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Analysis of key trends and drivers in greenhouse gas emissions in the EU between 1990 and 2015

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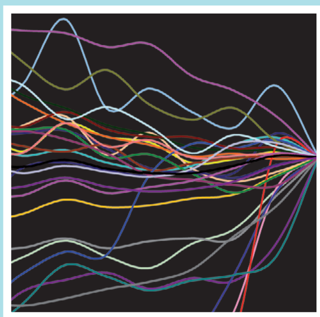

European Environment Agency

Analysis of key trends and drivers in greenhouse gas emissions in the EU between 1990 and 2015

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Foreword

Analysis of key drivers in greenhouse gas emissions in the EU

This paper analyses the major factors that accounted for decreased and/or increased greenhouse gas (GHG) emissions excluding land use, land use changes and forestry (LULUCF) in the EU-28. It consists of two parts: the first part looks at the year 2015 compared to 2014 and the second part looks at the whole period between 1990 and 2015, as well as an analysis of the effect of the economy and the weather on GHG emissions. The data is based on the EU's GHG inventory submission to UNFCCC in 2017 ([1]).

([1]) The EU GHG inventory comprises the direct sum of the national inventories compiled by the EU Member States making up the EU-28. In addition, the European Union, its Member States and Iceland have agreed to jointly fulfil and report on their quantified emission limitation and reduction commitments for the second commitment period to the Kyoto Protocol. In this paper the analysis is based on the EU-28 reporting under the UNFCCC (i.e. Convention reporting).
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). More information on the EU GHG inventory, including the GHG data viewer can be found on the EEA's website at: www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2017.

1 GHG emissions in 2015 compared to 2014

1.1 Summary (last year)

Total GHG emissions in the EU (excluding LULUCF) increased for the first time since 2010 by 23 million tonnes, or 0.5 % compared to 2014 ([2]), to reach 4 310 Mt CO_2 equivalent in 2015. This modest increase in emissions came along with an increase in gross domestic product (GDP) of 2.2 %, the largest increase since the economic crisis started in the second half of 2008. This resulted in a lower emissions-intensity of GDP in the EU in 2015 and contributed to a further decoupling of GHG emissions and economic growth.

The increase in emissions was triggered by the higher heat demand by households and services due to slightly colder winter conditions in Europe, as well as by higher road transport demand, which increased for the second year in a row. These sectors are not covered by the EU emissions trading system (ETS), and explains why overall net emissions increased in spite of the reduction in EU ETS emissions the same year. ETS emissions from stationary installations decreased by 0.7 %, whereas emissions from the non-trading sectors increased by 1.4 % in 2015.

Total energy consumption increased overall, with fossil emissions increasing, particularly for natural gas and crude oil. The consumption and emissions of solid fuels decreased in 2015 for the third consecutive year. The sustained increase in renewables, particularly biomass, wind and solar, offset otherwise higher emissions in 2015. Hydro (due to a low rainfall) and nuclear electricity production declined in 2015.

In spite of the 2015 increase in emissions, there were further improvements in the carbon intensity of the EU energy system because of the increased shares of renewables and gas relative to coal in the fuel mix. The energy intensity of GDP also improved as total energy consumption increased less rapidly than economic growth. The improvement in energy intensity was largely driven by lower energy-transformation losses and better energy efficiency of the overall EU economy.

Spain, Italy and the Netherlands accounted for the largest increases in GHG emissions in the EU in 2015. The UK recorded the largest reduction.

1.2 Overall results at EU level

Total GHG emissions, excluding LULUCF, increased for the first time since 2010 to reach 4310 Mt CO_2 eq. In 2015, and in line with the European Environment Agency's (EEA) Approximated GHG inventory published last year ([3]), EU emissions were 0.5 % above 2014 levels (0.6 % including international aviation), equivalent to a net increase of 23 million tonnes of CO_2 equivalents. Compared to 1990, total GHG emissions were 23.7 % lower in 2015 (22.1 % lower when including international aviation).

Figure 1.1 breaks down the 0.5 % overall increase in GHG emissions into several factors using the Kaya decomposition identity ([4]). Of these, the higher GDP per capita played the biggest role (dark blue section) in bringing emissions up. Population also contributed to the increase in emissions (light blue section). The lower energy intensity of GDP was the largest factor (yellow section) counterbalancing the increase in emissions, as the economy required less primary energy per unit of GDP. The carbon intensity of energy also improved in 2015 (red section), which reflects the lower use of

([2]) The current analysis focuses on GHG emission trends in the EU-28 and is based on Member States' GHG inventories reported to the EU by 8 May 2017. These inventories underpin the EU's GHG inventory submission to UNFCCC of end May.

([3]) Approximated EU GHG inventory: proxy GHG estimates for 2015, www.eea.europa.eu/publications/approximated-eu-ghg-inventory-2015

([4]) The chosen factors are an extension of the Kaya identity. The annual decomposition analysis shown in this paper is based on the Logarithmic Mean Divisia Index (LMDI) method. The equation for the aggregated decomposition analysis is: (y) [ln]GHG = (x_1) [ln]POP + (x_2) [ln]GDP/POP + (x_3) [ln]PEC/GDP + (x_4) [ln]GHG_en/PEC + (x_5) [ln]GHG/GHG_en, where: (y) GHG: total GHG emissions; (x1) POP: population (population effect); (x2) GDP/POP: GDP per capita (affluence effect); (x3) PEC/GDP: primary energy intensity of the economy (primary energy intensity effect); (x4) GHG_en/PEC: energy-related GHG emissions in primary energy consumption (carbon intensity effect); (x5) GHG/GHG_en: total GHG emissions in energy-related GHG emissions (non-combustion effect). The non-combustion effect refers to how energy-related emissions (combustion and fugitives) behave compared to non-energy related emissions (industrial processes, agriculture and waste sectors).

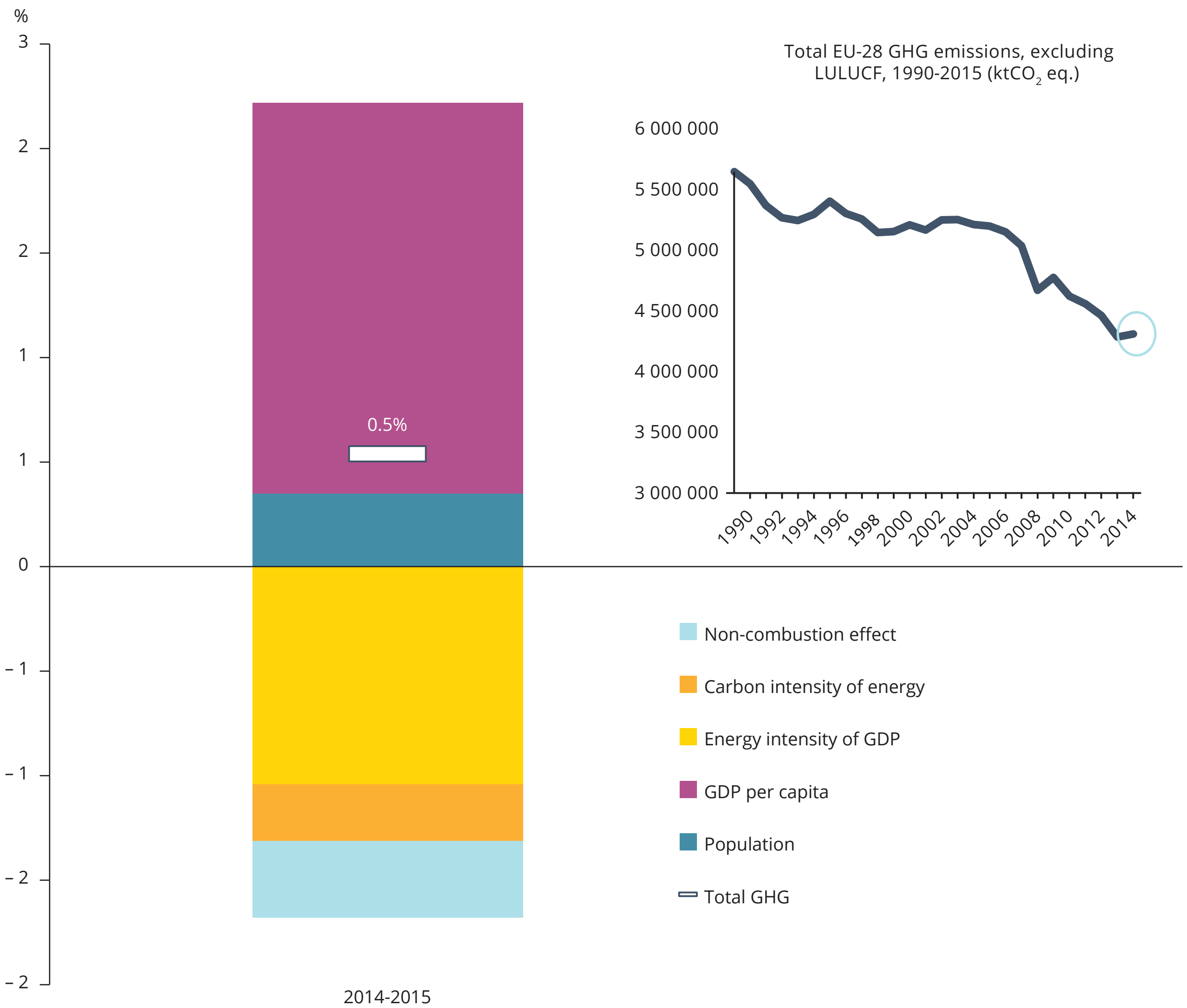
carbon intensive fuels like coal and an increase in the consumption of natural gas and renewables. The non-combustion factor (green section) shows that emissions from non-energy sectors performed better (i.e. emissions actually decreased) than energy-related emissions in 2015.

Overall, the four main findings from the decomposition analysis of Figure 1.1 are:

i. The increase of 0.5 % in total GHG emissions came along with an increase in GDP of 2.2 % in 2015. The growth in GDP in 2015 was the largest since the economic crisis started in the second half of 2008. This resulted in a lower emissions-intensity of GDP in the EU in 2015 and contributed to a further decoupling of GHG emissions and economic growth. The EU population increased by almost 2 million in 2015.

ii. The increase in total GHG emissions was almost fully-driven by emission increases in the energy sector, particularly in the residential and commercial sectors as well as in the transport sector. As explained below this was due to higher heat demand from the slightly colder winter conditions in Europe in 2015 and by the increase in the consumption of diesel in road transportation (mostly passenger, but also freight). The weight of non-combustion emissions relative to energy-related emissions decreased in 2015. Agriculture emissions increased modestly, whereas those from industrial processes and waste management decreased in 2015.

Figure 1.1 Decomposition of the annual change in total GHG emissions in the EU-28 in 2015



Note: The explanatory factors should not be seen as independent of each other. The bar segments show the changes associated with each factor alone, holding the respective other factors constant.

Source: EEA.

iii. The lower carbon intensity of energy was a factor counterbalancing otherwise higher emissions in 2015. This is in spite of a decline in hydro-electricity and lower nuclear production compared to 2014. The lower carbon intensity is by and large accounted for by a higher relative-contribution from renewable energy sources (mostly biomass, wind and solar) as well as by an increase in the share of natural gas relative to coal in the fuel mix. According to Eurostat, the share of renewable energy in gross final energy consumption (normalised to even out the annual variability in hydro and wind production) reached 16.7 % in 2015, up from 16.1 % the year before. Thus, a less carbon-intensive fuel-mix led to an overall improvement of the carbon intensity of energy production and use in the EU in 2015.

iv. The decrease in primary energy intensity was the largest offsetting factor to higher GHG emissions. Total energy consumption increased but GDP increased faster, leading to an improvement in the energy intensity of the EU economy as a whole. Final energy increased almost twice as fast as primary energy in 2015. The improvement in energy intensity was largely driven by lower energy-transformation losses and better energy efficiency of the overall EU economy, with more energy available for final consumption by the economic sectors per unit of primary energy.

1.3 Largest emission changes by sector at EU level

We now look deeper into the sectors accounting for the largest increase in emissions. Table 1.1 shows that the largest increases occurred in 'buildings', including residential, commercial and institutional, and in road transportation.

Heat consumption in the EU can be supplied via distributed systems from thermal stations (reported under public electricity and heat production) and/or as a process of direct combustion in buildings (reported under residential and commercial/institutional). The consumption and emissions of the residential and commercial sectors reported in GHG inventories capture by and large the bulk of heat consumption and emissions from fossil fuels. Emissions in these sectors increased by 4.9 % in 2015 yet 2015 had the second lowest heat consumption in the EU. This is because 2014 recorded the lowest ever heat consumption and the highest average temperatures in Europe during the previous 25 years. There was subsequently an increased demand for heating in 2015 compared to 2014.

It is worth noting that emissions from public electricity and heat production decreased in 2015 even though the production of both heat and electricity actually increased that year. The main reason was lower use of coal and increased use of gas and biomass, which led to an improvement of the carbon intensity of the power sector and resulted in lower emissions in spite of increased output. The question is whether the trigger for such increase in output was higher heat consumption or electricity, or both.

GHG inventories provide evidence of the fuel input and the emissions output from electricity and heat production, but without distinguishing between emissions from heat and from electricity. According to energy statistics reported to Eurostat, there was an increase in both heat output and electricity output

Table 1.1 Overview of the largest emission changes by key sector in EU-28, 2014-2015

Source category	Million tonnes (CO_2 equivalents)
Public electricity and heat production (CO_2 from 1.A.1.a)	– 13.2
Refrigeration and air conditioning (HFCs from 2.F.1)	– 5.0
Managed waste disposal sites (CH_4 from 5.A.1)	– 4.0
International aviation(CO_2 from 1.D.1.a)*	5.0
Commercial/institutional (CO_2 from 1.A.4.a)	5.6
Road transportation (CO_2 from 1.A.3.b)	13.6
Residential (CO_2 from 1.A.4.b)	19.5
Total	23.1

Note: The table shows only those sectors where emissions have increased or decreased by at least 3 million tonnes of CO_2 equivalent between 2014 and 2015. The table reflects the emission reductions according to the EU's geographical scope under KP and includes Iceland International aviation is not included in national totals under KP/UNFCCC but it is included under the EU internal scope. Iceland is included in the former but not in the latter.

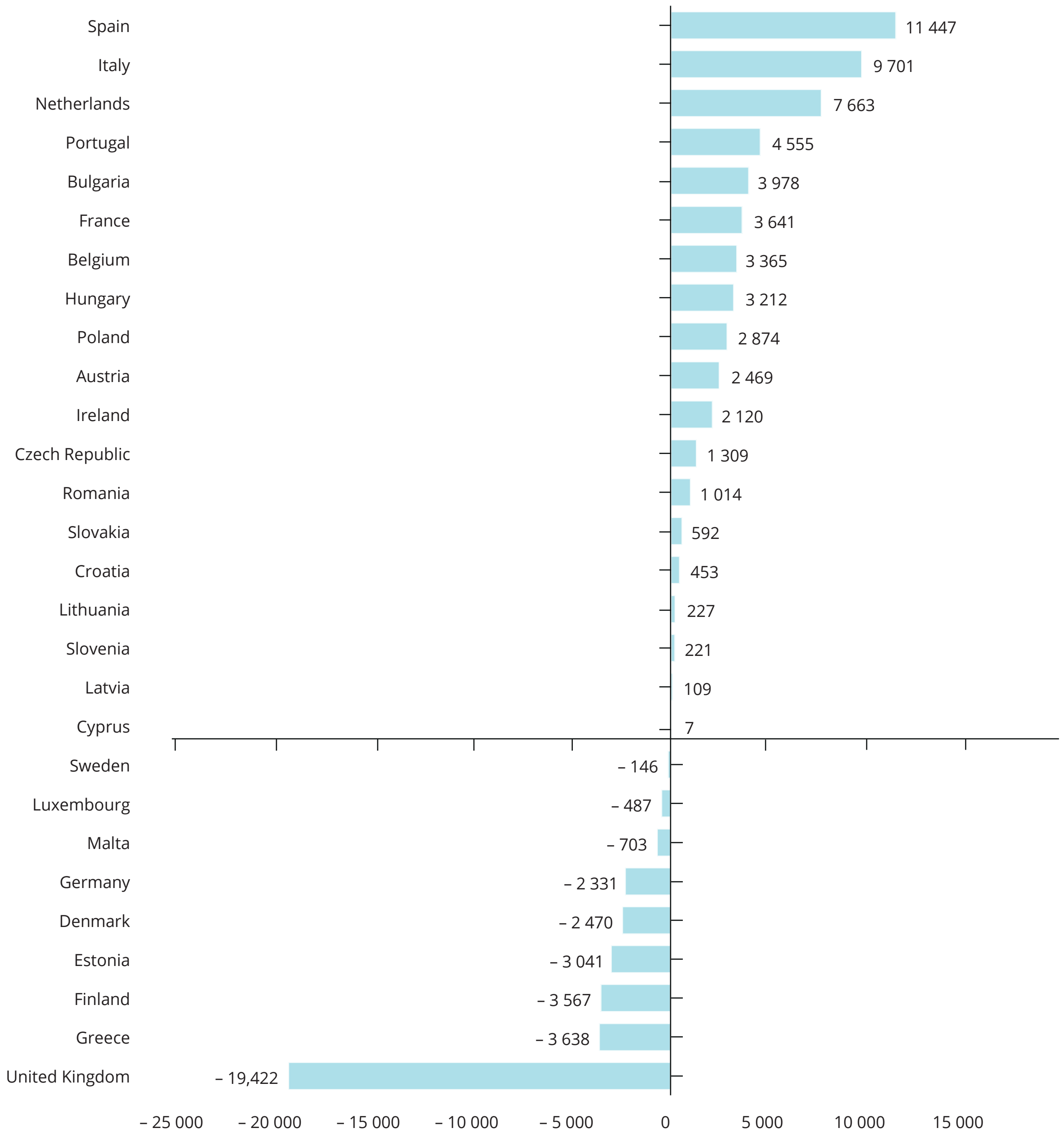
Source: EEA.

from conventional thermal power stations (including district heating) and this overall increase also applied to the residential sector. In addition, electricity in some countries is also used for heating purposes, so part of the increase in electricity in 2015 may also be attributed to higher heat demand in these countries.

The other key sector where emissions increased in 2015 was road transportation. It is the second largest source of emissions in the EU (after the power sector) and the positive trend of emission reductions observed since 2007 was reversed in 2014 and confirmed in 2015. Road transport emissions increased by 1.6 % in 2015. The increase was fully accounted for by diesel consumption, whereas gasoline emissions continued declining. About 70 % of the increase came from passenger cars, 20 % from heavy duty vehicles, 4 % from light duty vehicles and the remaining 1 % from motorcycles.

International aviation is not included in national totals under the Kyoto Protocol but it is integrated in the EU internal scope and the 20 % 2020 target. Emissions continued increasing in 2015.

Figure 1.2 Change in total GHG emissions, excluding LULUCF, between 2014 and 2015 by EU Member State (kt CO_2 equivalent)



Source: EEA.

Perhaps one of the most positive developments in 2015 was the decrease in hydrofluorocarbons (HFC) emissions from refrigeration and air conditioning, which has halted the almost exponential increase of these emissions since 1990.

1.4 Largest Member State contributions to the EU performance

Figure 1.2 shows the absolute change in total GHG emissions, excluding LULUCF, by Member States between 2014 and 2015. Emissions increased in 19 Member States, particularly in Spain, Italy and the Netherlands, and decreased in 9 Member States, mainly in the United Kingdom.

The main reasons for the increase in emissions in Spain are the substantial increase in coal for electricity generation, the increase in the use of diesel for road transportation, particularly passenger cars, and the higher use of gas in the commercial/institutional sector. GDP also went up strongly in 2015 and renewables decreased in terms of primary energy, mainly for hydro but also for wind and biogas. In Italy, the main reasons were the strong increase in gas consumption in the residential sector, due to higher heat demand, as well as in the power sector. In the Netherlands, higher emissions were by and large the result of increased coal used for power generation as well as of gas in the residential sector due to colder winter conditions. Finally, the United Kingdom reported the largest decrease in emissions of the EU in 2015, in spite of the colder winter. This was primarily due to a strong reduction in coal use and an increase in renewables and nuclear for electricity generation.

As shown in Section 1.3, the largest increases in emissions at EU level occurred in the residential and commercial sectors and in road transportation. A closer analysis at country level shows that the top 10 contributors to the increase in GHG emissions in the EU in 2015 were: a) higher gas use in the residential sector in Italy, Germany, France and the United Kingdom; b) higher gas consumption in commercial and institutional sectors in Spain and Italy; and, c) higher consumption of diesel for road transportation in Germany, United Kingdom, Spain and Poland. This is shown in Table 1.2.

Table 1.2 Top 10 contributors to the total GHG emission increase in the EU in 2015

Ranking in top 10	Member State	Sector	Gas	Fuel	Increase (kt)	% total EU (net) increase
1	Italy	Residential	CO_2	Gaseous fuels	4 420	19.1 %
2	Germany	Residential	CO_2	Gaseous fuels	3 574	15.4 %
3	Germany	Road transportation	CO_2	Diesel oil	3 121	13.5 %
4	United Kingdom	Road transportation	CO_2	Diesel oil	3 058	13.2 %
5	Spain	Commercial/ institutional	CO_2	Gaseous fuels	2 958	12.8 %
6	France	Residential	CO_2	Gaseous fuels	2 657	11.5 %
7	United Kingdom	Residential	CO_2	Gaseous fuels	2 628	11.4 %
8	Spain	Road transportation	CO_2	Diesel oil	2 537	11.0 %
9	Poland	Road transportation	CO_2	Diesel oil	2 048	8.8 %
10	Italy	Commercial/ institutional	CO_2	Gaseous fuels	1 739	7.5 %
Sum of top 10	–	–	CO_2	–	28 741	124.2 %
EU total net reduction	–	all sectors excluding LULUCF	GHG		23 137	100.0 %

Note: Table 1.2 (at Member State level) builds from the three largest contributors to the net increase in EU GHG emissions from Table 1.1 (EU level). Other emission sources at Member State level may have increased by a larger amount but are not shown in Table 1.2

Source: EEA.

Clearly, there are strong indications that higher heat demand and consumption was one of the determinants for the increase in emissions in 2015, not only in the EU as a whole but also at Member State level. The other key determinant was road transportation which increased for the second year in a row. The next sections will show that slightly colder winter conditions in 2015 and higher diesel consumption in road transportation largely explain the increase of 23 million tonnes of CO_2 equivalent in the EU.

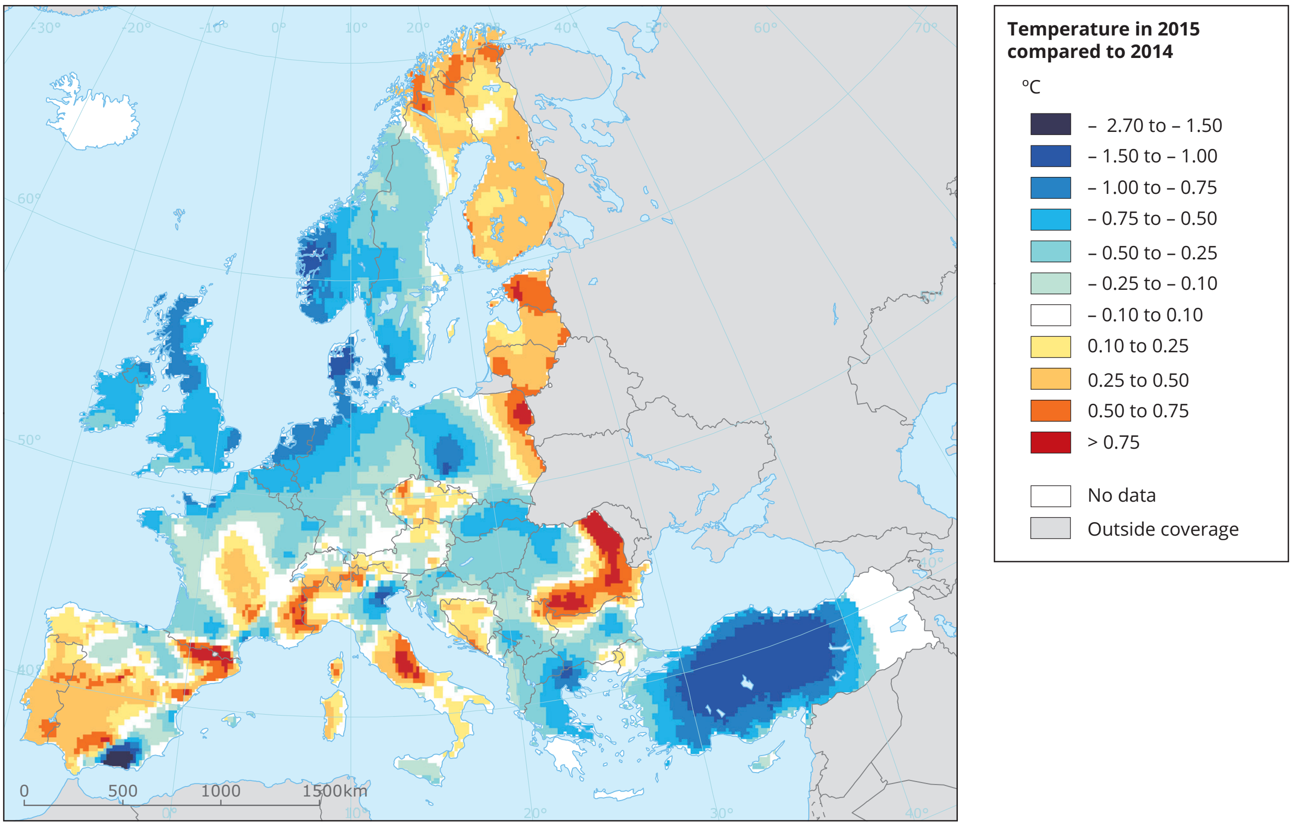
1.5 Weather conditions and road transport drive emissions up

A warm 2015 but slightly colder than 2014

The years 2014 and 2015 were jointly the warmest years in Europe since instrumental records began ([5]). There is, however, evidence of significantly higher heat consumption and heat demand in the residential and commercial sectors, as well as in the power sector, due to somewhat colder weather conditions in Europe during 2015 compared to 2014. The year 2014 was the hottest year on record in Europe and the second hottest worldwide, whereas 2015 was the hottest year worldwide and the second hottest in Europe. This resulted in higher demand for heating in the EU in 2015.

Based on data for Europe from the United Kingdom's Met Office Hadley Centre, the average monthly near-surface temperatures over land were lower in most months where heating is usually needed ([6]). Furthermore, according to Eurostat, there was a 3.4 % increase in the number of heating degree days (an indicator of household demand for heating) in the EU in 2015 compared to 2014. Thus, mean temperatures for Europe as well as heating degree days strongly

Figure 1.3 Mean near-surface temperature change between 2014 and 2015 in Europe: average temperature of the season January, February, March, October, November and December



Source: EEA. Data source for the underpinning daily gridded temperatures, http://www.ecad.eu.

([5]) Global and European temperature http://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature-3/assessment.

([6]) Data from 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 Centre (NOAA's NCDC), also confirm average colder conditions in Europe in 2015 compared to 2014.

suggest that colder winter conditions in 2015 are partly responsible for the increase in fuel use and emissions from buildings (residential, commercial and institutional) that year. This result is statistically significant on average for the EU, when considering the evolution of heating degree days (HDDs) and GHG emissions in 2015 in all Member States.

Figure 1.3, which is based on daily gridded data (E-OBS) ([7]), illustrates the difference in average annual near-surface temperatures in Europe between 2014 and 2015. The map shows that, notwithstanding regional variability, mean temperatures in many parts of the continent were lower in 2015 compared to 2014.

Table 1.3 Change in road transport emissions by vehicle type in 2015

Member States	Road transportation	Passenger cars	Light duty trucks	Heavy duty trucks and buses	Share of CO_2 from road transport in total GHG emissions
Luxembourg	– 6.9 %	– 4.4 %	2.4 %	– 9.0 %	54.9 %
Sweden	0.3 %	1.2 %	0.6 %	– 2.1 %	31.3 %
Slovenia	– 0.4 %	– 0.3 %	– 0.1 %	– 1.1 %	31.2 %
Austria	1.5 %	1.0 %	1.7 %	2.2 %	27.4 %
France	0.9 %	1.6 %	1.5 %	– 1.6 %	27.1 %
Malta	5.1 %	–	–	–	25.7 %
Latvia	7.2 %	7.5 %	6.5 %	6.7 %	25.2 %
Lithuania	6.0 %	5.1 %	1.6 %	8.0 %	23.9 %
Denmark	1.8 %	2.2 %	0.4 %	1.8 %	23.7 %
Spain	3.5 %	7.2 %	15.3 %	– 9.4 %	23.3 %
Croatia	6.1 %	7.6 %	4.2 %	2.6 %	22.7 %
Italy	– 2.3 %	0.2 %	– 19.7 %	2.2 %	22.7 %
Portugal	1.0 %	– 1.9 %	– 1.6 %	11.2 %	22.3 %
United Kingdom	2.1 %	1.2 %	4.2 %	3.0 %	21.9 %
Belgium	6.9 %	6.7 %	9.0 %	6.7 %	21.7 %
Cyprus	3.9 %	–	–	–	21.7 %
Hungary	9.6 %	7.7 %	7.9 %	14.0 %	19.3 %
Ireland	4.6 %	4.0 %	12.2 %	– 0.6 %	18.7 %
Finland	0.7 %	–	–	–	18.6 %
Germany	0.5 %	– 1.8 %	1.1 %	5.4 %	17.0 %
Slovakia	3.1 %	33.1 %	20.6 %	– 21.3 %	15.4 %
Greece	1.7 %	– 0.7 %	19.8 %	– 2.5 %	15.2 %
Netherlands	1.2 %	0.5 %	2.8 %	2.0 %	15.0 %
Bulgaria	10.9 %	10.7 %	13.7 %	9.7 %	14.3 %
Czech Republic	4.8 %	4.9 %	–	4.7 %	13.3 %
Romania	0.5 %	– 0.7 %	1.5 %	1.7 %	12.8 %
Estonia	2.4 %	5.5 %	– 10.1 %	– 0.7 %	12.2 %
Poland	5.4 %	6.0 %	0.6 %	6.4 %	11.6 %
EU-28	**1.6 %**	**1.9 %**	**0.5 %**	**1.5 %**	**19.8 %**

Note: Based on Member States' GHG inventory reporting to the EU and UNFCCC.

Source: EEA.

([7]) The European Climate Assessment & Dataset (ECA) contains series of daily observations at meteorological stations throughout Europe and the Mediterranean. 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.

Road transport emissions on the rise again in 2015

GHG emissions from road transportation increased again in 2015, confirming the upward trend in emissions that started in 2014 (Table 1.3). Emissions went up by 1.6 % compared to the previous year mainly due to higher diesel consumption in passenger cars as well as from heavy duty and light duty vehicles. Road transport represents about 20 % of total GHG emissions in the EU, and about one third of emissions from the sectors not covered by the EU ETS. Thus, transport emissions would need to fall significantly if Member States are to meet their limitation targets under the Effort Sharing Decision (ESD) for non-trading sectors by 2020 compared to 2005 ([8]).

According to the latest report by the EEA ([9]) , the average CO_2 emissions level of new cars sold in 2015 was 119.5 g CO_2/km, well below the 2015 target of 130 g CO_2/km. The average emission of new light commercial vehicles in 2015 was 168.3 g CO_2/km, which is also below the 2017 target of 175 g CO /km by 2017. Car and van manufacturers will have to keep reducing emissions levels to meet the targets of 95 g CO_2/km and 147 g CO_2/km, respectively.

Finally, the EU's climate change mitigation policy framework is based on a distinction between GHG emissions from large industrial sources, which are governed by the EU emissions trading system (ETS) covering about 42 % of total GHG emissions, and emissions from the sectors covered by the ESD and where national targets apply. With the exception of electric vehicles, road transportation is not included under the EU ETS. Similarly, residential, commercial and institutional (i.e. buildings) are by and large not covered by the EU's trading system. The 0.5 % net increase in emissions in 2015 was fully accounted for by the non-trading sectors. ETS emissions from stationary installations decreased by 0.7 %, whereas emissions from the non-trading sectors increased by 1.4 % in 2015.

([8]) In 2009, the EU adopted legislation establishing emission performance requirements for new passenger cars, with the setting of a CO_2 emission target of 130 g CO_2/km by 2015 and of 95 g CO_2/km to be phased in from 2020. A more recent Regulation (EU) No 510/2011 introduced mandatory CO_2 emission performance standards for new vans, with a CO_2 emission target of 175 g CO_2/km by 2017 and of 147 g CO_2/km by 2020. A more recent Regulation (EU) No 510/2011 introduced mandatory CO_2 emission performance standards for new vans, with a CO_2 emission target of 175 g CO_2/km by 2017 and of 147 g CO_2/km by 2020.These targets refer to the average value for the fleet of newly registered vans in the EU.

([9]) 'CO_2 emissions from cars and vans: all larger manufacturers met their 2015 targets', EEA. http://www.eea.europa.eu/highlights/co2-emissions-from-cars-and.

2 GHG emissions trends between 1990 and 2015

2.1 Summary (last 25 years)

Total GHG emissions in the EU (excluding LULUCF) decreased by 1 337 million tonnes since 1990 (or 23.7 % reaching their lowest level during this period in 2014 before increasing slightly in 2015 (4 310 Mt CO_2 eq.). The reduction including international aviation was 22.1 % compared to 1990. There has been a progressive decoupling of GDP and GHG emissions compared to 1990, with an increase in GDP of about 50 % alongside a decrease in emissions of almost 24 % over the period.

The reduction in GHG emissions over the 25-year period was due to a variety of factors, including the growing share in the use of renewables, the use of less carbon intensive fuels and improvements in energy efficiency, as well as to structural changes in the economy and the economic recession. Demand for energy to heat households has also been lower, as Europe on average has experienced milder winters since 1990, which has also helped reduce emissions.

GHG emissions decreased in the majority of sectors between 1990 and 2015, with the notable exception of transport, including international transport, and refrigeration and air conditioning. At the aggregate level, emission reductions were largest for manufacturing industries and construction, electricity and heat production, and residential combustion. The largest decrease in emissions in relative terms was in waste management (over 40 % reduction compared to 1990)

A combination of factors explains lower emissions in industrial sectors, such as improved efficiency and carbon intensity as well as structural changes in the economy, with a higher share of services and a lower share of more-energy-intensive industry in total GDP. The economic recession that began in the second half of 2008 and continued through to 2009 also had an impact on emissions from industrial sectors. Emissions from electricity and heat production decreased strongly since 1990. In addition to improved energy efficiency there has been a move towards less carbon intense fuels. Between 1990 and 2015, the use of solid and liquid fuels in thermal stations decreased strongly whereas natural gas consumption doubled, resulting in reduced CO_2 emissions per unit of fossil energy generated. Emissions in the residential sector also represented one of the largest reductions. Energy efficiency improvements from better insulation standards in buildings and a less carbon-intensive fuel mix can partly explain lower demand for space heating in the EU as a whole over the past 25 years. Since 1990 there has been a gradual warming of the autumn/winter period in Europe; although there is high regional variability. The very strong increase in the use of biomass for energy purposes has also contributed to lower GHG emissions in the EU.

In terms of the main GHGs, CO_2 was responsible for the largest reduction in emissions since 1990. Reductions in emissions from N_2O and CH_4 have been substantial, reflecting lower levels of mining activities, lower agricultural livestock, as well as lower emissions from managed waste disposal on land and from agricultural soils. A number of policies (both EU and country-specific) have also contributed to the overall reduction in GHG emissions, including key agricultural and environmental policies in the 1990s and climate and energy policies in the 2000s.

Almost all EU Member States reduced emissions compared to 1990 and thus contributed to the overall positive EU performance. The United Kingdom and Germany accounted for about 48 % of the total net reduction in the EU over the past 25 years.

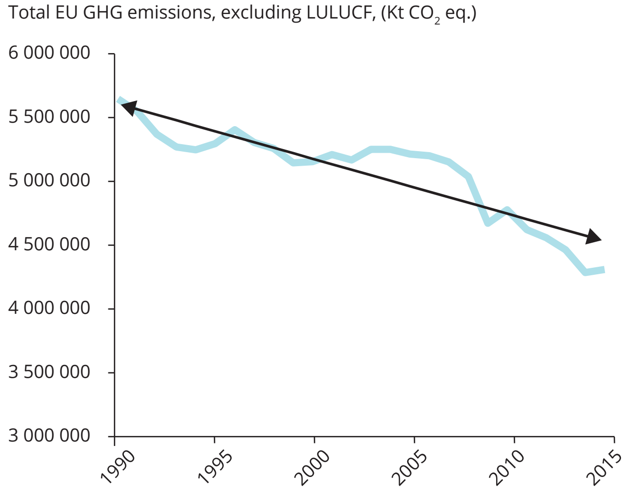
In spite of good progress in reducing GHG emissions intensity and decarbonising the EU economy, fossil fuels still represent the largest source of energy and emissions in the EU. There cannot be a complete decoupling of emissions from economic growth in a fossil-fuel economy since energy demand, by and large driven by fossil fuels, remains connected to economic growth. This also means the higher the contribution from renewable energy sources the easier it will be to break the link between economic growth, energy demand and GHG emissions.

2.2 Overall results at EU level

The Paris Agreement sets out a global action plan to keep global temperature rise to below 2 °C and to drive efforts to limit the increase even further to 1.5 °C above pre-industrial levels. It is the first multilateral agreement on climate change covering almost all of global emissions and is coherent with the EU's path to a low carbon economy by 2050. Already in the past 25 years, total GHG emissions (excluding LULUCF) in the EU decreased substantially since 1990, reaching their lowest level in 2014 (Figure 2.1). The EU emitted 4 310 million tonnes of CO_2 eq. in 2015, which is 23.7 % less than in 1990, and currently accounts for less than 8 % of global GHG emissions.

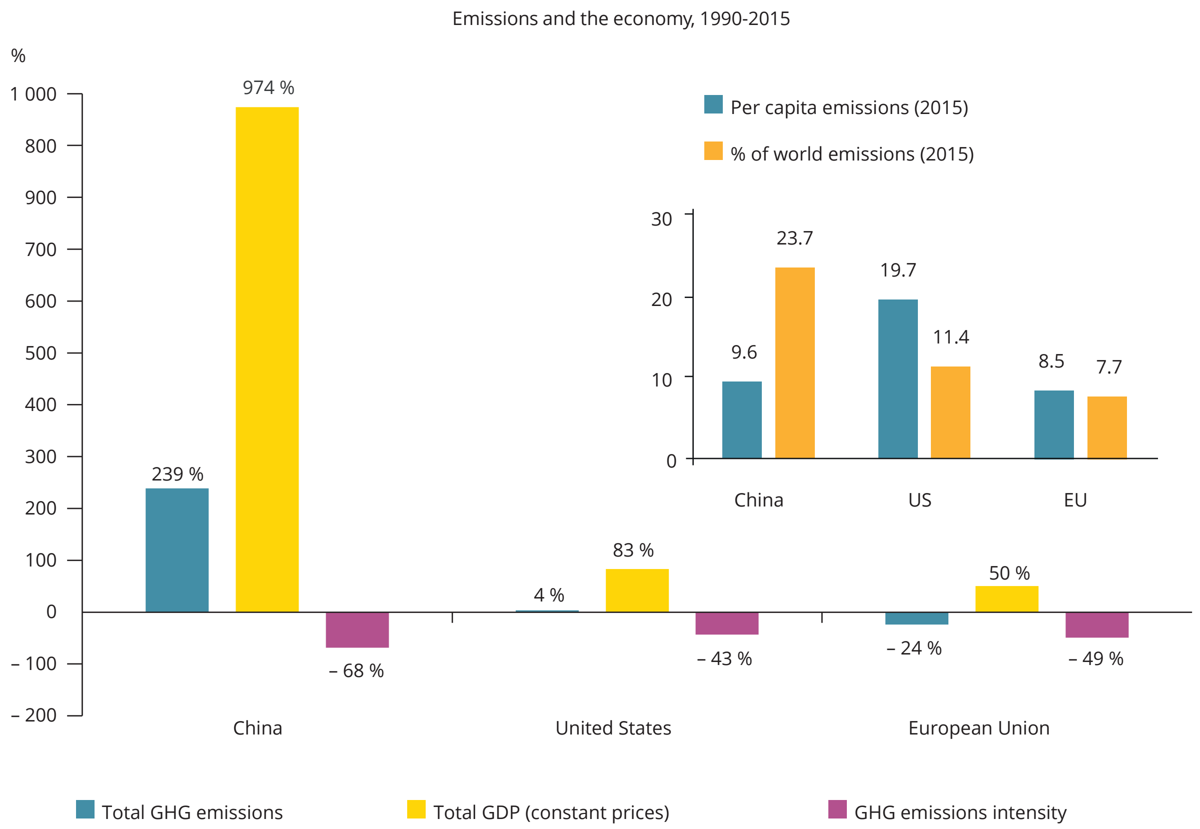
Figure 2.2 shows total GHG emissions, GDP in constant prices and the GHG intensity of the economy during the period 1990-2015, for the EU, the US and China. In all three regions, the GHG emissions intensity of the overall economy decreased over the 25-year period. In the EU, and using standard terminology, there was an absolute decoupling of emissions from economic growth, whereas in both the US and China there was a relative decoupling, with emissions increasing less rapidly than economic growth.

Figure 2.1 Total GHG emission trend in the EU-28, 1990-2015



Source: EEA.

Figure 2.2 GHG emissions, GDP and intensity in the EU, US and China



Note: GHG emissions intensity is defined as total GHG emissions excluding LULUCF divided by total GDP in constant prices. Per capita emissions is measured in tonnes of CO_2 equivalent per person.

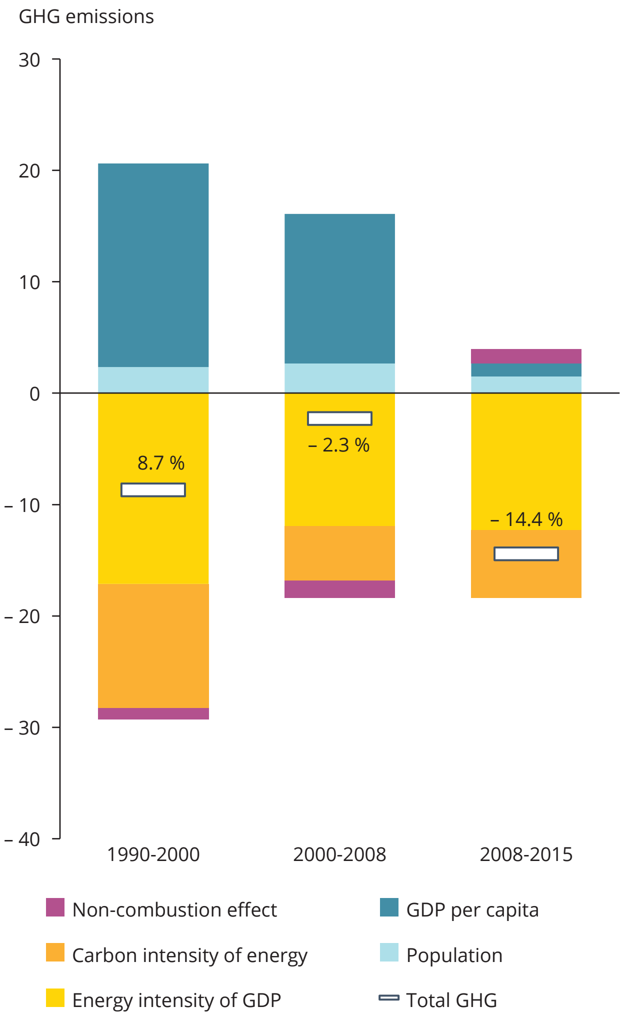
Source: EEA, based on data from EEA, JRC's EDGAR, Eurostat, UNPD and DG ECFIN's AMECO.

EU's per capita emissions stood at about 12 tonnes of CO_2 eq. in 1990 and went down to 8.5 tonnes of CO_2 eq. in 2015. The average EU citizen emits about 8.5 t CO_2-equivalent (excluding LULUCF), which is above the world average of approximately 7.6 t CO_2 equivalent per person, just below China's 9.6 t CO_2 eq. and well below per capita emissions in the United States (19.7 t CO_2 eq.). GHG emissions per capita also vary widely between European countries, mainly reflecting differences in the fuel mix for the conversion of primary fuels to heat and electricity (see Table 2.5 in Section 2.6).

Figure 2.3 breaks down the 25-year 24 % overall reduction in GHG emissions, for the three different periods, into several factors using the Kaya decomposition identity ([10]). In the first period (1990-2000) the overall reduction of GHG emissions from fossil fuel energy use was 8.7 %. Of this, lower energy intensity of GDP played the biggest role (yellow section) in bringing emissions down, as the economy required less energy per unit of GDP. The carbon intensity of energy also improved during this period, which reflects the lower use of more carbon-intensive fuels such as coal, and a switch to less carbon intensive fuels such as gas or renewables. The reduction in emissions from non-combustion sectors, such as agriculture, industrial processes and waste also contributed to the overall positive trend. These three factors driving emissions down were partially offset by higher population and by higher GDP per capita. The second period (2000-2008) was also characterised by high economic growth and lower GHG emissions. The reduction in GHG emissions was lower (2.3 %) than during the 1990s, as the improvement in the carbon intensity slowed due to less substantial reductions in coal use and declining nuclear production. In the third period (2008-2015), the GDP per capita factor was less determinant. Indeed, as the economy and industrial production first contracted and then somewhat recovered, GDP had a small negative effect on emissions and partly offset an otherwise larger decline. Of the 14.4 % overall decrease in GHG emissions from fossil fuel use, energy intensity and carbon intensity played the biggest role bringing emissions down. The reduction in energy-related emissions in this last period was stronger than for non-combustion sectors.

Overall, the four main findings from the decomposition analysis of Figure 2.3 are ([11]):

Figure 2.3 Decomposition of the cumulative changes in total GHG emissions in the EU-28 in three different periods: the 1990s, the 2000s before the recession, and post-2008



Note: The explanatory factors should not be seen as independent of each other. The bar segments show the changes associated with each factor alone, holding the respective other factors constant.

Source: EEA.

([10]) The chosen factors are an extension of the Kaya identity. The annual decomposition analysis shown in this paper is based on the Logarithmic Mean Divisia Index (LMDI) method. The equation for the aggregated decomposition analysis is:
(y) [ln]GHG = (x1) [ln]POP + (x2) [ln]GDP/POP + (x3) [ln]PEC/GDP + (x4) [ln]GHG_en/PEC + (x5) [ln]GHG/GHG_en, where:
(y) GHG: total GHG emissions; (x1) POP: population (population effect); (x2) GDP/POP: GDP per capita (affluence effect); (x3) PEC/GDP: primary energy intensity of the economy (primary energy intensity effect); (x4) GHG_en/PEC: energy-related GHG emissions in primary energy consumption (carbon intensity effect); (x5) GHG/GHG_en: total GHG emissions in energy-related GHG emissions (non-combustion effect). The non-combustion effect refers to how energy-related emissions (combustion, and fugitives) behave compared to non-energy related emissions (industrial processes, agriculture and waste sectors).

([11]) When interpreting the results from this decomposition analysis, there are certain conclusions that should not be automatically assumed. For example the factors not linked to changes in GDP should not automatically be linked to policies or other factors which are assumed to be independent from the economy. In addition, recession is broader than GDP, and there is a recession effect in 'energy intensity' (e.g. lower fuel use by industry), or in 'carbon intensity' (e.g. if recession affected relative fuel prices).

i. Emissions decreased with increasing GDP (per capita) during all periods considered (1990-2000, 2000-2008, and 2008-2015). This shows that emissions can decrease with a growing economy. But it also suggests that emissions may decrease faster with a stagnating economy, and/or a declining economy as concluded by previous EEA work ([12]). The economic recession has resulted in substantial emission reductions in the last of the three periods referred to, particularly until 2013.

ii. The lower carbon intensity of energy was a key factor underpinning lower emissions in all three periods. This factor has been stronger in the period 2008-2015 than in the period 2000-2008, despite a decline in nuclear electricity production. The lower carbon intensity during both 2005-2008 and 2008-2015 is by and large accounted for by a higher contribution from renewable energy sources in the fuel mix. In the 1990s, renewables, although still positive, contributed less to emissions reductions compared to nuclear; however, the largest factor of emission reductions was the switch between more carbon-intensive coal to less carbon intensive gas.

iii. The decrease in primary energy intensity was the largest contributing factor to lower CO^2 emissions from fossil fuel combustion in all three periods. In the period 2008-2015, total energy consumption decreased while GDP increased, leading to an improvement in the emissions intensity of energy production and use. The economic recession partly explains lower energy demand from industry and

Table 2.1 Key statistics for the variables used in the decomposition analysis of Figure 2.3

	2000/1990	2008/2000	2015/2008	Annual average 2000/1990	Annual average 2008/2000	Annual average 2015/2008
Original variables						
Total GHG (million tonnes)	– 8.7 %	– 2.3 %	– 14.4 %	– 0.9 %	– 0.3 %	– 2.2 %
POP (millions)	2.5 %	2.7 %	1.6 %	0.2 %	0.3 %	0.2 %
GDP (Mrd EUR at 2005 market prices)	24.1 %	17.7 %	2.9 %	2.2 %	2.1 %	0.4 %
Total primary energy supply (TJ)	3.7 %	4.3 %	– 9.9 %	0.4 %	0.5 %	– 1.5 %
GHG energy (million tonnes)	– 7.7 %	– 0.7 %	– 15.6 %	– 0.8 %	-0.1 %	-2.4 %
Decomposition analysis (factors): ln(total GHG) = ln(POP) + ln(GDP/POP) + ln(PEC/GDP) + ln(GHG energy/PEC) + ln(total GHG/GHG energy)						
Total GHG (million tonnes)	– 8.7 %	– 2.3 %	– 14.4 %	– 0.9 %	– 0.3 %	– 2.2 %
Population	2.3 %	2.7 %	1.5 %	0.2 %	0.1 %	0.6 %
GDP per capita	18.3 %	13.4 %	1.2 %	1.1 %	0.9 %	3.1 %
Primary energy intensity	– 17.1 %	– 11.9 %	– 12.3 %	– 1.1 %	– 0.8 %	– 3.6 %
Carbon intensity (energy sector)	– 11.2 %	– 4.9 %	– 6.1 %	– 1.0 %	– 0.5 %	– 2.0 %
Non-combustion	– 1.0 %	– 1.6 %	1.3 %	– 0.1 %	– 0.1 %	– 0.2 %

Note: The decomposition analysis used in Figure 2.3 and Table 2.1 are based on an extension of the original IPAT and Kaya identities, which are often used to illustrate the primary forces of emissions. The most important limitation from this method is that the relationship between the variables in the equation is true by definition, allowing no country-specific variation and assuming independence between the different factors. Therefore, one should avoid over-interpretation of the different effects. However, decomposition analysis can point to interesting findings, which can be explored further using other methods. The table shows the results of the multiplicative decomposition analysis where the factors are (almost) additive. For example, the carbon intensity factor contributed to 5.9 percentage points to the 14.4% reduction in GHG emissions in EU-28 between 2008 and 2015 [or 41 % of the total net reduction in GHG emissions].

Source: EEA.

([12]) See Section 7 'The role of economic growth and recession in GHG emission reductions in the EU' of 'Why did GHG emissions decrease in the EU between 1990 and 2012', published in 2014 http://www.eea.europa.eu/publications/why-are-greenhouse-gases-decreasing.

road transportation since 2008. However, energy intensity also decreased in the periods 1990-2000 and 2000-2008 where energy demand was high. Lower energy intensity of GDP can be explained by improvements in energy efficiency (transformation and end-use) and the strong uptake of renewables, as well as by changes in the structure of the economy and a higher share of the services sector compared to the more energy intensive industrial sector.

iv. The largest emission reductions occurred in the energy combustion sector. Contributions from other sectors, particularly industrial processes, waste and agriculture have also been important. In the last period, non-energy emissions decreased, though at a lower rate than energy-related.

In addition to the reduction of the energy intensity of GDP there has been a substantial improvement of the GHG emissions intensity of the EU economy as a whole. Emissions per GDP decreased substantially in all Member States during the 25-year period. This improvement came along with a significant convergence of GHG emission intensities across Member States, both per capita and per GDP ([13]). One reason for this convergence has been the extraordinary growth in renewables in most Member States and a clear move towards less carbon intensive fuels.

Table 2.1 above summarises the growth rates in the original variables and factors used in the decomposition analysis for the periods 1990-2000, 2000-2008 and 2008-2015 for the EU-28 ([14]).

2.3 Largest emission changes by sector at EU level

Table 2.2 shows the largest emission changes by key source in the EU-28 between 1990 and 2015. GHG emissions decreased in the majority of sectors between 1990 and 2015, with the notable exception of transport, including international transport. The sectors and gases ([15]) explaining the largest decreases for EU-28 were manufacturing industries and construction (CO_2), public electricity and heat production (CO_2), and residential combustion (CO_2). The sectors and gases with the largest increases over the period were road transportation (CO_2) and the consumption of HFCs in industrial processes. CO_2 emissions from international aviation and shipping also increased very rapidly during the 25-year period, although these emissions are excluded from the Kyoto targets.

The largest emission reductions in the EU with 373 million tonnes of CO_2 eq. were achieved in the production of electricity and heat. Emissions from electricity and heat production decreased strongly since 1990. The improvement in the transformation efficiency has to be seen in the context of lower heat production and higher electricity production between 1990 and 2015. In addition to improved energy efficiency there has been a move towards less carbon intensive fuels at the EU level. Between 1990 and 2015, the use of solid and liquid fuels in thermal stations decreased strongly whereas natural gas consumption doubled, resulting in reduced CO_2 emissions per unit of fossil energy generated ([16]). The steady and significant increase in biomass use for electricity and heat production has also served as a substitute for fossil fuels. This improvement in the carbon intensity of combustible fuels, with the switch from coal and oil to natural gas and biomass, is only part of the story. Some renewables can produce electricity by means of mechanical energy without any combustion. The very strong increase in other renewables, such as wind power, has led to both an improvement in transformation efficiency of the whole energy system and a positive contribution to the reduction in emissions. Nuclear generation of electricity has increased since 1990 although its share in total electricity production has fallen since 2005. This sector remains the largest contributor to GHG emissions in the EU. This trend could revert if gas prices become more attractive compared to coal. A higher carbon price (or prospects for it) should also affect the relative demand of coal to gas for power generation in the EU. Currently about 76 % of emissions from power plants come from coal, compared to 17 % for gas.

([13]) This convergence has been calculated on the basis of GDP in purchasing power standards and refers to the reduction in the coefficient of variation of Member States' GHG emissions intensities.

([14]) Looking forward, an interesting policy question is whether the same key factors driving emission reductions in the past, such as the lower GHG intensity of the economy and the improvements in the carbon intensity of the energy system, are expected to play a key role reducing emissions in the future.

([15]) Overall, emissions from CO_2 (81 % of total GHG emissions in 2015) decreased by 22 % since 1990 and accounted for 72 % of the total net reduction in GHG emissions in the EU-28 between 1990 and 2015. N_2O emissions (5 % of the total in 2015) decreased by 39 %, and accounted for 11 % of the net reduction, whereas CH_4 emissions (11 % of the total) fell by 37 % and represented 20 % of the total reduction. F-gases (almost 3 % of the total) actually increased by 64 % over the 25-year period.

([16]) The implied emission factor for coal and lignite (combined) in the EU-28 in 2015 was on average 101 tonnes of CO_2 equivalent per terajoule in 2015. The emission factor for liquid fuels was 78 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.

Table 2.2 Overview of the largest emission changes by key source in the EU, 1990-2015

Source category	Million tonnes (CO_2 equivalents)
Road transportation (CO_2 from 1.A.3.b)	142
Refrigeration and air conditioning (HFCs from 2.F.1)	97
International aviation (CO_2 from 1.D.1.a)*	73
International navigation (CO_2 from 1.D.1.b)*	25
Fugitive emissions from natural gas (CH_4 from 1.B.2.b)	– 21
Aluminium production (PFCs from 2.C.3)	– 21
Agricultural soils: direct N_2O emissions from managed soils (N_2O from 3.D.1)	– 26
Cement production (CO_2 from 2.A.1)	– 28
Fluorochemical production (HFCs from 2.B.9)	– 29
Commercial/institutional (CO_2 from 1.A.4.a)	– 43
Enteric fermentation: cattle (CH_4 from 3.A.1)	– 44
Nitric acid production (N_2O from 2.B.2)	– 45
Adipic acid production (N_2O from 2.B.3)	– 57
Manufacture of solid fuels and other energy industries (CO_2 from 1.A.1.c)	– 62
Coal mining and handling (CH_4 from 1.B.1.a)	– 67
Managed waste disposal sites (CH_4 from 5.A.1)	– 78
Iron and steel production (CO_2 from 1.A.2.a +2.C.1)	– 106
Residential: fuels (CO_2 from 1.A.4.b)	– 126
Manufacturing industries (excl. iron and steel) (energy-related CO_2 from 1.A.2 excl. 1.A.2.a)	– 279
Public electricity and heat production (CO_2 from 1.A.1.a)	– 373
Total	– 1 336

Note: The table shows only those sectors where emissions have increased or decreased by at least 20 million tonnes of CO_2 equivalent between 1990 and 2015. Emissions from manufacturing and construction decreased by 353 million tonnes of CO_2 equivalent between 1990 and 2015. The distinction with iron and steel responds to internal consistency issues of the EU inventory and reflects different reporting of activity data by Member States. International transport emissions (from aviation and shipping) are not included in the GHG total under the Kyoto Protocol. The table reflects emission changes according to the EU's geographical scope under the KP and includes Iceland.

Source: EEA.

Manufacturing and construction was the second largest source of emission reductions in absolute terms in the EU between 1990 and 2015 (353 million t CO_2 eq.) ([17]). A combination of factors explain lower emissions in industrial sectors, such as improved efficiency in restructured iron and steel plants, substantial improvements in the carbon intensity, with emissions from solid fuels more than halving in 25 years, and structural changes of the economy with a higher share of services and a lower share of more-energy-intensive industry in total GDP. Trade is also important for understanding GHG emission trends. While Europe may be indirectly generate some of the emissions elsewhere — exported EU emissions — a share of Europe's own emissions can be traced to consumption of European goods in some of Europe's main trading partners — imported EU emissions ([18]). The energy and carbon intensity of the production of goods and services will by and large determine the real shares of exported and imported emissions. Finally, the economic recession

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

([18]) Climate change - driving forces, Eurostat 2017 http://ec.europa.eu/eurostat/statistics-explained/index.php/Climate_change_-_driving_forces.

that began in the second half of 2008 and continued through to 2009 also had a substantial impact on emissions from this sector.

Emissions in the residential sector decreased by 126 million t CO_2 eq. between 1990 and 2015 and represented the third largest reduction. Energy efficiency improvements from better insulation standards in buildings and a less carbon-intensive fuel mix can explain lower demand for space heating in the EU as a whole over the past 25 years. These factors have more than offset the effects of a population increase of 33 million, and in the number and average size of households in the EU. Emissions from the residential sector fluctuate according to weather conditions and heat demand. The years 2014 and 2015 were the hottest years on record in Europe with mean annual land temperatures about 2 °C above the pre-industrial average. In the last 25 years since 1990 there has been a warming of the winter/autumn months in Europe which has partly contributed to lower heat demand by households and therefore to lower GHG emissions (see Figure 2.9).

On the negative side, CO_2 emissions from road transportation increased by 142 million tonnes in the 25-year period. Emissions increased steadily between 1990 and 2007, decreased up to 2013 and increased again in 2015. The overall net increase was fully accounted for by a strong uptake of diesel and a decline in gasoline use. Energy efficiency improvements and to a lesser extent increased use of less carbon intensive fuels, such as liquefied petroleum gas (LPG) and biofuel blends, have led to levels of road transport emissions that would have been otherwise higher. The economic recession that started in 2008 has also contributed to lower road transport emissions (for freight and passenger) in the last years. Despite these improvements in efficiency and carbon intensity, demand has grown substantially and road transport still represented about 20 % of total GHG emissions in the EU in 2015. Transport roughly represents about one third of emissions from the sectors not covered by the EU ETS. Thus, transport emissions would need to fall significantly if Member States are to meet their limitation targets under the Effort Sharing Decision for non-trading sectors by 2020 compared to 2005.

The second largest increase came from hydrofluorocarbons (HFCs) used in refrigeration and air conditioning (97 million tonnes of CO_2 eq.). HFCs were the only group of gases for which emissions increased since 1990 and accounted for 2.5 % of total EU GHG emissions in 2015. This increase has been a side effect from the implementation of the Montreal Protocol on ozone depleting substances. The banning of Montreal Protocol CFCs, both ozone-depleting substances and potent GHGs, led to new substitutes and their replacement with Kyoto Protocol HFCs. HFCs are used in the production of cooling devices such as air conditioning systems and refrigerators and the increase is consistent with both warmer climatic conditions in Europe (i.e. summers) and higher standards of comfort demanded by citizens. After the 2016 amendment under the Montreal Protocol signed in Kigali, countries committed to cut the production and consumption of these group of gases by over 80 % over the next 30 years. HFCs are regulated under both the Kyoto Protocol and the Montreal Protocol.

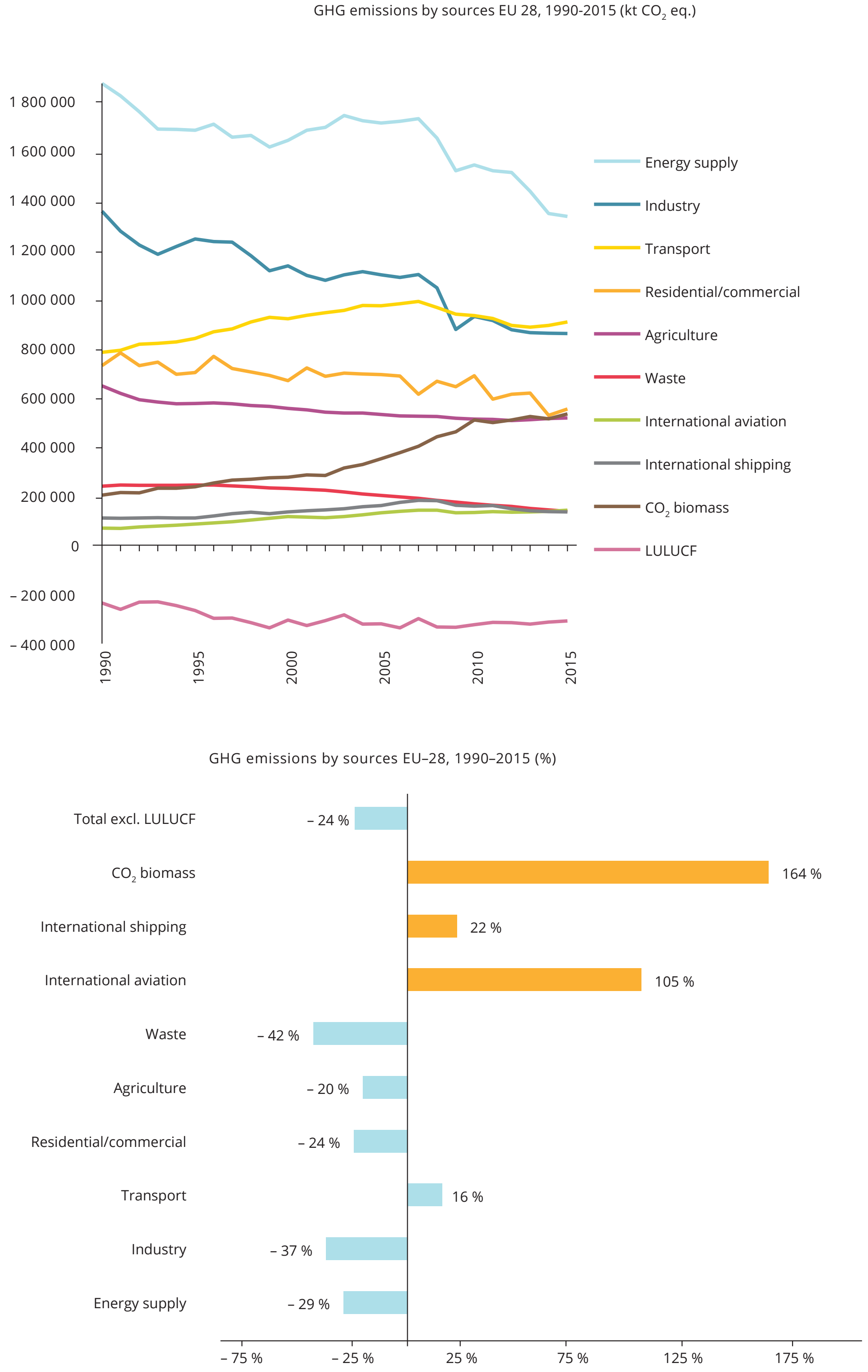
Figure 2.4 shows GHG emissions by sources and sinks in the EU-28 between 1990 and 2015. The top chart shows the emissions by sector over the 25-year period for the EU-28. The effect of the economic recession is clearly visible in energy supply and industry from 2008 onwards. The downward emission trend in the residential and commercial sectors fluctuates over the time series, generally reflecting the effect of warmer or colder winters on heat demand. In the case of transport, emissions increased substantially until 2007 and have declined somewhat in the past years, although they increased again in 2014 and 2015.

Of all trends, perhaps the most interesting ones are the increase in emissions from international aviation and international shipping as well as the stark increase in CO_2 emissions from biomass. The increase in these three emission sources is more visible from the bottom chart. What they have in common is the fact that neither of them are included in national GHG totals and are excluded from Kyoto targets (depicted by the red bars), and that their emissions have increased more than the sectors included in national GHG totals (depicted by the blue bars).

Emissions from international aviation and maritime transport are not relevant for Kyoto compliance. They are reported in GHG inventories as 'Memorandum items' and are therefore not included in national GHG totals. Contributions from international aviation and shipping increased by 97 million tonnes between 1990 and 2015. Together, the two sectors in 2015 accounted for about 6 % of total EU GHG emissions. Emissions from international aviation have been included in the EU ETS since 2012. A decision on the inclusion of GHG emissions from international maritime transport has not been taken so far.

CO_2 emissions from biomass combustion increased by 332 million between 1990 and 2015, highlighting the rapidly increasing importance of bioenergy in replacing fossil fuel sources. In addition, net removals from land use, land use change and forestry (LULUCF)

Figure 2.4 GHG emissions by aggregated sector in EU-28, 1990-2015



Notes: Indirect CO_2, sector CRF 1A5 (mostly including emissions from military use) and sector 6 'other' are not included in the graph and represented a combined 0.2 % of total GHG emissions in 2015. The red bars denote items not included in national GHG totals and therefore excluded from Kyoto targets. The sectoral aggregations in the top chart are: Energy supply: CRF 1A1 (energy industries) + 1B (fugitives); industry: CRF 1A2 (manufacturing industries and construction) + CRF 2 (industrial processes); transport: CRF 3; residential and commercial: CRF 1A4a (commercial) + CRF 1A4b (residential); agriculture: CRF 1A4c (agriculture, forestry and fishing) + CRF 3 (agriculture); waste: CRF 5 (waste); LULUCF: CRF 4 (LULUCF); international aviation, international shipping and CO_2 biomass are Memorandum items not included in national totals.

Source: EEA.

increased in the EU over the same 25-year period ([19]). Based on the 2017 EU GHG inventory, net removals increased by about 31 % in the EU 28 between 1990 and 2015 and the net sink has increased from 4.3 % of total net GHG emissions in 1990 to 7.6 % in 2015. In 2015, net removals from the LULUCF sector in the EU 28 amounted to 305 million tonnes of CO_2 equivalent. The key driver for the increase in net removals is a significant build-up of carbon stocks in forests. Environmental policies have also resulted in less intensive agricultural practices and an increase in forest and woodland conservation areas for the purpose of preserving biodiversity and landscapes.

However, biomass can only reduce GHG emissions effectively if it is produced in a sustainable way. There is growing concern about the environmental and climatic integrity of biomass as a source of energy, with consumption from both domestic production and imports from third countries growing very rapidly. According to Eurostat's energy statistics, solid biomass represents about three quarters of all biomass consumed in the EU, with both biogas and liquid biofuels accounting for the remaining 25 %. According to the same energy statistics, about 95 % of all biomass consumed in Europe in 2015 was produced in Europe. However, biomass imports are growing very rapidly, not only for liquid biofuels, where there are mandatory sustainability criteria ([20]), but also for woody biomass, where such binding criteria are yet to be agreed at EU level.

In 2016, the European Commission presented a legislative proposal to integrated GHG emissions and removals from LULUCF into the 2030 climate and energy framework and the 2030 emission reduction target. In this proposal, energy-related biomass emissions will count towards each Member State's 2030 commitments.

2.4 EU policies and GHG emission reductions

In addition to key drivers such as improved energy efficiency, improved GHG intensity and the strong increase in renewables, a number of policies have also played a key role in GHG emission reductions. The paragraphs that follow are a non-exhaustive list of international and EU-wide policies underpinning lower GHG emissions in the EU-28 between 1990 and 2015.

All GHGs

- The Kyoto Protocol to the UNFCCC is the main international instrument to reduce GHG emissions not controlled by the Montreal Protocol, although it only commits developed Parties who agreed to take on these binding emission reduction targets under the principle of 'common but differentiated responsibilities'. The Protocol was adopted in 1997 and entered into force in 2005. The first commitment period started in 2008 and ended in 2012. The EU-15 was Party to the first period of the Protocol, with a joint commitment to reduce GHG emissions by 8 % compared to base year.

- The 'Doha Amendment to the Kyoto Protocol' was adopted in 2012 and included new commitments for the period between 2013 and 2020. The EU-28 and Iceland agreed to fulfil their commitments jointly and reduce emissions by 20 % compared to the base year.

- Looking further ahead, the Paris Agreement entered into force on 4 November 2016. The Agreement, which sets out a global action plan to keep global temperature rise to below 2 °C and to drive efforts to limit the increase even further to 1.5 °C above pre-industrial levels, is the first multilateral agreement on climate change covering almost-all of global emissions. The EU's path towards a low carbon economy by 2050 is also consistent with the Paris agreement.

Ozone-depleting substances (ODS) and fluorinated gases (F-gases)

- The Montreal Protocol on ozone-depleting substances (ODS) has been one of the most successful multilateral environmental (and indirectly climatic) agreements to date, contributing to substantial GHG emissions reductions in Europe and worldwide. Many of the substances

([19]) Net LULUCF emissions and/or removals and 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.

([20]) The Renewable Energy Directive provides a sustainability framework at the EU level for liquid biomass used for transport, electricity, heating and cooling. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (OJ L 140, 5.6.2009, p. 16).

addressed in the Montreal protocol such as chlorofluorocarbons (CFCs) are also potent GHGs. The banning of CFCs led to an increase in the consumption of substitute gases such as HFCs, regulated under the Kyoto Protocol, and where emissions at EU level have increased substantial since 1990, to represent about 2.5 % of total GHG emissions in 2015. Indeed, the consumption of HFCs recorded the second largest increase of emissions after CO_2 emissions from road transportation ([22]), even though they remain small in relation to other GHGs.

- In 2016, the Montreal Protocol was amended in Kigali, where countries committed to cut the production and consumption of HFCs by over 80 % over the next 30 years. HFCs are regulated under both the Kyoto Protocol and the Montreal Protocol, with the latter having a global coverage.

- EU legislation on F-gases also aimed at controlling GHG emissions. For instance, the EU's 'MAC Directive' prohibits the use of F-gases with a global warming potential (GWP) of more than 150 times greater than CO_2 in new types of cars and vans registered after 2011, and in all new cars and vans produced from 2017. A new EU F-gas regulation from 2015 establishes that by 2030 the EU's F-gas emissions should be reduced by two-thirds compared with 2014 levels.

Air pollutants and co-benefits

The EU's Large Combustion Plant Directive also had a significant effect on lower emissions, not only of air pollutants but also of greenhouse gases. The setting up of limit values on certain pollutants (i.e. gases which may be acidifying substances, ozone-precursors and/or particles) has encouraged efficiency improvements and fuel switching from solid fuels to cleaner fuels. These improvements have also highlighted the co-benefits of air pollution and climate policies.

Methane (CH_4) and nitrous oxide (N_2O) from agriculture and waste

The two largest non-CO_2 GHGs are CH_4 and N_2O, accounting for 11 % and 5 % of total GHG emissions, respectively. The reduction in CH_4 emissions over the past 25 years reflects lower levels of coal mining and post-mining activities as well as lower emissions from managed waste disposal on land. There has also been a very significant reduction in CH_4 emissions from agricultural livestock, due to a reduction in numbers but also to changes in the agricultural management of organic manures. N_2O emissions decreased substantially in adipic acid production (a precursor in the production of nylon) due to abatement techniques implementing by industry and in adipic acid production (used in the production of fertilisers). There were also substantial reductions in N_2O emissions from agricultural soils and nitric acid production.

Key EU polices such as the Nitrates Directive, the Common Agriculture Policy (CAP) and the Landfill Waste Directive have been successful in reducing greenhouse gas emissions from methane and nitrous oxides.

- The EU Nitrates Directive, which aims to reduce and prevent water pollution caused by nitrates from agricultural sources, has had a significant positive impact on greenhouse emissions. The directive addresses the use of synthetic and nitrogen-based fertilisers. Lower use of fertilisers per cropland combined with lower cropland area led to substantial reductions in N_2O emissions from agricultural soils.

- The first pillar of the EU Common Agriculture Policy (CAP), dealing with market support, had a strong impact through the milk quota system by reducing animal numbers in the dairy sector to compensate for increasing animal productivity. The CAP also had a very strong effect on emissions, particularly of CH4 from enteric fermentation. Overproduction control through 'milk quotas' has limited the economic attractiveness of cattle production in the EU and has incentivised higher milk yield to sustain production levels with less cattle. The so-called 'agro-environmental schemes' have also provided incentives to limit overproduction of arable crops. The CAP and rural development programs have also stimulated less intense agricultural practices and a general decrease of area of the utilized arable land, compensated by the increase in forest and urban areas. The 'Natura 2000 network' also supported the increase of forest and woodlands area under conservation regime with the purpose of preserving biodiversity and landscapes.

([22]) HFC emissions from air-conditioning systems in motor vehicles are of concern because HFC-134a is the largest contributor to total HFCs emissions and has a global warming potential (GWP) 1 430 times stronger than CO_2. In Europe, however, the use of HFC-134a for mobile air-conditioning in new cars will be phased out between 2011 and 2017. From January 2011, EU Member States should no longer grant EC type-approval or national type-approval for a type of vehicle fitted with an air conditioning system designed to contain fluorinated GHGs with a GWP higher than 150, and from January 2017, Member States will have to refuse registration and prohibit the sale of such new vehicles.

- The EU's Landfill Waste Directive, which requires Member States to reduce the amount of biodegradable waste landfilled, has intensified separate collection, recycling and pre-treatment of waste, as well as landfill-gas recovery by Member States. This has led to significant reductions in CH4 emissions from solid waste disposal of biodegradable waste on land. The EU's Waste Framework Directive laid down basic waste management principles and introduced a hierarchy that MS have to apply as a priority order, starting with prevention, preparing for re-use, recycling, recovery and finally disposal. The recent 'Circular Economy Package' includes revised legislative proposals on waste to further increase re-use and recycling and limit landfilling, which aims at using resources in a more sustainable way and should contribute to the transition to a low carbon economy.

Carbon dioxide (CO_2) in energy production and use as well as industrial processes

Even though the reduction in N_2O and CH_4 emissions in the EU have been large, the largest reduction in GHG emissions was in terms of CO_2 in the energy sector, which represents 81 % of total GHG emissions. The reductions were mainly linked to improved GHG intensity, less carbon intensive fossil fuels and renewables, as well as improvements in energy efficiency in the past 25 years. The key policy strategy is the '2020 climate and energy package'. Looking further ahead, key strategies include the '2030 climate and energy framework' and the 'Energy Union'.

The current climate and energy framework: 2020

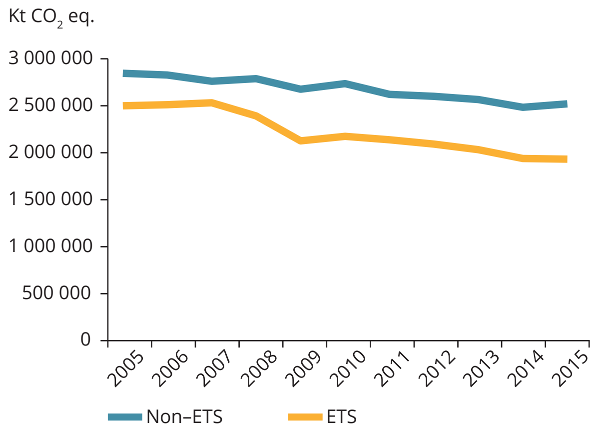
The '2020 climate and energy package', adopted in 2009, including the 'Europe 2020 strategy'. The EU committed to a reduction of 20 % in its GHG emissions, a 20 % share of renewables and a 20 % improvement in energy efficiency by 2020 compared to 1990. Some key 2020 climate mitigation policies include:

- The EU's climate mitigation policy framework is based on a distinction between GHG emissions from large industrial sources, which are governed by the EU emissions trading system (ETS), and emissions from the other sectors, covered by the Effort Sharing Decision (ESD) and where national targets apply ([23]). Overall, the sectors covered by the EU Emissions Trading System (EU ETS) contributed more to the overall emissions reduction, particularly between 2008 and 2012 (i.e. during the first commitment period under the Kyoto Protocol) than the non-trading sectors (i.e. those outside the EU ETS). ETS emissions increased faster than non-ETS emissions during the first phase of the EU ETS between 2005 and 2007 (Figure 2.5). This period also coincided with larger consumption of hard coal and lignite for power generation. The overall EU ETS cap for the period 2008-2012 put a limit to emissions from installations by setting the maximum amount of emissions allowed during the 5-year period. By design, the EU ETS has contributed to the overall GHG emission reductions. The effects of the economic crisis which resulted in even lower emissions than expected also resulted in the accumulation of a large surplus of allowances. In comparison, the bulk of the decrease in non-ETS emissions in this period was due to lower consumption of gas and liquid fuels in the residential sector, and lower consumption of gasoline and diesel in road transportation. As explained in Chapter 1, the net increase in GHG emissions in 2015 came from key sectors mostly outside of the EU ETS (road transportation and residential/commercial), whereas emissions from EU ETS installations decreased that year.

- The directive setting a common EU framework for the promotion of energy from renewable sources establishes an overall policy for renewables in order to reach the 20 % target by 2020, including national renewable energy targets for each country. Indeed, one of the key European success stories has been the deployment of renewable energy sources by Member States, which started well before the directive was adopted. There has been a strong

([23]) The 2009 package underlines the objective of limiting the rise in global average temperature to no more than two degrees Celsius above pre-industrial levels. To achieve this goal, the EU committed to a unilateral emission reduction target of 20 % by 2020, compared with 1990 levels. The main instruments to reduce emissions under the Climate and Energy Package are the EU Emissions Trading System, covering more than 11 000 power stations and industrial plants in 31 countries, as well as airlines, and the Effort Sharing Decision for sectors not included under the EU ETS. Both trading (i.e. EU ETS) and non-trading sectors are to contribute to the 20 % objective. Minimising overall reduction costs implies a 21 % reduction in emissions from EU ETS sectors compared to 2005 by 2020, and a reduction of approximately 10 % compared to 2005 by 2020 for non-EU ETS sectors. Emissions from international aviation have been included in the EU ETS since 2012. A decision on the inclusion of GHG emissions from international maritime transport has not been taken so far. The non-ETS sectors fall under the scope of the so called Effort Sharing Decision, which establishes binding annual greenhouse gas emission targets for Member States for the period 2013-2020. These targets concern emissions from most sectors not included in the EU Emissions Trading System, such as transport (except aviation and international maritime shipping), buildings, agriculture and waste. The non-trading sectors currently represent almost 60 % of total greenhouse gas emissions.

Figure 2.5 **GHG emissions in the EU ETS and non-ETS sectors in the EU-28 between 2005 and 2015**



Note: Non-ETS emissions have been calculated by subtracting scope-corrected ETS emissions, CO_2 from domestic aviation and NF_3 emissions from total GHG emissions excluding LULUCF and including indirect CO_2 emissions. International aviation has been included in the ETS (using GHG inventory data). The data across different ETS trading-periods are comparable. A scope-correction has been applied since 2005 to reflect the current scope of the EU ETS, incorporating successive changes in terms of countries, activities and gases. More information can be found on the EEA website http://www.eea.europa.eu/data-and-maps/data/data-viewers/emissions-trading-viewer.

Source: EEA.

uptake of renewables for electricity, heating and transport, which have doubled since 1990. The share of renewables in gross final energy consumption (normalised to even out the annual variability in hydro and wind production) stood at 16.7 % in 2015, according to Eurostat figures. Growing concern about the environmental/climatic integrity of (all types) of biomass as a source of energy and the very rapid growth in the use of biomass resulted in the new LULUCF proposal, as explained below.

- The Energy Efficiency Directive sets rules and binding measures to help the EU reach the 20 % energy efficiency target by 2020. The Directive requires that all EU countries use energy more efficiently throughout the energy chain, from production to final consumption. A key element of the directive is that Member States have to establish a long-term strategy to mobilise investment in the renovation of the national stock of residential and commercial buildings. The directive also promotes higher efficiency in heating and cooling. As mentioned earlier, one of the explanations for somewhat decreasing overall fuel use in the residential sector has been the lower demand for space heating due to better insulation standards in new buildings as well as the retrofitting and more efficient heating appliances. The increasing size of the new housing stock relative to the existing stock and improvements in existing buildings will reinforce this positive effect.

- The 2020 package also set the first legally-binding standards for CO_2 emissions from new passenger cars. The first Regulation [(EC) No 443/2009] introduced mandatory CO_2 emission performance standards for new passenger cars, with the setting of a CO_2 emission target of 130 g CO_2/km by 2015 and of 95 g CO_2/km to be phased in from 2020. These targets refer to the average value for the fleet of newly registered passenger cars in the EU. A more recent Regulation (EU) No 510/2011 introduced mandatory CO_2 emission performance standards for new vans, with a CO_2 emission target of 175 g CO_2/km by 2017 and of 147 g CO_2/ km by 2020. These targets refer to the average value for the fleet of newly registered vans in the EU. According to the latest report by EEA ([24]), the average CO^2 emissions level of new cars sold in 2015 was 119.5 g CO_2/km, well below the 2015 target of 130 g CO_2/ km. The average emission of new light commercial vehicles in 2015 was 168.3 g CO_2/km, which is also below the 2017 target of 175 g CO_2/km by 2017. Car and van manufacturers will have to keep reducing emissions levels to meet the targets of 95 g CO_2/km and 147 g CO_2/km, respectively. Because of the volume of newly registered vehicles to the total fleet these mitigation measures will take time to have a substantial effect in reducing GHG emissions from the transport sector.

Clearly, Member States' own policies can be complementary and/or additional to EU polices. The effects of EU policies cannot always be distinguished from the effects implemented at national level. Also, the integration/mainstreaming of environmental and climate concerns into the design and implementation of other policies makes it difficult to quantify the individual effects of each policy because of confounding effects.

According to information reported to the EEA by Member States, a number of EU-related policies are expected to deliver significant emission savings through implementation at national level, and in

([24]) CO_2 emissions from cars and vans: all larger manufacturers met their 2015 targets', EEA. http://www.eea.europa.eu/highlights/co2-emissions-from-cars-and.

particular in the areas of energy generation and energy efficiency. The largest expected emission savings by 2020 comes from the implementation of the EU renewable energy Directive. The second largest emission savings are expected form the EU ETS Directive. Much of the CO_2 emitted in Europe nowadays comes from combustion and industrial installations under the EU ETS. Emissions are expected to continue declining as a result of improvements in energy efficiency and fuel switch motivated by the restricted supply of emission allowances. The third largest group of emission savings are linked to different policies linked to energy efficiency. This means that in the sectors not covered by the EU ETS, for which Member States have national annual targets under the ESD and will have under the Effort Sharing Regulation (ESR), energy efficiency measures are expected to play an important role in reducing emissions. Of course, effective and full implementation of policies and measures is key to the delivery of these emission reductions. Some Member States will rely on the implementation of planned policies that have not yet been adopted to ensure they reach their annual objectives under the ESD.

The future climate and energy framework: 2030 and beyond

Building from the 2020 climate and energy package, the European Council adopted the '2030 climate and energy framework'. The framework includes legislative proposals related to the ESR across Member States and LULUCF as well as a Communication on decarbonising transport. It also includes a whole range of legislative proposals to lead the clean energy transition and modernise the economy, while increasing growth and job creation.

The headline targets proposed by the Commission are: a 40 % reduction in greenhouse gas emissions by 2030 (Effort Sharing Regulation and LULUCF proposals); a share of renewable energy in the EU final energy consumption of at least 27 % by 2030; and a binding EU-wide target of 30 % for energy efficiency by 2030.

- In July 2015, the Commission presented a legislative proposal to revise the EU ETS for the period after 2020. This is consistent with the EU's target to reduce overall GHG emissions by at least 40 % domestically by 2030. To achieve the overall GHG emission reduction, the sectors covered by the ETS have to reduce their emissions by 43 % compared to 2005.

- The proposed Effort Sharing Regulation (ESR) translates the 40 % commitment into binding annual greenhouse gas emission targets for each Member State for the period 2021-2030, based on the principles of fairness, cost-effectiveness and environmental integrity. The resulting 2030 targets range from 0 % to – 40 % compared to 2005 levels. The 2030 framework is an EU priority linked with the Paris Agreement and is consistent with the longer term objective of the '2050 low-carbon economy roadmap' ([25]), which sets the EU's ambition to reduce its GHG emissions by 80 % compared to 1990, with milestones of 40 % by 2030 and 60 % by 2040.

- In 2016 the European Commission presented a legislative proposal to integrate GHG emissions and removals from LULUCF into the 2030 climate and energy framework, since all sectors should contribute to the EU's 2030 emission reduction target, including the land use sector. The LULUCF proposal sets a binding commitment for each Member State to ensure that accounted emissions from land use are fully offset by CO_2 removals (i.e. 'no debit rule'). Energy-related emissions from biomass will count towards each Member State's 2030 climate commitments.

- The Commission also proposed a revised Renewable Energy Directive to make the EU a global leader in renewable energy and ensure that the target of at least 27 % renewables in the final energy consumption in the EU by 2030 is met.

- Also as part of the 2030 framework, the Commission put forward a proposal to update the Energy Efficiency Directive, including a new 30 % energy efficiency target for 2030.

Finally, the key overarching political strategy for Europe to bring about the transition to a low-carbon, secure and competitive economy is the Energy Union Framework Strategy ([26]), which includes objectives to reduce energy demand, improve energy efficiency and decarbonise the energy mix. It has three over-arching objectives: secure, competitive and sustainable; and five specific objectives: expand security of energy supply; connected EU energy

([25]) In 2011, the European Council reconfirmed the EU objective of reducing GHG emissions by 80-95 % by 2050 compared to 1990. The European Commission's Communication 'a Roadmap for moving to a competitive low carbon economy in 2050' suggests that all sectors should contribute to this objective and by 2050, the EU should cut GHG emissions to 80 % below 1990 levels, with milestones of 40 % emissions cuts by 2030 and 60 % by 2040.

([26]) European Commission Communication 'A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy' http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2015%3A80%3AFIN.

market; reducing energy demand and improving energy efficiency; decarbonising the energy mix; and to increase research and development.

By 1 January 2019 Member States shall report to the Commission an integrated national energy and climate plan covering the period 2021-2030 and addressing the five key dimensions of the Energy Union. The focus should be on actions to meet the targets under the 2030 EU Climate and Energy Framework.

There is also a proposal for a Governance Regulation to deliver on the Energy Union objectives and ensure that the EU and its Member states also meet their commitments under the Paris Agreement. The proposed Regulation foresees Commission recommendations to Member States related to climate and energy policies, and is complementary to the European Semester, which provides a framework for the coordination of economic policies across the EU, and focuses on recommendations linked to macro-economic issues. To ensure that both processes are consistent, the integrated national energy and climate plans should consider the latest country-specific recommendations from the European Semester.

2.5 Largest Member State contributions to the positive EU performance

Figure 2.6 shows the absolute emission increase or reduction by Member States between 1990 and 2015. About 48 % of the EU net decrease in GHG emissions was accounted for by Germany and the United Kingdom.

The main reasons for the favourable trend in Germany were increasing efficiency in power and heating plants and the economic restructuring of the five new Länder after the reunification of Germany, particularly in the iron and steel sector. Other important reasons include the improvement in the carbon intensity of fossil fuels (from coal to gas), the strong increase in renewable energy use, and waste management measures that reduced the landfilling of organic waste ([27]). Lower GHG emissions in the United Kingdom were primarily the result of liberalising energy markets and the subsequent fuel switch from oil and coal to gas in electricity production. Other reasons include the shift towards more efficient combined cycle gas turbine stations (CCGT), decreasing iron and steel production and the implementation of methane recovery systems at landfill sites ([28]).

Table 2.3 shows the top 25 contributors to the reduction in GHG emissions at Member State level in the EU in 2015. All these together can explain 63 % of the total reduction in EU emissions in 2015. One should inevitable analyse the reasons underpinning the reduction in emissions in the sectors and countries mentioned in table 2.3 to better understand the reasons underpinning the reduction in GHG emissions in the EU as a w hole. This goes beyond the scope of this paper ([29]).

2.6 The economy and the link to GHG emissions

The EU-28 has reduced total GHG emissions (excluding LULUCF) by 24 % between 1990 and 2015, while GDP has increased by 50 % (left side of Figure 2.7). However, the apparent decoupling of emissions and GDP (relative to 1990) does not imply that the link between GDP and GHGs is broken (right side of Figure 2.7). There is some degree of correlation, or coupling, when looking at GDP and GHG emissions on an annual basis. In a previous EEA analysis ([30]), GDP was shown to be one of several key drivers of GHG emissions, with other factors and policies contributing to the decline. The 2014 analysis also showed that the strength of the relationship between GHG emissions and economic growth varies across countries. This relationship is, on average, stronger in periods of economic recession than during periods of positive economic growth ([31]).

([27]) These are just some of the many drivers of lower GHG emissions in Germany. As in other Member States, the economic recession also had a significant effect in GHG emissions. Other relevant emission drivers can be found in Germany's National Inventory Report submitted to UNFCCC in 2017 http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/10116.php.

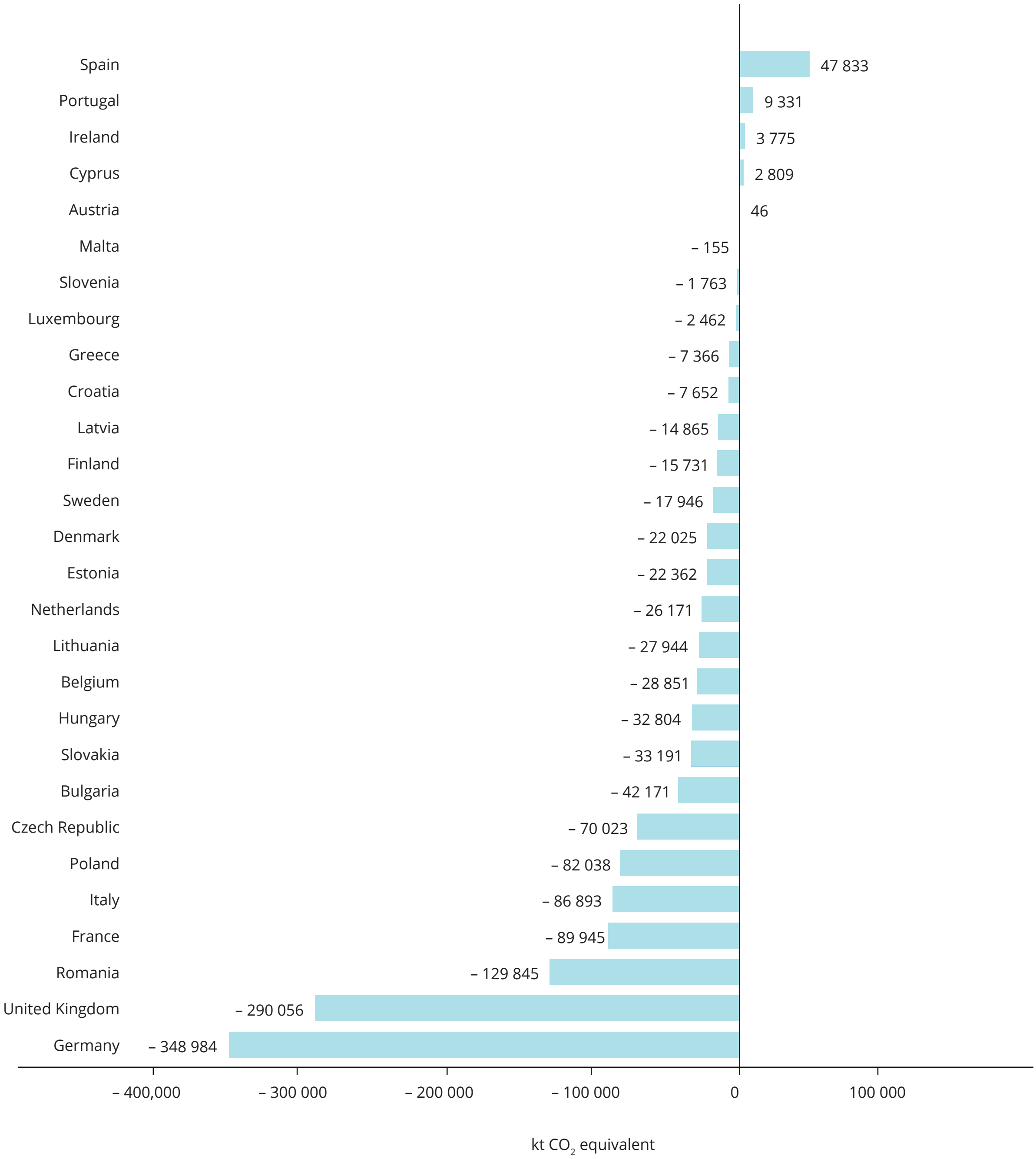
([28]) For a more detailed description of emission drivers, see the United Kingdom's 2017 National Inventory Report to UNFCCC http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/10116.php.

([29]) Whereas the EU GHG inventory is a bottom up process starting from Member States' GHG inventories, the analysis of emission trends at EU level is a top-down process. The effect of drivers, including policies, on EU GHG emissions is larger the bigger the Member State. Table 2.3 shows indeed that the majority, although not only, of the top-25 contributors is accounted for by the larger EU Member States. Some of the drivers may be common across Member States (e.g. implementation of EU legislation, economic crisis, weather patterns, energy efficiency and carbon intensity improvements, etc). However, there are also country-specific drivers, policies and measures at play that need a more detail analysis to understand both the cause and effect on total EU emission reductions.

([30]) For an overview of the effect of GDP on GHG emissions, see Section 7 of 'Why did GHG emissions decrease in the EU between 1990 and 2012' http://www.eea.europa.eu/publications/why-are-greenhouse-gases-decreasing.

([31]) When GDP goes down GHG emissions usually go down. However, when GDP increases GHG emissions can either increase or decrease. One reason to explain why GHG emissions are more sensitive to periods of recession is the coupling of energy demand, GHG emissions and economic activity for coal-based industrial installations. There are options for breaking this link: less carbon intensive fossil fuels; more renewables (or nuclear) in the fuel mix; improvements in energy efficiency; structural changes in the economy, and reducing final energy demand. There can be a different type of economic growth, which is low-carbon based, and which effectively breaks the relationship between GHG emissions and the economy.

Figure 2.6 Change in total GHG emissions, excluding LULUCF, between 1990 and 2015 by EU Member State (kt CO_2 equivalent)



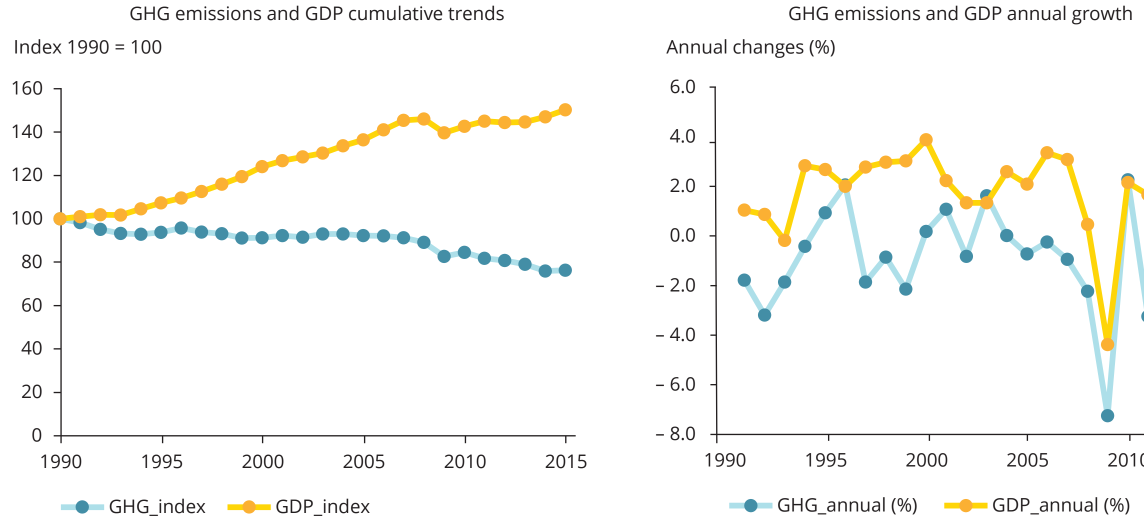
Source: EEA.

Table 2.3 Top 25 contributors to the total GHG emission reduction in the EU between 1990 and 2015

Ranking in top 25	Member State	Sector	Gas	Reduction (kt)	% total EU reduction
1	United Kingdom	Electricity and heat production	CO_2	– 99 799	7.5 %
2	Poland	Electricity and heat production	CO_2	– 74 371	5.6 %
3	Germany	Industrial combustion (excl. iron/steel)	CO_2	– 62 438	4.7 %
4	Germany	Manufacture of solid fuels	CO_2	– 55 131	4.1 %
5	United Kingdom	Managed waste disposal	CH_4	– 48 135	3.6 %
6	Germany	Residential combustion	CO_2	– 43 272	3.2 %
7	Romania	Electricity and heat production	CO_2	– 39 287	2.9 %
8	Germany	Electricity and heat production	CO_2	– 36 746	2.7 %
9	United Kingdom	Industrial combustion (excl. iron/steel)	CO_2	– 33 913	2.5%
10	Romania	Industrial combustion (excl. iron/steel)	CO_2	– 32 334	2.4 %
11	Germany	Commercial combustion	CO_2	– 29 587	2.2 %
12	Italy	Electricity and heat production	CO_2	– 28 441	2.1 %
13	Czech Republic	Industrial combustion (excl. iron/steel)	CO_2	– 28 169	2.1 %
14	Germany	Managed waste disposal	CH_4	– 25 300	1.9 %
15	Italy	Industrial combustion (excl. iron/steel)	CO_2	– 25 004	1.9 %
16	Germany	Coal mining	CH_4	– 22 457	1.7 %
17	France	Industrial combustion (excl. iron/steel)	CO_2	– 21 790	1.6 %
18	United Kingdom	Coal mining	CH_4	– 20 434	1.5 %
19	France	Electricity and heat production	CO_2	– 18 249	1.4 %
20	Estonia	Electricity and heat production	CO_2	– 18 190	1.4 %
21	Germany	Adipic acid production	N_2O	– 17 826	1.3 %
22	Czech Republic	Iron and steel production	CO_2	– 15 703	1.2 %
23	United Kingdom	Residential combustion	CO_2	– 14 799	1.1 %
24	Denmark	Electricity and heat production	CO_2	– 14 443	1.1 %
25	United Kingdom	Fluorochemical production	HFCs	– 14 376	1.1 %
Sum of top 25	–	–		– 840 195	62.8 %
EU total net reduction	–	all sectors excluding LULUCF	GHG	– 1 337 450	100.0 %

Source: EEA.

Figure 2.7 Annual and cumulative changes in GDP and GHG emissions at EU level, 1990-2015



Source: EEA. GDP based on the 2017 Spring Forecasts by the European Commission (AMECO database).

Notwithstanding the complexity of inferring a cause-effect relationship at Member State level ([32]), EU economies can grow and emissions decrease, alongside a growing share of renewables, less carbon intensive fuels in the energy mix and improvements in energy efficiency. The reliance on coal, gas and oil remains high but has decreased from 83 % in 1990 to about 73 % of primary energy in 2015.

Even though the trends are encouraging, emissions should increase alongside GDP, on average, if the EU continues relying on fossil fuels to meet the majority of its final energy demand. Shifting relative prices between gas and coal can reduce and/or increase emissions due to the very different carbon intensities ([33]). According to the 2016 report by the European Commission on energy prices and costs in Europe, 'Member States should take advantage of the current lower energy prices to remove inappropriate subsidies and tax exemptions which distort prices signals and delay the transition to a low-carbon economy'.

EEA analysis published in 2016 ([34]) showed that there cannot be total decoupling of emissions from economic growth as long as the economy remains by and large based on fossil fuels. This finding is still coherent with GHG emissions decreasing and GDP increasing in the EU over the past 25 years. The question is whether the EU will be able to fully decouple ('break the link') GHG emissions from both fossil energy use and economic growth.

([32]) The link between the economy, and economic recession in particular, and GHG emissions is complex. Economic recession is broader than GDP impacts. For example, there is a recession effect in the 'energy intensity' factor due to, for example, lower demand from certain sectors than from others, e.g. manufacturing industries or from transport by individuals and/or companies. Even population growth can be affected by an economic recession (e.g. lower birth rates and/or net migration rates). Therefore, one should not extrapolate any conclusions regarding the average relationship between GHG emissions and GDP to the causal relationship, without considering that other factors are also at play. Some of these factors are indeed country specific and may be as important as economic growth. The relationship between GDP and GHG emissions also depends on the type of economic sector. For instance, there is a clearer link between industrial economic activity and energy use and emissions from industrial sectors such as those included in the EU ETS. For other sectors, such as residential, the link to GDP is not as clear and other factors, such as warmer or colder winters, or better insulation standards in buildings, would have a much bigger effect on emissions. In addition, the link between GHG emissions and GDP also varies widely across Member States, partly reflecting the fact that the energy mix is different from country to country. Clearly, energy demand which is met by fossil fuel combustion should have a larger effect on GHG emissions than energy demand which is by and large met by renewables. Yet, coal will have a larger effect on emissions than natural gas due to its higher carbon intensity. Thus, economic growth that increases demand for electricity that is largely generated by burning hard coal and/or lignite will have a larger effect on emissions than less carbon intensive fuels, other things being equal. Therefore, the more a country relies on fossil fuels, and particularly the more carbon-intensive fuels, the more difficult will be to completely decouple GHG emissions from economic growth.

([33]) On energy prices and their determinants, see the recent report by the Commission on energy prices and costs in Europe. The European Commission also published a study on the nature of energy costs and subsidies in Europe 'subsidies and costs of EU energy'. The study found that a wide range of government interventions constituted significant subsidies to the energy sector, quantified at the time between EUR 138 billion and EUR 300 billion (if including external costs).

([34]) Analysis of key trends and drivers in greenhouse gas emissions in the EU between 1990 and 2014, https://www.eea.europa.eu/publications/analysis-of-key-trends-ghg.

Table 2.4 below illustrates the results of a cointegration analysis for four different periods using the Engle and Granger method ([35]). The four periods considered are 1990-2015, 1990-2020, 1990-2030 and 1990-2050. The first period is based on historic data and essentially updates the 2016 EEA analysis. The other three periods are based on GHG emissions from the EU Reference Scenario 2016 based on the PRIMES and GAINS models.

There are some important messages from this analysis:

i. The short-run elasticities for economic growth and energy consumption are highly significant. This means they are important variables for explaining GHG emissions.

ii. When the consumption of fossil fuels increases, GHG emissions would generally increase, unless there is a substitution effect between gas and coal.

iii. The coefficient for economic growth is significantly lower than that of energy consumption for all the periods mentioned. This is because the EU has been able to reduce emissions in years when positive economic growth took place.

iv. There is statistical evidence of a long-run equilibrium between GHG emissions, economic growth and fossil-energy use ([36]). This means that how GHG emissions behave in the medium term can be predicted with some potential variations due to, for example, extraordinary cold or warm years.

v. Returning to the equilibrium relationship takes longer as the years go by. This would seem to suggest that climate change mitigation policies and measures are gradually working and are expected to have a stronger effect over time. This progressive decoupling suggests a stronger policy effect over time which underpins the need to continue improving energy efficiency and carbon intensity (including renewables) to meet the EU's 2030 and 2050 objectives.

vi. The progressive decoupling observed since 1990, and which is expected to continue until at least 2030, should reach a point where GHG emissions would be independent from economic growth and energy demand. This total decoupling is consistent with a halving of GHG emissions compared to 1990. The EU's low carbon economy roadmap suggests that, by 2050, the EU should cut its emissions to 80 % below 1990 levels, with milestones of 40 % emissions cuts by 2030 and 60 % by 2040. This would seem to suggest that total decoupling could be achieved between 2030 and 2040

Overall, the link between GHG emissions, GDP and energy use can be broken if less fossil fuels are used. Therefore, and assuming no change in energy efficiency, the higher the share of renewables in the energy mix, the more decoupling one should expect between emissions and economic growth.

The fact that a fossil fuel economy still exists today is not at odds with the strong reduction in the GHG emission intensity that has taken place in the EU since 1990. Because GHG emissions decreased and GDP increased, there has been a substantial improvement of the GHG emissions intensity (defined as GHG per GDP) of the economy for the EU as a whole. In addition to these improvements there has been a convergence of GHG emission intensities across Member States from the widely divergent values in 1990 to the significantly closer values in 2015 (Figure 2.8). One reason for this convergence is the extraordinary growth in renewables and a move towards less carbon intensive fuels ([37]).

Due to this strong convergence, GHG emissions per capita and per GDP are more similar now across Member States than they were back in 1990. Table 2.5 shows total GHG emissions per capita and per GDP relative to the EU-28 in purchasing power standards for the year 2015. A comparison between Table 2.5 and Figure 2.2 of Section 2.2 shows that, while China improves GHG emissions intensity faster than the EU, 18 EU countries had in 2015 per-capita emissions below those of China. All 28 Member States had per-capita emissions below the US. Differences among countries can be explained by a number of factors, including the carbon intensity of fossil fuel production (i.e. fossil fuel mix), the penetration of renewables, the existence of

([35]) Engle, Robert F.; Granger, Clive W. J. (1987). 'Co-integration and error correction: Representation, estimation and testing'. Econ ometrica 55 (2): 251-276. JSTOR 1913236.

([36]) This is shown by the so-called 'speed of adjustment' coefficients of the residual lagged error correction. These coefficients are 0.387, 0.386, 0.286, and 0.067 for the four periods mentioned above, respectively. The three first periods up to 2030 are highly significant but not the last. In relation to the first three periods, this means a) that there is a long-run equilibrium between the variables, and b) a short-run disequilibrium, which is corrected in the short term. For 1990-2015, it takes about 2.5 years to return to the equilibrium where fossil fuels and GDP drive emissions in a predictable way. This is almost the same as 1990-2020. For the 1990-2030 period, it would take about 3.5 years. In the last period up to 2050, it would take up to 20 years, which may explain why the coefficient is insignificant.

([37]) Convergence across countries for any given year of the time series has been analysed in GDP in purchasing power standards. To look at the reduction in GHG emissions intensity over time for a given country, GDP in constant prices should be used. Although the convergence is clearly visible from Figure 2.8, it has also been measured as the reduction in the coefficient of variation (i.e. standard deviation relative to the EU).

Table 2.4 GHG equilibrium in a fossil economy

Cointegrating relationship [38]: d.ln(ghg) f{d.ln(gdp) d.ln(ff) l.res}		Test results [coefficients and standard errors] (D.ln(ghg)			
Variable names	Variables model				
Time from 1990 to …		**2015**	**2020**	**2030**	**2050**
GDP in constant prices (first difference of the log)	D.ln(gdp)	0.213 **	0.218***	0.234***	0.280 ***
		– 0.081	– 0.068	– 0.065	– 0.06
Fossil-fuel energy use (first difference of the log)	D.ln(ff)	0.690 ***	0.691***	0.685***	0.662 ***
		– 0.05	– 0.043	– 0.041	– 0.038
Residual (lagged error correction)	L.res	– 0.387 ***	– 0.386***	– 0.286 ***	– 0.067
		– 0.12	– 0.091	– 0.082	– 0.053
Intercept	Constant	– 0.009 ***	– 0.009 ***	– 0.010 ***	– 0.011 ***
		– 0.002	– 0.002	– 0.001	– 0.001
F test	Prob > F	0	0	0	0
Adjusted R squared	Adj. R2	0.935	0.944	0.931	0.909
Root mean square error	Root MSE	0.005	0.005	0.004	0.004

Note: Standard errors in parentheses. * p<0.1; ** p<0.05; *** p<0.01.
Projections data from the 2016 EU Reference Scenario based on the PRIMES and GAINS, European Commission.

Source: EEA.

nuclear power for electricity generation, the efficiency in the transformation of primary energy into useful energy as well as the penetration of combined heat and power, the actual energy demand of end users, and energy efficiency improvements (and savings) linked to that demand. Other factors arising from specific climatic conditions (i.e. wind, hydro, average temperature) and the economy (i.e. fuel prices and economic growth) may also affect the ranking of countries in specific years, sometimes significantly.

2.7 The weather, the climate and GHG emissions

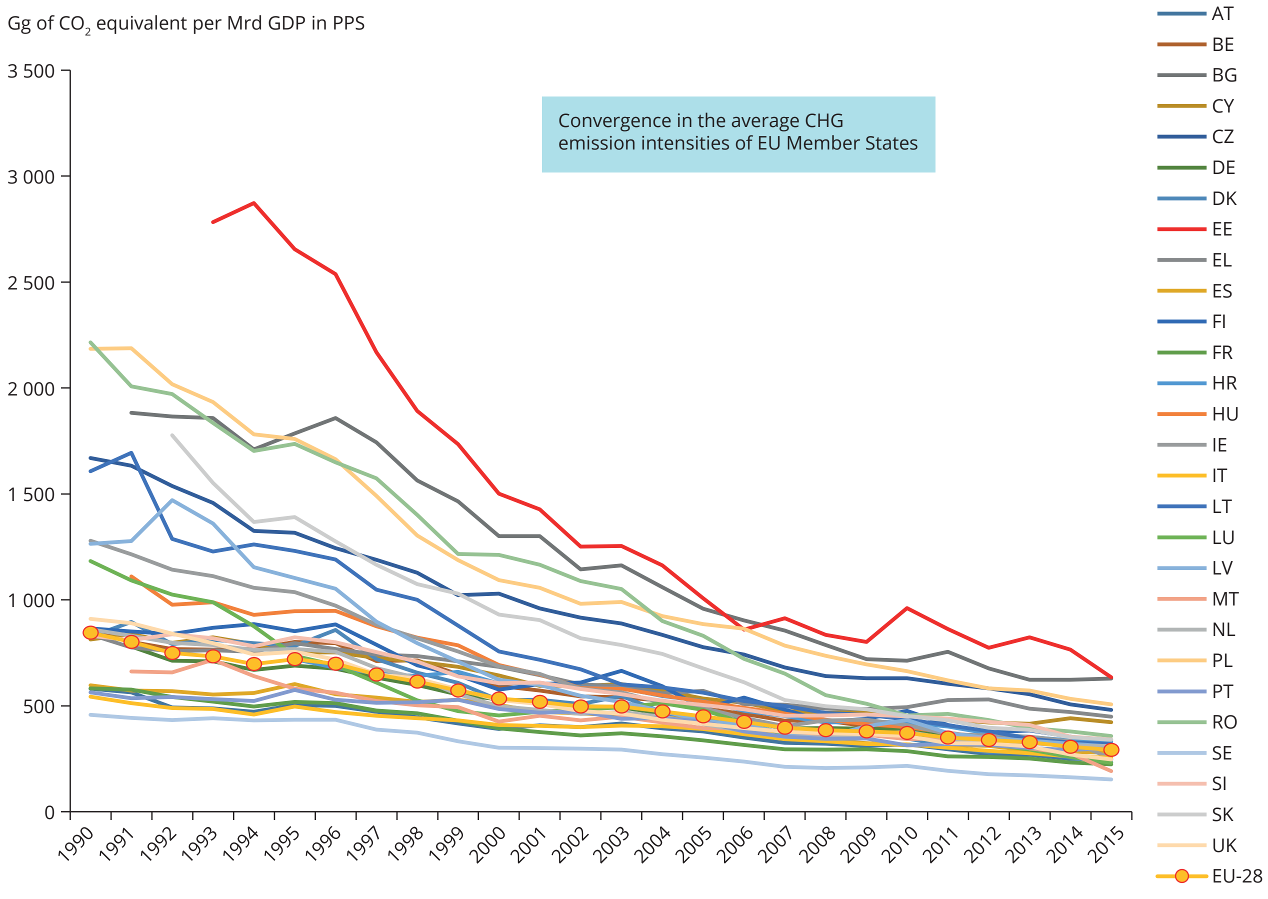
Emission reductions from the residential (i.e. households) and commercial (i.e. services) sectors are one of the key reasons for lower GHG emissions in the EU. Emissions from households, and to a lesser extent from the services sector, have decreased substantially since 1990, despite the growth in the number of private households and the increase in population. Households represent one of the largest sources of GHG emissions and are affected by variables such as climatic conditions, fuel prices, the existence of district heating, energy efficiency in buildings and the fuel mix for heat generation. Emissions in the residential sector alone decreased by 126 million t CO_2 eq. between 1990 and 2015 and represented the third largest reduction of all sectors in the EU.

Energy efficiency improvements from better insulation standards in buildings and a less carbon-intensive fuel mix can partly explain lower demand for space heating and lower emissions in the EU as a whole over the past 25 years. These factors have more than offset the effects of an increase in the EU population of 33 million, and in the number and average size of households in the EU.

Fuel consumption, including biomass, by the residential sector decreased by over 17 % between 1990 and 2015. The most popular fuel in European households is gas, with more than half of all the fuel input in 2015. Biomass is the second and oil the third most widely-used fuels for heating. The use of gas has

[38] Cointegration is used to test whether the EU on average expects total decoupling. The three variables used in this analysis are: total GHG emissions excluding LULUCF, GDP in constant prices and gross inland energy consumption from fossil fuels. GHG historic data is based on Member States inventory submissions. Because GHG projections are not complete for all Member States by the time of writing this report, the EU Reference Scenario 2016 has been used. The EU Reference Scenario 2016 is also the main source for projections of energy and GDP. Historic data for GDP and energy is based on DG ECFIN and Eurostat, respectively.

Figure 2.8 **Greenhouse gas emissions intensity of GDP by EU Member State, 1990-2015**



Source: EEA.

increased significantly since 1990. In parallel there has been a steady increase in the use of biomass. Coal use in households has declined throughout the period and represents less than 5 % of the fuel mix nowadays. As a result, the change in the fuel mix in households has led to important savings in CO_2 emissions because of the better emission intensity per unit of energy of the fuels being replaced ([39]).

One of the explanations for somewhat decreasing overall fuel use has been the lower demand for space heating due to better insulation standards in new buildings, the retrofitting of existing buildings and the diffusion of more efficient heating appliances ([40]). Whereas energy efficiency improvements from new and better buildings should not affect heat demand substantially from one year to another, the increasing

([39]) Not all the heat consumption by households is included under residential combustion in GHG inventories. Part of the heat is supplied via distributed systems from district heating and combined heat and power thermal stations. The primary energy to generate distributed heat (mainly from coal and gas) is reported under 'public electricity and heat production' in GHG inventories (by and large under the EU ETS). According to Eurostat, derived heat consumption in the residential sector decreased by 23 % in the EU between 1990 and 2015. The other part of the heating consists of non-distributed heat, which is generated directly by households/services (mainly from gas and biomass) and is reported under 'residential and commercial' in GHG inventories. Based on GHG inventories, direct heat consumption by the residential sector, including biomass, decreased by 17 % in the EU between 1990 and 2015. Direct heat consumption emissions from the residential sector are outside the EU ETS and account for about 90% of total heat consumption compared to distributed heat (10 %). Fuel changes in derived heat have a larger effect on GHG emissions because of the higher carbon intensity used compared to direct heat combustion. In addition, some Member States also use electrical energy for heating purposes; however, it is not possible at this stage to quantify this heat using Eurostat's energy balances without more detail in final energy consumption by specific end-use.

([40]) Energy efficiency trends in the EU, Odyssee-Mure, http://www.odyssee-mure.eu/publications/br/energy-efficiency-trends-in-Europe.html

Table 2.5 Greenhouse gas emissions per capita and GDP in 2015 (sorted)

GHG emissions per GDP in 2015	(PPS, EU-28 = 100)	GHG emissions per capita in 2015	(t CO_2 eq. per person)
Sweden	52	Malta	5.2
Malta	66	Sweden	5.5
France	77	Croatia	5.6
Luxembourg	79	Latvia	5.7
Denmark	79	Romania	5.9
Austria	85	Hungary	6.2
United Kingdom	85	Portugal	6.7
Ireland	86	France	6.9
Italy	88	Lithuania	6.9
Spain	95	Italy	7.1
EU-28	100	Spain	7.2
Portugal	103	Slovakia	7.6
Belgium	104	United Kingdom	7.7
Latvia	105	Slovenia	8.2
Germany	105	EU-28	8.5
Netherlands	106	Denmark	8.5
Hungary	107	Bulgaria	8.6
Lithuania	109	Greece	8.8
Finland	110	Austria	9.1
Croatia	114	Cyprus	9.9
Slovakia	116	Finland	10.1
Slovenia	117	Poland	10.2
Romania	122	Belgium	10.4
Cyprus	144	Germany	11.0
Greece	153	Netherlands	11.5
Czech Republic	164	Czech Republic	12.1
Poland	173	Ireland	12.8
Bulgaria	215	Estonia	13.7
Estonia	217	Luxembourg	18.0

Source: GHG emissions, EEA. Average population, Eurostat. GDP, Ameco database, European Commission.

size of the new housing stock relative to the existing stock and improvements in existing buildings will reinforce this positive effect. Policies such as the EU Directive on the Energy Performance of Buildings ([41]) should continue to play a key role in reducing emissions from the residential sector and contribute to Member States' targets under the Effort Sharing Decision.

The other factor that helps explain the changes in fuel use (and emissions) from the residential sector is weather related. There are two aspects to consider: a) possible long term effects from warmer winter conditions in Europe; and b) short-term effects from annual variations in winter temperatures.

([41]) Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings was adopted in 2010 and repeals Directive 2002/91/EC on the energy performance of buildings. The Buildings Directive is one of the main instruments which have been put in place to reach the EU's 20 % reduction target for primary energy consumption by 2020. The Directive obliges Member States to set minimum standards for the energy performance of new buildings and for existing buildings that are subject to major renovation work to achieve cost optimal levels. By 31 December 2020, all new buildings shall be 'nearly zero-energy buildings'. New buildings occupied and owned by public authorities shall comply with the same criteria by 31 December 2018.

Mean near-surface temperature over land has been increasing globally, as well as in Europe, during the past 30-40 years both for the summer and winter periods. Since 1990 the autumn/winter months have become warmer in Europe, defined as the average of the first and last quarters of the calendar year. However, spatial variability is very high and the warming of the winter months is not always clearly evident across Europe. In some regions of Europe the trend is more visible, particularly in the South East and parts of the Iberian Peninsula as shown in Figure 2.9. Notwithstanding the different trends by country and region regarding the effect of warmer winters, one can say that Europe has been experiencing milder winters since 1990.

Annual variations in winter temperatures also explain changes in fuel use and emissions from the residential sector. 2014 and 2015 were the hottest years on record in Europe with mean annual land temperatures about 2 °C higher than the pre-industrial average.

There is also a clear positive correlation between heating degree days (HDDs) (an indication of household demand for heating based on outdoor temperatures) and fuel use and emissions from the residential sector. HDDs fluctuate annually depending on the prevailing weather conditions in a specific year, and this is translated into a lower or higher heat consumption by households. According to Eurostat data, the current demand for heating in Europe is below its long-term average (defined as 1980-2004). Although there is no consistent trend in the number of HDDs, the average number of HDDs in the 1980s was higher than the average in the 1990s (i.e. less demand for heating in the 1990s), whilst the average number of HDDs in the 1990s was higher than the average in the 2000s up to 2015 (i.e. less demand for heating in the 2000s). Despite the lack of a long-term trend in the number of HDDs, there is strong evidence that annual changes in HDDs can explain annual changes in residential CO_2 emissions.

A recent EEA analysis on heating and cooling ([42]), shows that HDDs have decreased by about 0.5 % per year between 1981 and 2014, and particularly in northern and north-western Europe. In parallel, cooling degree days (CDDs) increased on average by almost 2 % per year during the same period, particularly in southern Europe. Because temperatures in Europe are projected to increase, the trends of lower HDDs and higher CDDs are also expected to continue, and even accelerate.

2.8 Early indications of 2016 emissions

The most recent official data available for total EU GHG emissions is the GHG inventory 1990-2015.

Verified 2016 emissions from the EU emissions trading system (EU ETS) decreased by about 2.6 % compared to 2015. The EU ETS covers more than 11,000 installations across the 28 Member States of the European Union, Iceland, Norway and Liechtenstein, as well as airlines. In 2015, emissions from stationary installations under the EU ETS represented approximately 41% of total GHG emissions in the EU.

In addition, early Eurostat estimates of CO_2 from fossil fuel combustion point to a 0.4 % decrease in emissions between 2015 and 2016. 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.

According to the International Energy Agency (IEA), energy-related CO_2 emissions in the European Union remained broadly stable in 2016.

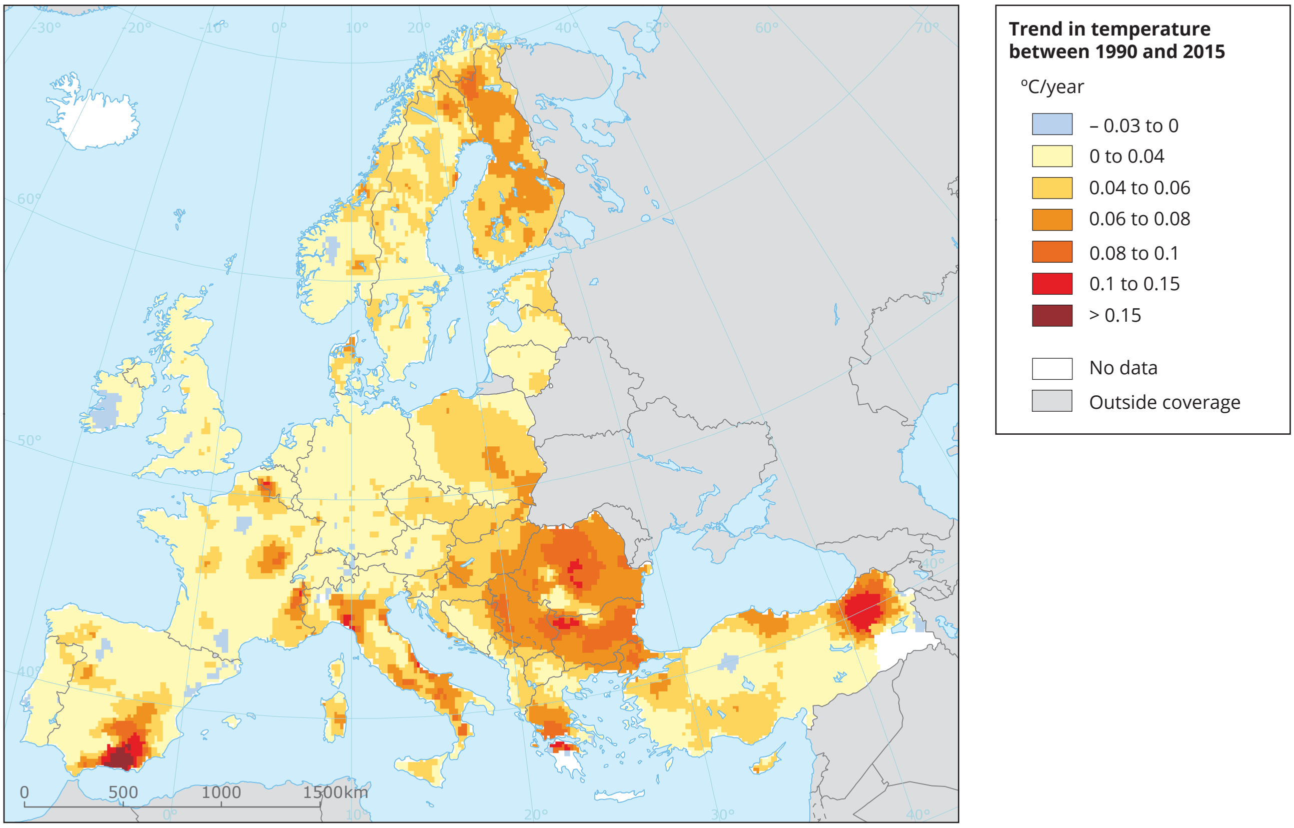
By 30 September, the EEA will finalise its annual Approximated GHG inventory for 2016 The EEA's Approximated GHG inventory covers all major sectors reported under the UNFCCC and is consistent with a full emissions inventory, therefore covering 100 % of total GHG emissions.

The final 2016 GHG emissions for the EU and its Member States will be submitted to the UNFCCC in the spring of 2018.

Other EU bodies also publish emission estimates, with a somewhat different scope in terms of methods, sectors, gases and/or geographical coverage. For more details see the paper 'different emission estimates by EU bodies/institutions', which is updated and publish regularly as a joint collaboration between EEA, JRC, Eurostat and DG CLIMA.

([42]) Heating and cooling degree days, EEA: http://www.eea.europa.eu/data-and-maps/indicators/heating-degree-days/assessment.

Figure 2.9 Trends in mean near-surface temperature between 1990 and 2015 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 ([43]).

([43]) 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'.

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