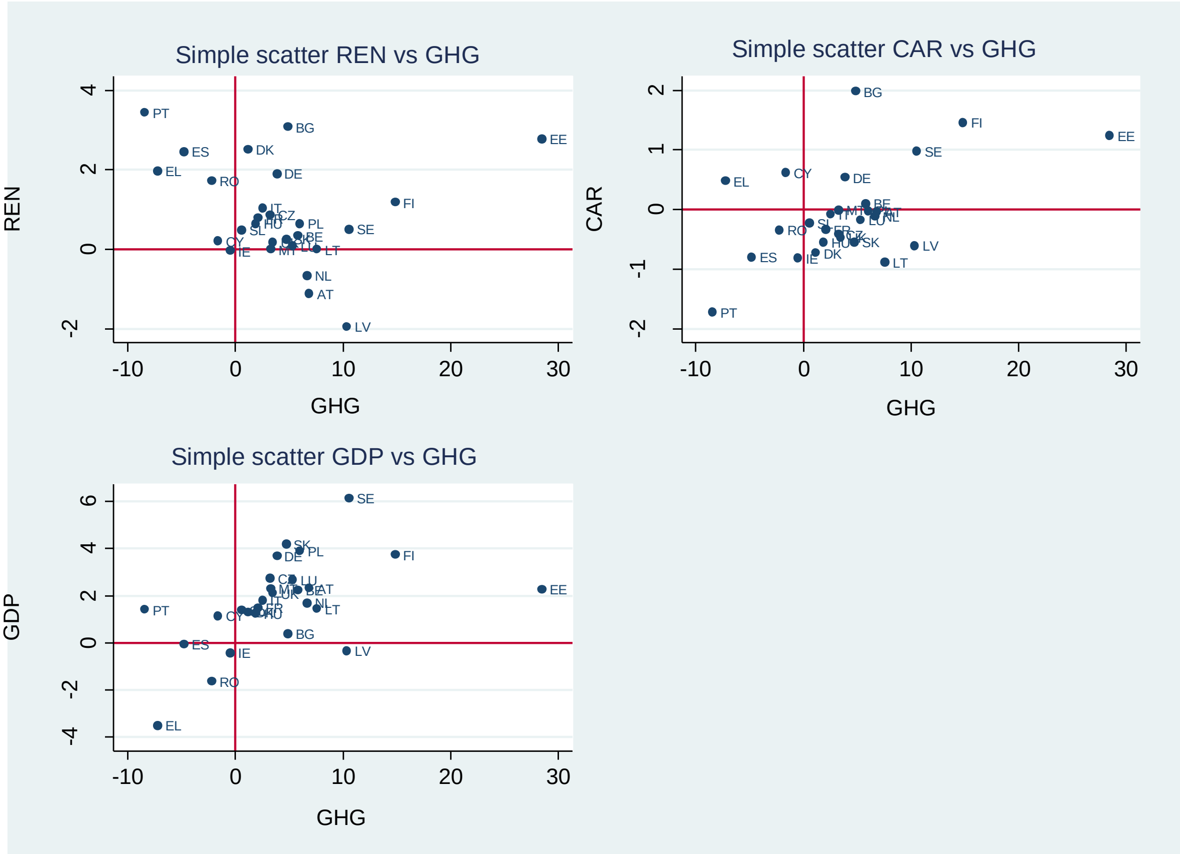
μ: error term

([11]) 'Why did greenhouse gas emissions fall in the EU in 2009? EEA analysis in brief' (http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2011).

The WLS coefficients in the full regression model do not suggest the presence of collinearity in the independent variables. The full model (F-value) is highly significant and only a few of the predictors have non-significant p-values. Moreover, the correlation matrix of the dependent and all independent variables shows higher correlations between GHG and GDP (0.68), between GHG and CAR (0.53), and between GHG and REN (0.43). The remaining three variables, EFF, POP and the interaction term between GDP and POP are discarded because of the very low correlation coefficients.

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

Figure 9 Relationship between GHG emissions and predictor variables, change 2009–2010 – non-weighted



Final model

The coefficients from the reduced regression suggest that GHG is a function of GDP, CAR and REN. The change in greenhouse gas emissions can therefore be written as a function of the individual and combined effects of economic growth, the change in the CO_2 implied emission factor for fossil fuels and the change in the share of renewables in final energy in 2009. The OLS regression coefficients of the interaction term, population and efficiency are not significant at the 5 % level and are dropped from the equation.

The final model consists of three independent variables (REN, GDP and CAR). Based on this final model, the increase in greenhouse gas emissions in 2010 can be explained not only by the increase in economic growth but also by the strong increase in renewable energy relative to overall final energy demand and by improved carbon intensity in fossil fuel production. The latter two offset an otherwise larger increase 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 2009 and 2010 (see Figure 10).

Figure 10 Growth in modelled variables in EU Member States, 2009–2010

GDP was positive in most EU countries in 2010, and emissions fell primarily in those countries where GDP was negative. This was particularly the case in Greece, Spain, Portugal and Romania.

Clearly, the growth in renewables, both combustible (biomass) and non-combustible (wind and solar) influenced GHG emissions in most EU countries. Renewables shows the highest statistical significance of all predictors. The contribution of renewables to final energy consumption increased in 2010, except in the Netherlands (partly due to less wind and biofuels production in 2010 compared to 2009), Ireland (less hydro and wind than in 2009) and Malta (because of the absence of a renewable energy sector there). In two other countries, Austria and Latvia, growth in primary consumption of renewables was outpaced by faster growth in final energy consumption.

Member States vary in terms of changes in their CO_2 average emission factors from fossil fuel combustion. Changes in the average EF depend on several factors. At EU level the implied emission factor (IEF) has decreased since 1990 and this continued in 2010, due to a very strong increase in gas relative to other fossil fuels, partly driven by falling gas prices. The IEF for gas is substantially lower than that of coal or oil. In some big Member States, such as Germany, both GHG emissions and the average CO_2 EF increased in 2010, whereas in other big Member States, for example Spain, both emissions and the average CO_2 EF decreased. Overall there is a significant positive correlation between GHG emissions and the IEFs and this helps explain why the 'net' increase in emissions was 2.4 % in EU-27 in 2010.

Standard and robust regression analysis

All three predictors (GDP, REN and CAR) played a role in the net increase in GHG emissions in the EU in 2010. 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 ([12]).

A closer look at the influence of specific observations shows that Estonia, particularly, but also other countries (Latvia, Lithuania, Finland, Cyprus) could be considered statistical outliers because of their large residuals of more than two standard deviations from the mean of expected predicted values ('large residual effect').

In addition to the overall large residual effect, Portugal, Bulgaria, Greece, Latvia, Estonia, Finland and Sweden have extreme values on at least one of the predictor variables ('high leverage effect'). Finally, Estonia, Latvia and Greece have a significant effect on the regression coefficients of the model ('high influence effect'). In Estonia, there is overall influence from all predictor variables, whereas the influence in Latvia is mostly triggered by the negative contribution from renewables and GDP. In Greece, the specific influence can be attributed to the very strong contraction in GDP in 2010.

None of the observations are removed from the model as they just represent the country-specific changes in the dependent variable (GHG) to changes in the three explanatory variables (REN, GDP and CAR). A robust specification of the standard errors from the WLS regression can 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]).

As shown in Table 1, the regression coefficients in using the robust specification of standard errors (column 2) are identical to those using the standard approach (column 1), as expected. The confidence intervals around the mean estimates are slightly different. The WLS coefficients indicate that when the share of renewables in final energy increases by 1 percentage point greenhouse gas emissions are expected to decrease by about 2.1 % (holding GDP and CAR constant). Also, if GDP increases by 1 %, greenhouse gas emissions are expected to increase by about 1.1 % (holding REN and CAR constant). Finally, if the CO_2 implied emission factor for fossil fuels increases by 1 %, greenhouse gas emissions are expected to increase by about 3.4 % (holding REN and GDP constant).

([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. 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.

([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. Estonia, particularly, 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 and homoscedastic errors.

Table 1 **Final model results**

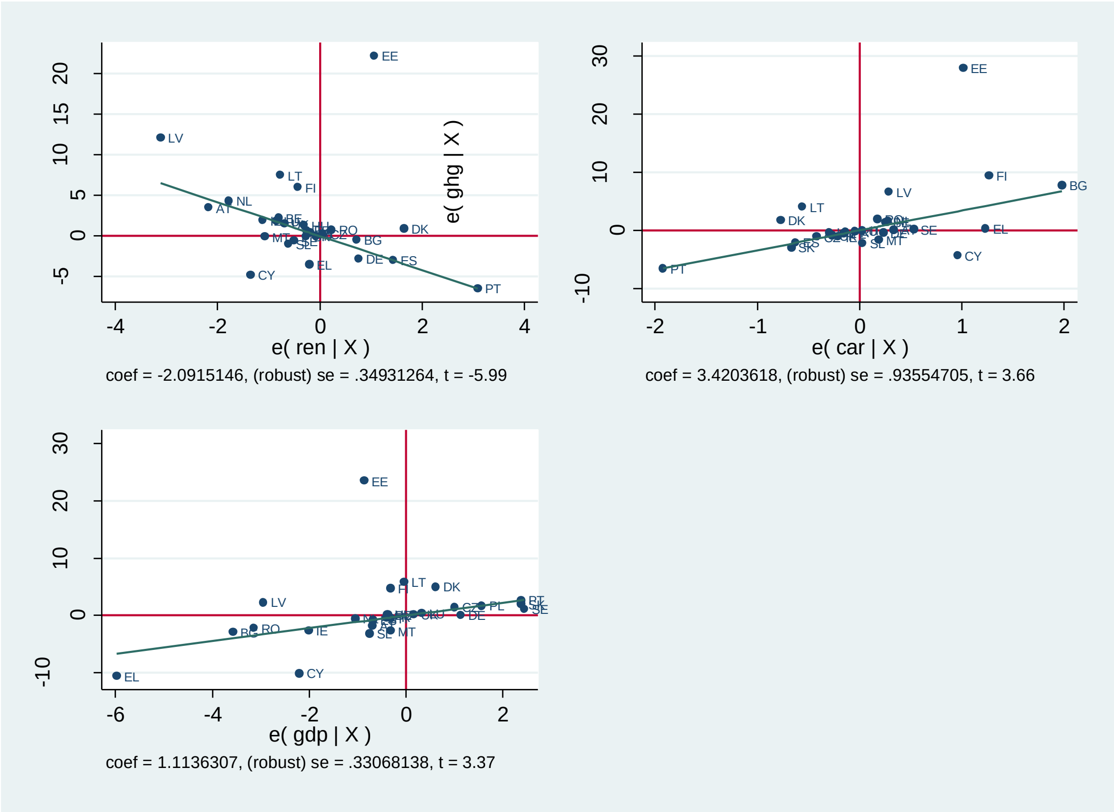
	(1)	(2)
	Weighted least squares	**WLS with robust standard errors**
Variables	**GHG**	**GHG**
GDP	1.114**	1.114**
	(0.308)	(0.331)
Beta coefficient	*0.433*	*0.433*
CAR	3.420**	3.420**
	(0.912)	(0.936)
Beta coefficient	*0.454*	*0.454*
REN	–2.092***	–2.092***
	(0.506)	(0.349)
Beta coefficient	*–0.464*	*–0.464*
Constant	3.067**	3.067**
	(1.075)	(0.899)
Observations	27	27
R-squared	0.74	0.74
Adj. R-squared	0.70	0.70
Mean square error	363.59	363.59
Residual square error	129.18	129.18
Root MSE	2.37	2.37

Standard errors in parentheses

*** $p<0.001$, ** $p<0.01$, * $p<0.05$

Both the standard and robust methods use weighted least squares and take into account country-size effects on the dependent variable. Standard regression diagnostics have been applied iteratively to confirm the residuals meet Gauss-Markov conditions ([14]). Figure 11 shows the partial regression plots for each explanatory variable.

Figure 11 Added-variable plots with robust standard errors



6 Verified EU ETS emissions for 2011

Verified EU ETS data for 2011 show that greenhouse gas emissions decreased by about 3 % compared to 2010. This is despite positive economic growth and industrial demand, with EU-27 GDP growing by 1.5 % in 2011.

The EEA will publish early EU-27 greenhouse gas estimates for 2011 in autumn 2012, a few months before the official EU greenhouse gas inventory is submitted to the UNFCCC.

([14]) The residuals are independent, homoscedastic, have zero mean and are normally distributed. The residual v. fit 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.

For 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 EU greenhouse gas inventory 1990–2010 and inventory report 2012 (http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2012).

EEA GHG data viewer (http://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer).

EEA EU-ETS data viewer (http://www.eea.europa.eu/data-and-maps/data/data-viewers/emissions-trading-viewer).