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TRENDS IN GLOBAL CO_2 AND TOTAL GREENHOUSE GAS EMISSIONS

2017 Report

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Executive summary

In 2016, total global greenhouse gas (GHG) emissions (excluding those from land use) continued to increase slowly by about 0.5% (±1%), to about 49.3 gigatonnes in CO_2 equivalent (Gt CO_2 eq). Taking into account that 2016 was a leap year, and therefore 0.3% longer, and together with the 0.2% increase in 2015, the 2016 emission increase was the slowest since the early 1990s, except for global recession years. This is mainly the result of lower coal consumption from fuel switches to natural gas and increased renewable power generation; in particular, in wind and solar power. Most of the emissions (about 72%) consist of CO_2, but methane (CH_4), nitrous oxide (N_2O) and fluorinated gases (so-called F-gases) also make up substantial shares (19%, 6% and 3%, respectively).

These percentages do not include net emissions from land use, land-use change and forestry (LULUCF), which are usually accounted for separately, because they are inherently very uncertain and show large interannual variations. When including LULUCF emissions — for 2016 estimated at about 4.1 Gt CO_2 eq — estimated global total GHG emissions come to 53.4 Gt CO_2 eq. The trend in global CO_2 emissions excluding those from LULUCF has remained more or less flat, over the last two years (±0.5%). Non-CO_2 greenhouse gases retained an annual growth rate of about 1%.

Global greenhouse gas emissions and emission trends

- Total global greenhouse gas emissions have shown a slowdown in growth, and increased in 2016 by about 0.5% to reach 49.3 Gt CO_2 eq (excluding those from LULUCF, thus also from forest and peat fires) (uncertainty estimate in the trend ±1%).
- Since the early 1990s, such slow annual emission increases have only occurred in 2015, during the global economic recession in 2008–2009, and during the major global financial crisis in 1998 that resulted from the Asian financial crisis.
- Over the past three years, non-CO_2 greenhouse gas emissions have continued to grow somewhat faster than CO_2 emissions, namely by 1.5% (2014), 1.2% (2015) and 1.0% (2016), whereas over the same period CO_2 increased by a respective 0.8%, -0.2% and 0.3%.
- Globally, the combined share of CH_4, N_2O and F-gas emissions is about 28% in total GHG emissions (19%, 6%, and 3%, respectively), of which F-gases show the highest growth rate of about 3% in 2016, followed by N_2O of about 1.3%, whereas methane has remained at 2015 levels in 2016.
- The global share of non-CO_2 greenhouse gases is estimated to have declined from 35% in 1970 to 27% in 2013, after which it started to increase, slowly, to about 27.5% in 2016, because of the reduction in the growth in CO_2 emissions.
- For methane (CH_4), coal mining, oil and natural gas production and gas distribution, together, account for 25% of methane emissions. Cattle are responsible for another 23% of methane emissions, worldwide, and rice cultivation contributes 10%. The relatively large fraction of methane that stems from energy-related emissions, together with stagnation of growth in energy-related emissions, causes methane to show the least growth in non-CO_2 GHG emissions.
- The main sources of N_2O emissions are agricultural sources, such as animal manure and the use of fertilisers, which together account for about 75% of N_2O emissions. Contrary to energy-related emissions, agricultural-related emissions continue to grow.

- F-gases are a very heterogeneous category, with large differences in growth rates and often very large uncertainties in emissions. The largest sub-categories are HFC-134a from refrigeration and air conditioning (about 19%), HFC-125 and HFC-143a from consumption (17% and 19%), and HFC-23, which is a by-product of the production of HCFC-22 (19%).
- Net emissions from land-use change are usually accounted for separately, among other things because they are inherently very uncertain and show large interannual variation. In 2016, those emissions are estimated at 4.1 Gt CO_2 eq.

CO_2 emissions

- The trend in global CO_2 emissions, excluding those from LULUCF, has remained more or less flat over the last years at 35.7, 35.6 and 35.8 Gt CO_2 in 2014 to 2016 with -0.2% and +0.3%,respectively (uncertainty estimate in the trend ±0.5%).
- In 2016, the five largest emitting countries (China, the United States, India, the Russian Federation, and Japan) and the European Union, which together account for 51% of the world population, 65% of global gross domestic product (GDP) and 67% of the total primary energy supply (TPES[1]), accounted for 68% of total global CO_2 emissions and about 63% of total global GHG emissions.
- The group of 20 largest economies (G20) accounted for 81% of global CO_2 emissions and 78% of global GHG emissions.
- Most of the large countries showed a decrease in CO_2 emissions in 2016; most notably the United States (-2.0%), the Russian Federation (-2.1%), Brazil (-6.1%), China (-0.3%), and, within the European Union, the United Kingdom (-6.4%). The CO_2 emissions in the European Union as a whole remained flat.
- The largest absolute increases in 2016 were seen in India (+4.7%) and Indonesia (+6.4%) and smaller increases in Malaysia, Philippines, Turkey and the Ukraine.
- Emissions from international transport (aviation and shipping) constitute about 3% of global total greenhouse gas emissions.
- Despite lower GDP growth in recent years, compared to pre-crisis years, the energy intensity of the economy, defined as total primary energy use (TPES[1]) per unit of GDP has continued to decrease, but no structural change on this indicator has occurred in recent years.
- The emission intensity of energy, represented by CO_2 per unit of energy, has decreased over most of the past five years. This can be attributed to the recent trend of coal having been substituted by other fuels (with lower emission factors) and of renewable energy having increased in the energy mix, in particular in China and the United States.

CO_2 concentrations

- The global average CO_2 concentration in the atmosphere increased in 2016 by a record amount of 3.3 parts per million, which is in part due to a very strong El Niño event in 2015/2016: in tropical regions more forest and peat fires and regional less photosynthesis and more carbon decomposition due to local dryer and generally much warmer weather and less ocean absorption has led to more CO_2 emissions and less CO_2 removal by the LULUCF sector and thus to more net emissions.

[1] TPES, or Total Primary Energy Supply, is the total amount of energy consumption of a country (or the world). It is calculated as in BP (2017): using a substitution method for nuclear, hydropower and other non-biomass renewable energy and assuming 38% conversion efficiency in all cases.

1 Introduction

In this report we present recent trends, up to 2016, in greenhouse gas (GHG) emissions for both CO_2 and non-CO_2 greenhouse gas emissions. We calculated these emissions based on the new EDGAR database version 4.3.2 (Janssens-Maenhout et al., 2017a,b). In 2017 this version of the EDGAR database has been finalised and includes comprehensive activity and emission factor data up to 2012, and where available until later years. For the years after 2012 up to 2016 a Fast Track method was used for CO_2 emissions (using the methodology as described in Olivier et al. (2016a) and Box 1.1), and for non-CO_2 emissions we used a hybrid method of partly fast track and partly extrapolation for non-CO_2 emissions, see Box 1.1 and Appendix D for more details.

The JRC booklet by Janssens-Maenhout et al. (2017b) provides for all countries and the European Union one graph showing the emissions of CO_2 and one for the three main greenhouse gases CO_2, CH_4 and N_2O using data from EDGAR v4.3.2 (1990–2012). The CO_2 graph in that report shows the trend up to 2016 as compiled in FT2016 for this report, whereas the greenhouse gas graph covers the 1990-2012 period.

Please note that the EDGAR v4.3.2 data set, and thus also the JRC booklet, does not include emissions from savannah burning (IPCC/UNFCCC subcategory 3E of the Agriculture sector), because international statistics are lacking. However, the FAO has compiled emission estimates for CH_4 and N_2O per country for this source based on the figures of area burned on a spatial grid of pixels in the GFED4.1s data set[2] (Van der Werf et al., 2010) and default emission factors from IPCC (2006). Therefore, to have a complete data set covering all sources of greenhouse gas emissions, we included in this report the CH_4 and N_2O emissions from savannah burning as reported by the FAO. The share of these emissions in global total emissions is 1.5% for CH_4 (5.6 Mt CH_4 or 140 Mt CO_2 eq) and 5% for N_2O (0.5 Mt N_2O or 149 Mt CO_2 eq). However, for individual countries the shares can be much larger, in example for Australia, which savannah burning emissions are one third of the global total, shares in the national CH_4 and N_2O emissions in the EDGAR data set are 25% and 50%, respectively.

Non-CO_2 emissions constitute a significant fraction of global greenhouse gas emissions. For climate policies this refers to methane (CH_4), nitrous oxide (N_2O) and the so-called F-gases (HFCs, PFCs, SF_6 and NF_3). To our knowledge this report is the first to provide estimates of the total global emissions including 2016 that is based on detailed activity data and trends in emission factors for these years. Other work is available for historical time series of anthropogenic greenhouse gas emissions until 2005, 2012 and 2014, respectively: US Environmental Protection Agency (EPA) on global non-CO_2 greenhouse gas emissions for 1990–2005 (US EPA, 2012); the CAIT database for greenhouse gas emissions for 1990–2012 compiled by the WRI (2015) and the PRIMAP-hist data set for 1850–2014 developed at the Potsdam Institute for Climate Impact Research (PIK) (Gütschow et al., 2016).

For net CO_2 emissions from land use, land-use change and forestry (LULUCF), we used data recently generated in the Global Carbon Project (GCP) (Houghton et al., 2012) through 2015

[2] The UN Food and Agricultural Organisation (FAO) has compiled savannah burning emissions using monthly burned area data per 0.25°x0.25° grid cell for five land cover types from the GFED4.1s dataset (Van der Werf et al., 2010), multiplied by biomass consumption per hectare and tier 1 emission factors from IPCC (2006) and aggregated at country level. The GFED data cover the period 1996-2014. For years before 1996 FAO used the average of the 1996 to 2014 values and for 2015 and 2016 we used the average of the 2010 to 2014 values. For details see: (a) Dataset Information at http://fenixservices.fao.org/faostat/static/documents/GH/GH_e.pdf, (b) Metadata at http://www.fao.org/faostat/en/#data/GH/metadata.

(Houghton and Nassikas, 2017), which include data on CO_2 emissions from forest and peat fires from the Global Fire Emissions Database version GFED4.1s through 2016 (Van der Werf et al., 2010). Those data are inherently very uncertain and therefore typically not included in representations of emission data. However, for the comprehensive overview of all GHG emissions and removals, we included them in the main figure (Figure 2.1) to illustrate their share in overall, total global anthropogenic GHG emissions. Discussions on emission data focus on those derived from the EDGAR database, which excludes LULUCF emissions.

Box 1.1 Extending EDGAR v4.3.2 from 2012 to 2016: *Fast Track* method for CO_2 and *hybrid* method for non-CO_2 gases

The data presented here have been calculated using the new EDGAR 4.3.2 data set, which provides emissions per source and country, for the 1970–2012 period (Janssens-Maenhout et al., 2017a,b). The data set was extended for CO_2, using international statistics through 2016 (so-called Fast Track 2016), and for other greenhouse gases, using statistics through 2014 (FAO), 2016 (IEA, BP), and other data sources (including CDM projects in developing countries through 2016 to account for reductions in CH_4, N_2O and HFC-23 emissions). In cases where data through 2016 were lacking, which was often the case for non-CO_2 greenhouse gases, we extrapolated data from three recent years. For a more detailed description of the Fast Track methodology for CO_2, see Olivier et al. (2016), and, for the hybrid methodology of partly fast track and partly extrapolation and the data sources used for estimating the non-CO_2 greenhouse gas emissions beyond 2012, see Appendix D.

The total in greenhouse gases emissions is expressed in terms of gigatonnes of global annual CO_2 equivalent emissions (Gt CO_2 eq), calculated using the so-called Global Warming Potentials for 100 years (GWP-100) as listed in the IPCC Fourth Assessment Report (AR4) (IPCC, 2007). These GWP's are now also used by so-called Annex I countries (developed countries) which are annually reporting their national GHG emissions inventory (NIR) to the UN Climate Secretariat (UNFCCC, 2017).

The historical GHG emission trends from the EDGAR database are also presented in UNEP's Emissions Gap Report 2017, but using the GWPs of the IPCC Second Assessment Report (UNEP, 2017). These GWP's are still used by so-called non-Annex I countries (developing countries) in their biannual reported Biennial Update Report (BUR) to the to the UN Climate Secretariat (UNFCCC, 2017).

The focus of this report is on the top 5 emitting countries and the European Union, and the global total. Uncertainty in non-CO_2 emissions data is by nature much larger than that for the CO_2 emissions (excluding forest and other land-use related emissions, 'LULUCF'). This is because these sources are much more diverse and emissions are determined by technological or other source-specific factors, whereas for CO_2 the emission factors are mainly determined by the fossil fuel type and carbon content.

In Chapter 2 we discuss the global emission trends. Firstly, in section 2.1, we discuss the total greenhouse gas emissions, with a focus on the non-CO_2 greenhouse gases, which are new in this report. Secondly, in section 2.2, we will discuss the trends of CO_2 emissions, for which we also make use of the Kaya identities (Kaya, 1990) to distinguish trends in gross domestic product (GDP), energy intensity, and emission intensity. In Chapter 3 the five main emitting countries and the European Union are discussed separately in more depth.

Tables with the new data on CO_2 and total GHG emissions and on electricity production can be found in Appendices A–C, and the new methodology that we have used to estimate non-CO_2 emission trends up to 2016 is discussed in Appendix D. There we also summarise the revisions in greenhouse gas emissions by switching from EDGAR v4.2 FT2010 to the new v4.3.2. Finally, we discuss in Appendix D the quality and completeness of CH_4 and N_2O emissions by comparing trends in the EDGAR dataset with the trend in total CH_4 and N_2O emissions from the official reported national emissions.

2 Trends in global emissions

2.1 Global trends in total greenhouse gas emissions

In 2016, total global greenhouse gas emissions continued to increase slowly by about 0.5% (±1%), to about 49.3 gigatonnes in CO_2 equivalent (Gt CO_2 eq). Taking into account that 2016 was a leap year, and therefore 0.3% longer, and together with the 0.2% increase in 2015, the 2016 emission increase was the slowest since the early 1990s, except for global recession years. This is mainly the result of lower coal consumption from fuel switches to natural gas and increased renewable power generation; in particular, in wind and solar power. Most of the emissions (about 72%) consist of CO_2, but methane (CH_4), nitrous oxide (N_2O) and fluorinated gases (F-gases) also make up substantial shares (19%, 6% and 3%, respectively).

These percentages do not include net emissions from land use, land-use change and forestry (LULUCF), which are usually accounted for separately, because they are very uncertain and show large interannual variations. They mostly consist of net CO_2 emissions from changes in land use and land cover, plus small amounts in CH_4 and N_2O from forest and peat fires. When including LULUCF emissions — for 2016, estimated at about 4.1 Gt CO_2 eq — estimated global total GHG emissions come to 53.4 Gt CO_2 eq. The trend in global CO_2 emissions excluding those from LULUCF has remained more or less flat over the last two years (±0.5%), as shown by the blue area in Figure 2.1.

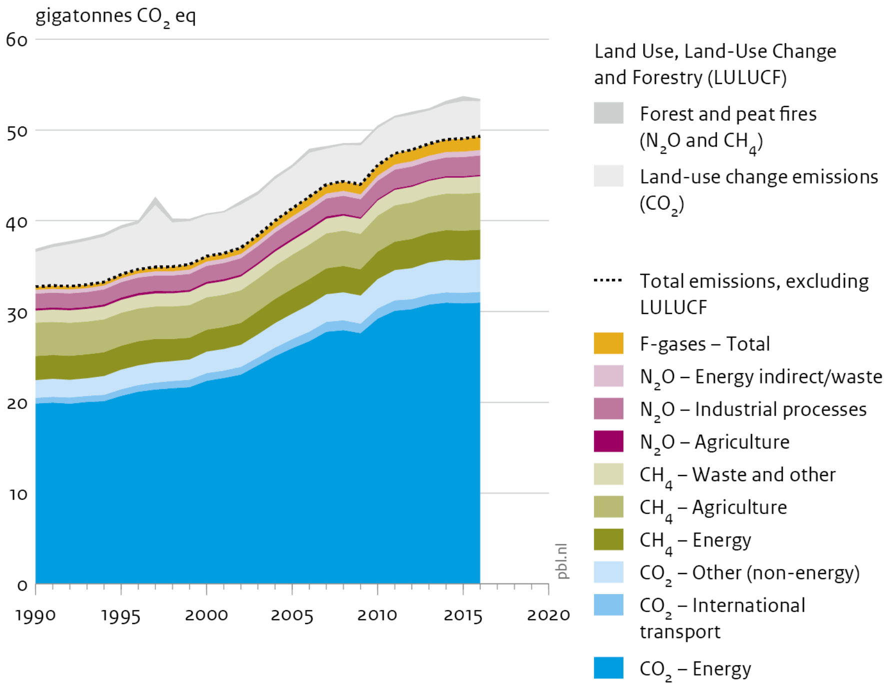
It should be noted that the time series data for total global CO_2 emissions used have been updated since the 2016 report (Olivier et al., 2016). The updated estimate for total global total CO_2 emissions in 2015 is now 35.6 Gt CO_2, which is slightly lower than the estimate of 36.2 Gt CO_2 as presented last year. The changes are due to regular annual statistical revisions of fuel consumption in International Energy Agency (IEA) and BP statistics (for example the decrease in global coal consumption in 2015 was revised from -1.8% to -2.7%) as well as revisions and some full updates, including emission factors, for several other sources (gas flaring, cement production, solvent use, ammonia production, urea and lime application). For more details, also on the revision of the non-CO_2 greenhouse gases, when changing from EDGAR 4.2 FT2010 to EDGAR v4.3.2, we refer to Appendix D.

Non-CO_2 greenhouse gases retained an annual growth rate of about 1%. In contrast, net emissions from LULUCF show a highly varying pattern that reflects the periodically occurring strong El Niño years, such as in 1997–1998 and 2015–2016, as shown by the grey area above the dashed line in Figure 2.1.

Over the past two years, total global greenhouse gas emissions (excluding those from LULUCF, thus also from forest and peat fires) have shown a slowdown in growth, reaching 49.3 gigatonnes CO_2 equivalent in 2016, with calculated increases of 1.0%, 0.2% and 0.5%,

Figure 2.1

Global greenhouse gas emissions, per type of gas and source, including LULUCF



Source: EDGAR v4.3.2 (EC-JRC/PBL 2017); Houghton and Nassikas (2017); GFED 4.1s (2017)

in 2014, 2015 and 2016, respectively (see Figure 2.1). Note that 2016 was a leap year and, therefore, about 0.3% longer than a normal year. Since the early 1990s, such slow annual emission increases have only occurred during the global economic recession in 2008–2009 and the major global financial crisis in 1998 that resulted from the Asian financial crisis.

Non-CO_2 GHG emissions originate from many different sources and are much more uncertain than CO_2 emissions (their uncertainty on a country and global level is of the order of 30% or more, whereas for CO_2 this is about ±10% or less). Over the past three years, non-CO_2 GHG emissions have continued to grow somewhat faster than CO_2 emissions, namely by 1.5% (2014), 1.2% (2015) and 1.0% (2016), whereas CO_2 over the same period increased by a respective 0.8%, -0.2% and 0.3%. Note that, due to limited statistical data for 2015 and 2016 for these sources, the annual trends in the emission of CH_4, N_2O and F-gases are much more uncertain than those in CO_2. Appendix B provides tables with the 1990–2016 time series of total GHG emissions for the top 30 countries/regions and for CH_4, N_2O and F-gas.

Although varying per country, non-CO_2 emissions constitute a significant share in total GHG emissions. The global share of non-CO_2 GHGs is estimated to have declined from 35% in 1970 to 27% in 2013, after which it started to increase, slowly, to about 27.5% in 2016, because of the reduction in the growth in CO_2 emissions.

In 2016, **methane** (CH_4) emissions have remained at virtually the same level as in 2015, with an estimated increase of 0.3%, which can be attributed to 2016 being a leap year, to a total of 9.2 Gt CO_2 eq. Methane is the largest contributor to non-CO_2 greenhouse gas emissions, predominantly from non-dairy cattle, with over 16% of global CH_4 emissions in 2016. Dairy cattle add another 5%, and cattle manure management another 1% — together, making cattle responsible for 23% of methane emissions, worldwide. Coal mining, oil and natural gas production and gas distribution, together, account for 25% of methane emissions, and rice cultivation contributes 10%. Figure 2.2 (top) shows the top 12 sources of methane. Since 2000, emissions from both this category and from coal and natural gas production have grown by more than 65% (despite decreasing emissions from coal production in the last four years). Methane emissions from industrial waste water is one of the fastest growing categories, accounting for 3% of CH_4 emissions. However, with an estimated 1.2% increase in 2016, landfills were the fastest growing source of methane emissions in 2016. In the same year, methane emissions from agriculture increased by 0.4%, while those from energy decreased by 0.3%. Emission factors can vary widely per country, for instance for crop cultivation and livestock, as a result of soil conditions and production methods.

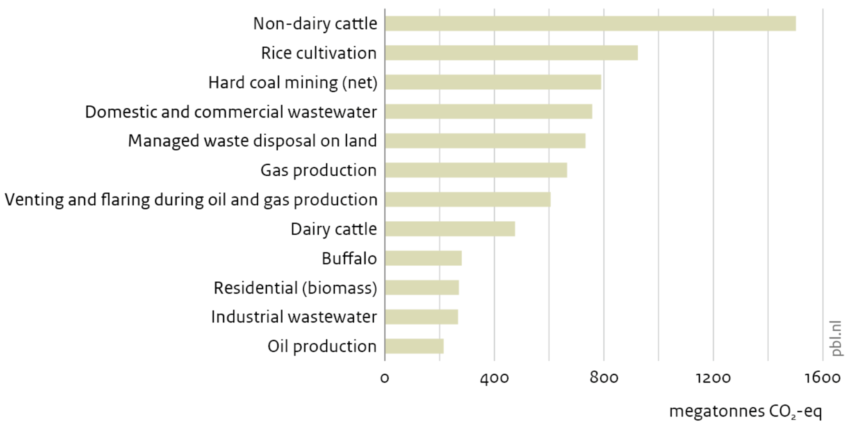
N_2O emissions in 2016 amounted to 2.9 Gt CO_2 eq, and increased by 1.3% with respect to 2015. The main sources of N_2O emissions consist of the manure in pastures, rangeland and paddocks, and synthetic fertilisers (22% and 18%, respectively, in 2016). Figure 2.2 (bottom) shows the top 12 sources of N_2O emissions. Agriculture, including indirect N_2O emissions, accounted for about 75% of N_2O emissions, and this was also the fastest growing category over the past three years (by a respective 1.7%, 2.1% and 1.3%). In recent years, savannah fires have been responsible for about 5% of N_2O emissions.

F-gases make up the smallest category but show the strongest emission growth in non-CO_2 emissions with an estimated global growth rate of 4.5% in 2016, extrapolated using on the

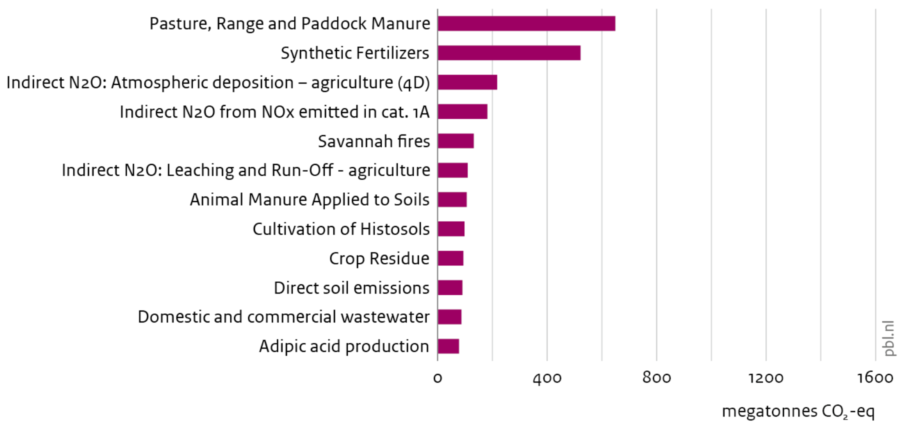
Figure 2.2

Top 12 sources for global CH_4 and N_2O emissions in 2016

Global CH_4 emissions per source category



Global N_2O emissions per source category



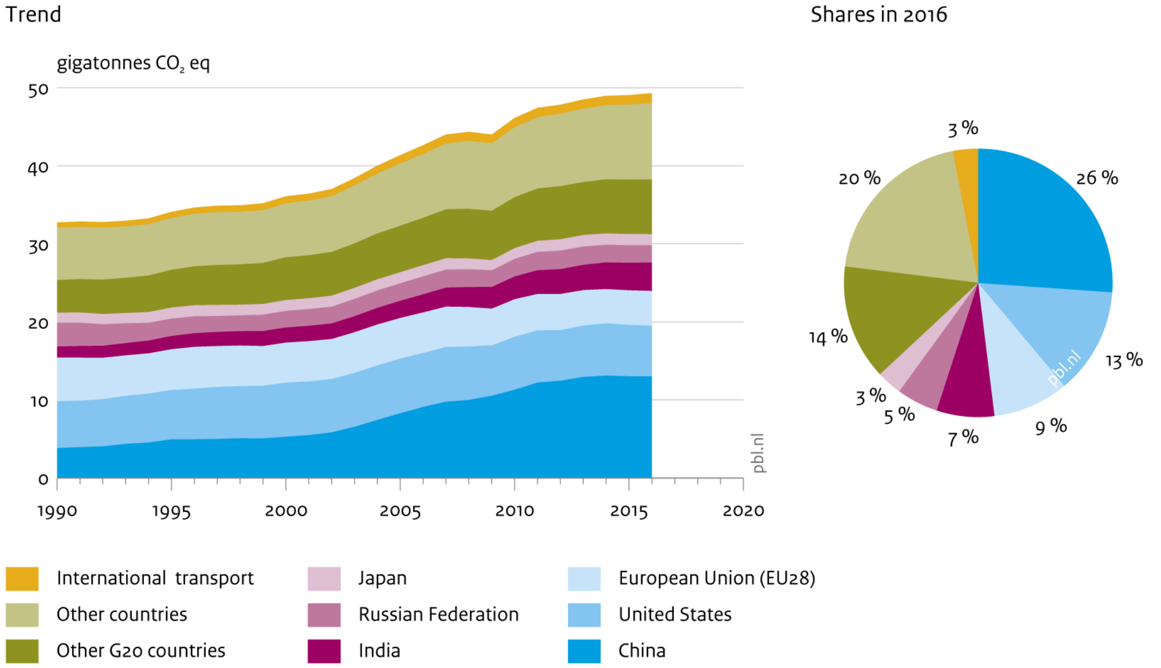
Bron: EDGAR v4.3.2 (EC-JRC/PBL 2017)

annual average 2007-2010 trend. Using this estimation method, total F-gases emissions amounted to 1.5 Gt CO_2 eq worldwide. We note that these are very heterogeneous categories, with large differences in growth rates for the different constituents, and often with very large uncertainties in emissions, at country level of the order of 100% or more. Using these estimates, the largest sub-categories are HFC-134a from refrigeration and air conditioning (about 19%), HFC-125 and HFC-143a from consumption (17% and 19%), and HFC-23, which is a by-product of the production of HCFC-22 (19%).

Net emissions from **land-use change** are usually accounted for separately, among other things because they are inherently very uncertain and show large interannual variation. Thus, they are less suited for determining trends in anthropogenic global GHG emissions. Estimates vary between 3 and 6.5 Gt CO_2 eq for 2016 (assessment of data sets by Houghton et al. (2012), Van der Werf et al. (2010) and of model outcomes as described in Le Quéré et al. (2016, 2017). We use the estimates developed for the Global Carbon Project (GCP) as described in Houghton and Nassikas (2017) for net CO_2 emissions and the GFED4.1s data set for the relatively small CH_4 and N_2O emissions from forest and peat fires from Van der Werf et al. (2010). They constitute net CO_2 emissions from changes in land use and land cover (estimated at about 3.9 Gt CO_2 in 2016) plus small amounts of CH_4 and N_2O emissions from forest and peat fires (about 0.2 Gt CO_2 eq). This adds another 4.1 Gt CO_2 eq, or 8%, to the global total GHG emissions, making it a significant component to consider for reducing greenhouse gas emissions.

Figure 2.3

Global greenhouse gas emissions, per country and region



Emissions do not include those from land use, land-use change and forestry and forest and peat fires (LULUCF)

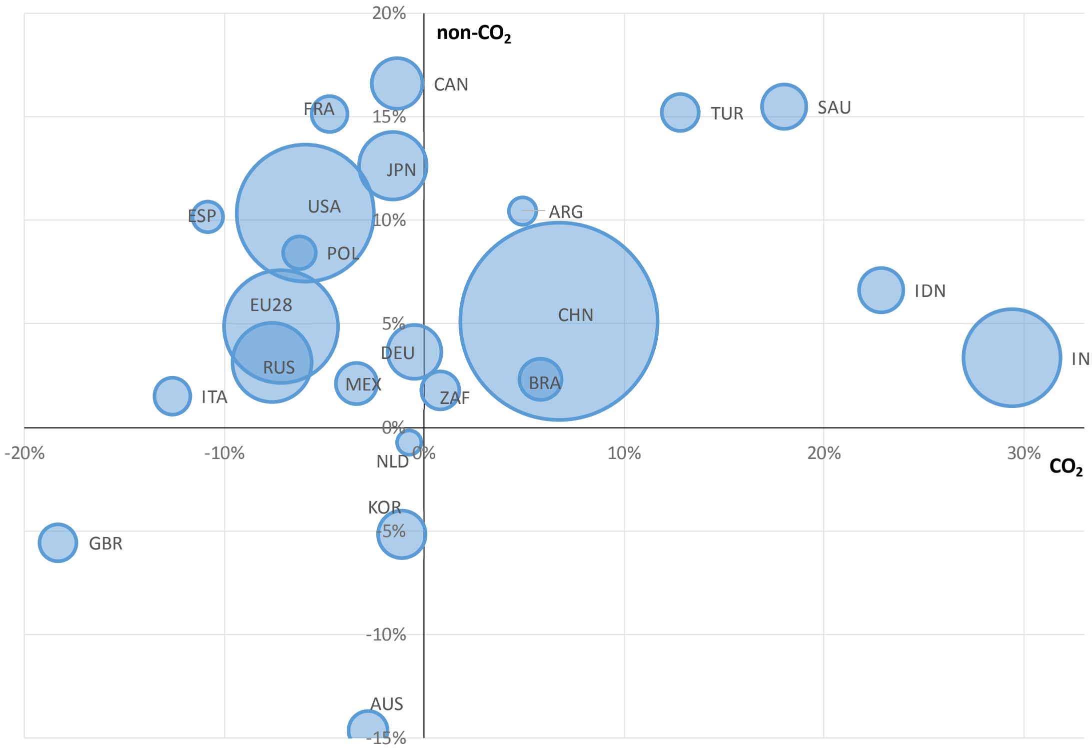
Bron: EDGAR v4.3.2 (EC-JRC/PBL 2017)

In 2016, the five largest emitting countries and the European Union, which together account for 51% of the world population, 65% of global gross domestic product (GDP) and 67% of the global total primary energy supply (TPES[1]), accounted for 68% of total global CO_2 emissions and about 63% of total global GHG emissions. Following UNFCCC reporting and accounting guidelines (UNFCCC, 2011), GHG emissions from international transport (aviation and shipping) are excluded from the national total in countries' GHG emission reports, but nevertheless constitute about 3% of total global GHG emissions. Figure 2.3 illustrates the 1990–2016 trends (left) and the shares per country and region in 2016 (right). CO_2 is the dominant component of GHG emissions in all countries. A country's share in global CO_2 emissions often very similar to its share in global GHG emission. An exception to this is China, where the share of CO_2 emissions in 2016 was 29% versus 26% in total greenhouse gas emissions, due to the large share of coal in the fossil fuel mix. The group of 20 largest economies (G20[3]) accounted for 81% of global CO_2 emissions and 78% of global GHG emissions (Figure 2.3).

Figure 2.4 shows the recent trend over the last five years in emissions of CO_2 and non-CO_2 gases for the G20 countries and the European Union. The 5-year growth rate in CO_2 emissions (horizontal axis) is plotted against the 5-year growth rate in non-CO_2 emissions (vertical axis) for the G20 countries/regions. The size of the bubble is proportional to the CO_2 emissions in 2016. In general, while most of the G20 countries are on the negative growth axis for CO_2, most countries have shown growth in non-CO_2 emissions in five years: more on the positive growth axis for non-CO_2 than for CO_2, amongst which are very large emitters. The spread in growth rates is large, both for CO_2 and for non-CO_2 emissions. On the CO_2 growth axis India and Indonesia have the largest 5-year growth rates, while the United Kingdom shows strong negative growth in both CO_2 and non-CO_2 emissions. Non-CO_2 emissions grow strongest in Canada, Saudi-Arabia, Turkey, and France, while the decrease is strongest in Australia. We note that for several European countries (Germany, Netherlands, Poland), the European Union as a whole and the Russian Federation the non-CO_2 emissions have decreased since 1990. Apparently that trend has not continued over the last five years.

Figure 2.4

Five-year trend ([%], 2011–2016) in CO_2 emissions versus non-CO_2 emissions per country/region for G20 countries



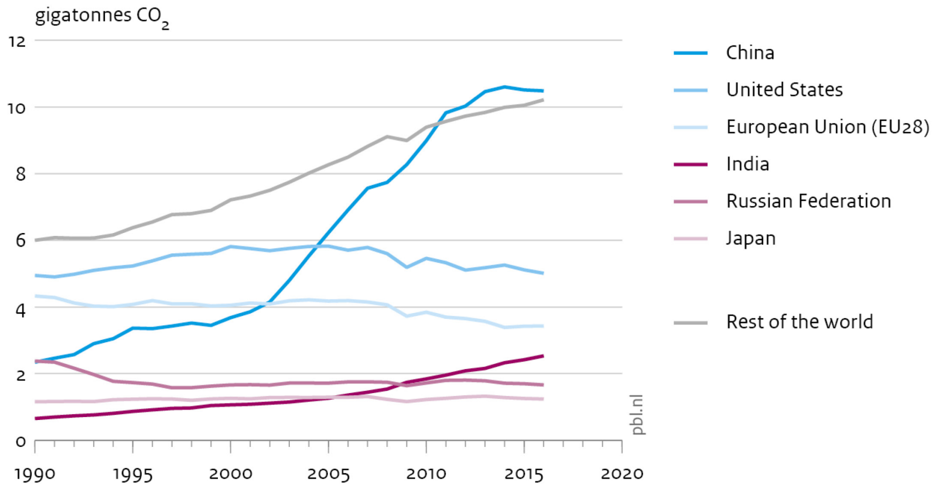
[3] Group of Twenty: 19 countries and the European Union. The 19 countries are: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea, Mexico, the Russian Federation, Saudi Arabia, South Africa, Turkey, United Kingdom, and the United States.

2.2 Global trends in CO_2 emissions

The trends in CO_2 emissions of the largest emitting countries/regions are shown in Figure 2.5. Most of them showed a decrease in CO_2 emissions in 2016; most notably the United States (-2.0%), the Russian Federation (-2.1%), Brazil (-6.1%), China (-0.3%), and, within the European Union, the United Kingdom (-6.4%). In contrast, the largest absolute increases were seen in India (+4.7%) and Indonesia (+6.4%) and smaller increases in Malaysia, Philippines, Turkey and Ukraine. For many of the largest emitting countries, this is a continuation of the trend of 2015. With an estimated 0.2% increase in CO_2 emissions, emissions in the European Union remained more or less the same in 2016. In contrast to most of the main emitters, the collective emissions from the rest of the world show a rising trend. Appendix A provides more detailed tables with the 1990–2016 CO_2 emission time series for the top 30 countries/regions and also emissions per capita and per USD of GDP.

Figure 2.5

CO_2 emissions from fossil-fuel use and cement production, per country and region



Source: EDGAR v4.3.2 CO2 FT2016 (EC-JRC/PBL 2017)

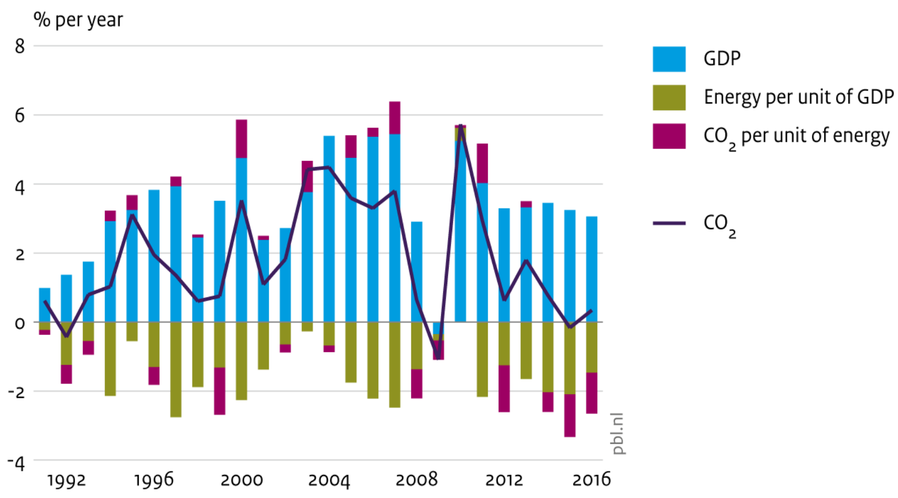
The trend in total greenhouse gas emissions and, more specifically, CO_2 emissions, can be further analysed using a decomposition method called 'Kaya identity' (Kaya, 1990; Van Vuuren et al., 2007; Peters et al., 2017), which is useful for separating the effects from three drivers of energy-related emissions: 1) changes in gross domestic product (GDP), 2) energy use per unit of GDP, which is an aggregate indicator of the overall energy intensity of an economy, and 3) CO_2 emissions per unit of energy (Figure 2.6). The latter depends on the share of fossil fuels in the total energy mix — with renewable energy sources and nuclear energy making up the remaining share – and also on the shares of coal, oil and natural gas within the fossil fuel mix. With respect to fossil fuel combustion, the combustion of coal emits more CO_2 than that of oil products and about twice as much as that of natural gas.

Figure 2.6 shows for the global economy how these factors change over time. The blue bars show the annual growth of global GDP in per cent (where we used GDP at Purchasing Power Parity, PPP). Although the interannual change can be large, in particular around economic recessions such as in 2008–2009, in the period since 1990 global GDP has increased by 3.3% per year on average, with a period of higher growth from 2003 to 2011 when the average annual growth was 4.1% (even 4.9% when excluding recession years 2008–2009).

Over the same period the average annual growth of global energy use was about 1.4% less than that of GDP, thus about 2.0%. This is shown with the negative green bars. The purple bars show whether the CO_2 emitted per unit of energy *increased* or *decreased* relative to the previous year. The *increases* shown for 2003 to 2007 coincide with years of high annual GDP growth, and this can be explained by China's very high growth rate of GDP and energy consumption, notably coal. Similarly, since 2011 the increasing global use of hydropower and new renewable power sources and nuclear power, and the global shift from coal to more oil and natural gas consumption *decreases* the CO_2 per unit of energy consumption on a global scale, as shown by the negative purple bars.

Figure 2.6

Change in global CO_2 emissions and their drivers, GDP and energy, based on Kaya decomposition



Source: EDGAR v4.3.2 CO2 FT2016 (EC-JRC/PBL 2017); World Bank (2017); IEA (2017); BP (2017)

The declining growth in annual CO_2 emissions since 2011 has continued over the past years, with 0.6% in 2012, 1.8% in 2013, and 0.8% in 2014, followed by -0.2% in 2015 and 0.3% in 2016 (±0.5%). This is not one-to-one related to the CO_2 concentration in the atmosphere, though. For more information on the CO_2 concentration, see Box 2.2. Over the last five years, global GDP has increased on average by about 3.3% per year, representing a slowdown relative to pre-economic crisis growth rates between 2003 and 2007, during which typical global economic growth was around 5% per year (for the 5-year average).

In 2016, the energy intensity of the economy, defined as total primary energy supply (TPES[4]) per unit of GDP (shown in green in Figure 2.6), has decreased by 1.5%. This is similar compared to the pre-crisis period. From this it can be deduced that, despite lower GDP growth, the global economy as a whole has maintained its annually decreasing energy intensity, but no structural change on this indicator has occurred in recent years. According to the International Energy Agency (IEA, 2017c), the annual energy intensity improvements should be at least 2.6% to be consistent with the climate goals from the Paris Agreement. According to the International Energy Agency (IEA) most of the energy intensity improvement in 2016 came from existing policies and two thirds of global energy supply is not covered by energy efficiency policies. Moreover, the rate of energy intensity improvement varies largely across countries. For further reduction in global CO_2 emissions, many more integrated policies on energy efficiency and renewable energy are pivotal.

[4] TPES, or Total Primary Energy Supply, is the total amount of energy consumption of a country (or the world). It is calculated as in BP (2017): using a substitution method for nuclear, hydropower and other non-biomass renewable energy and assuming 38% conversion efficiency in all cases.

Examples of areas for new or extending policies are the efficiency of heavy goods transport and air-conditioning and other cooling equipment (IEA, 2017c).

In 2016, global Total Primary Energy Supply (TPES[1]) increased by 1.3%. However, the emission intensity of energy, represented by CO_2 per unit of energy (shown in purple in Figure 2.6) has decreased over most of the past five years. This can be attributed to, firstly, the recent trend of coal having been substituted by other fossil fuels (with lower carbon emission factors) and, secondly, by renewable energy having increased in the energy mix, in particular in China and the United States. This trend is in sharp contrast with developments prior to the global economic crisis of 2008–2009. In several years in the early 2000s, global CO_2 emissions per unit of energy *increased*, which can be largely attributed to the fast industrialisation of China. Globally, the share of coal in total energy supply peaked in 2011 at 27.6% and declined to 25.3% in 2016, which corresponds with that in China, with a peak in 2011 at 66% and a much faster decline to 57.5% in 2016. In the United States, the share of coal in TPES also decreased relatively fast, from 21% in 2011 to 15% in 2016, with 4 percentage points in the last two years. In the European Union, the share also declined in these five years, from 14% to 11%, mainly due to a reduction in coal use in the United Kingdom. In contrast, large increases were seen in India and Indonesia, where coal consumption increased by a respective 4% and 23% in 2016. These countries showed a similar pattern in 2015 (BP, 2017).

Coal-fired power plants are the largest global source of CO_2 emissions. They contribute about one-third to global fossil-fuel related CO_2 emissions, only followed by road transport (17%) and coal used in the manufacturing industry (12%) (IEA, 2016). Their long lifetime may limit the potential for rapid reduction in global CO_2 emissions and new additions are therefore important for climate policy. More about trends and policies on coal-fired power plants can be found in Box 2.1.

Box 2.1 Coal-fired power plants worldwide

The amount of new coal capacity under construction plummeted in 2016, mainly due to a change in policy, economic conditions and the reducing costs of wind and solar power. In 2016, in China and India 68 GW was frozen at more than 100 project sites and globally more construction was frozen than entered the construction phase last year. With a total of 68 GW, retirements were very high in 2015 and 2016, mainly in the European Union and the United States (Shearer et al., 2017).

According to the most recent data at present there are 267 coal plants and units in construction, 154 of which are new coal plants and 113 are expansions of existing coal plants (new units) (Global Coal Plant tracker (Coalswarm, 2017). Of these 267, China is building 120 new plants and units (status of mid October 2017) and India has 45 under construction. Japan is building 14 new plants and units, the European Union is constructing 8 new station and units of which 5 are being build in Poland, and the Russian Federation is constructing 2 new plants. Other countries that have several under construction are Indonesia (13), the Philippines (11), Vietnam (10), South Korea (7), Pakistan (4). Turkey (3), Malaysia (3), and six more countries with 2 each (Morton, 2017).

As of July 2017 the *Global Coal Plant Tracker* showed a 40% decline in pre-construction planning capacity and a decline of 25% under construction, from the levels reported in July 2016. Although more coal-fired capacity is still being built than being closed, the average load factor for coal plants decreased globally since 2013. The average capacity factor of coal power plants in China and India is about 50% (Shearer, 2017). Investments in coal power in 2016 were down by 20%, with increasing investments in lower-cost solar, wind, and natural gas (IEA, 2017b).

Of the 1,675 companies owning coal-fired power plants or pursued development of them since 2010, over a quarter have exited the coal power business entirely, with no further development plans. India had most departing companies, followed by China, United States and Turkey (Huang, 2017).

In 2016, global fossil fuel consumption had a 75% share in total primary energy supply. The increase in oil and natural gas consumption of 2% more than offset the 1.4% decrease in coal use. The largest increases in the use of natural gas occurred in the European Union (notably in the United Kingdom and Germany), China and the United States. Oil consumption increased predominantly in China, India, the European Union, with smaller increases in South Korea and the United States. Hydropower and new renewable energy sources, such as wind and solar energy, had an 11% share, for nuclear power this was about 4.5%, and biofuels accounted for the remaining 10% of TPES. Wind and solar power together have continued to grow at double-digit growth rates, with a 20% increase in 2016. In absolute figures, the largest increases in wind and solar power in 2016 occurred in China and the United States.

The Global Carbon Project (GCP) has assessed the CO_2 trend for the current year 2017 individually for China, the United States and India and used GDP projections for all other countries, including the European Union countries, resulting in a forecast for the change in global CO_2 emissions in 2017 of +2.0% (range of +0.8% to +3.0%) (Le Quéré et al., 2017). In this report we made similar estimates for China, United States and the European Union based on available fossil fuel statistics for the first 8 months of 2017 for the consumption of coal, oil and gas (for China only monthly statistics for coal) and compared them with the GCP estimates (for details see Chapter 3).

In all cases, the estimates for 2017 based on more recent statistics suggest trends that are inconsistent with the GCP uncertainty ranges, which rises the question whether it is useful to estimate *annual* emissions in cases where only very partial and incomplete fuel statistics are available. Moreover, the estimation of CO_2 emissions for the subsequent year by using the Kaya identity means that the estimate for the next year is strongly related to estimated GDP growth. However, GDP growth is not a good a predictor of energy consumption for a single year, because a very large fraction of GDP is determined by low-energy intensive economic activities such as the service sector (that comprises two-thirds of global GDP).

2.3 Global atmospheric CO_2 concentrations surged in 2016

The increase of atmospheric concentrations of CO_2 is primarily due by the global CO_2 emissions from fossil fuel combustion, but the *very large* increase in 2016 was caused by other processes, as explained in Box 2.2.

Box 2.2 Global atmospheric CO_2 concentrations surged in 2016

Globally, average concentrations of CO_2 in the atmosphere surged at a record-breaking speed of 3.3 parts per million in 2016 to the highest level in 800,000 years of 403.3 ppm, an increase of 0.8%. The record increase in 2016 was mainly due to the man-made CO_2 emissions from fossil fuel combustion and other human activities, which did not change much compared to 2015, and partly due to the very strong 2015/2016 El Niño event (WMO, 2017).

The 2015/2016 El Niño event was one of the strongest since the 1950s and triggered the driest droughts in the last three decades in the tropical regions of South America and Asia, causing much more large-scale forest and peat fires in these three regions. In dry South America much higher temperatures caused vegetation to slow down photosynthesis, thus removing less CO_2 from the atmosphere. However, tropical Africa experienced hotter temperature but no drought, which enhanced the decomposition of dead vegetation, thus emitting more CO_2 into the atmosphere. Since global CO_2 emissions from fossil fuel use did not increase in 2015 and 2016, the strongly increased CO_2 concentrations can be attributed to the reduced capacity of the “land sink” of CO_2, the biosphere of forests and other vegetation also known as LULUCF, and/or a decrease in the “ocean sink” by less absorption of CO_2 (Irving, 2017; Liu et al., 2017).

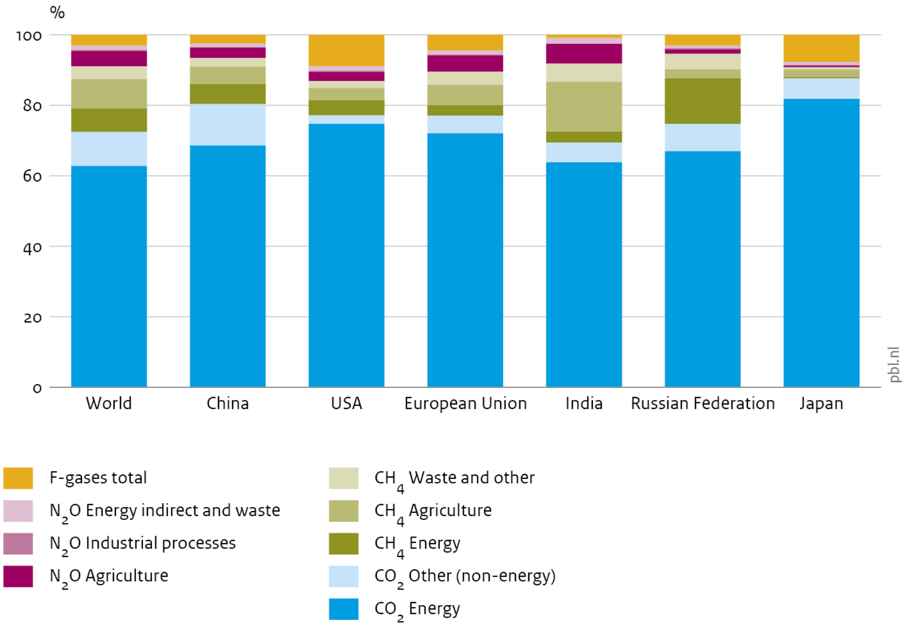
3 Trends in largest emitting countries and the EU28

In this chapter we discuss the emission trends of the six main emitters, consisting of five large countries, being the United States, China, India, the Russian Federation and Japan, and of the European Union (EU28) as a region. Between them there are large differences, in the share of the various GHGs, and in the emission intensity of their energy use. Globally, the combined share of CH_4, N_2O and F-gas emissions is about 28% in total GHG emissions (19%, 6%, and 3%, respectively), but it varies for the largest countries, from 11% for Japan to 31% for India. China's current share is estimated at 20%, that of the United States and the European Union at 23%, and of the Russian Federation at 25%, as illustrated by the non-blue parts of the bars in Figure 3.1.

These shares reflect the relative importance of non-CO_2 GHG emission sources, such as coal, oil and natural gas production (releasing CH_4), agricultural activities such as livestock farming (CH_4 emissions from ruminants and manure), rice cultivation (wet fields release CH_4 through fermentation processes in the soil), animal manure and fertiliser use on arable land (N_2O), and landfill and wastewater practices (CH_4).

Figure 3.1

Contribution to 2016 greenhouse gas emissions per emission category



Source: EDGAR v4.3.2. (EC-JRC/PBL 2017); IEA (2017); BP (2017)

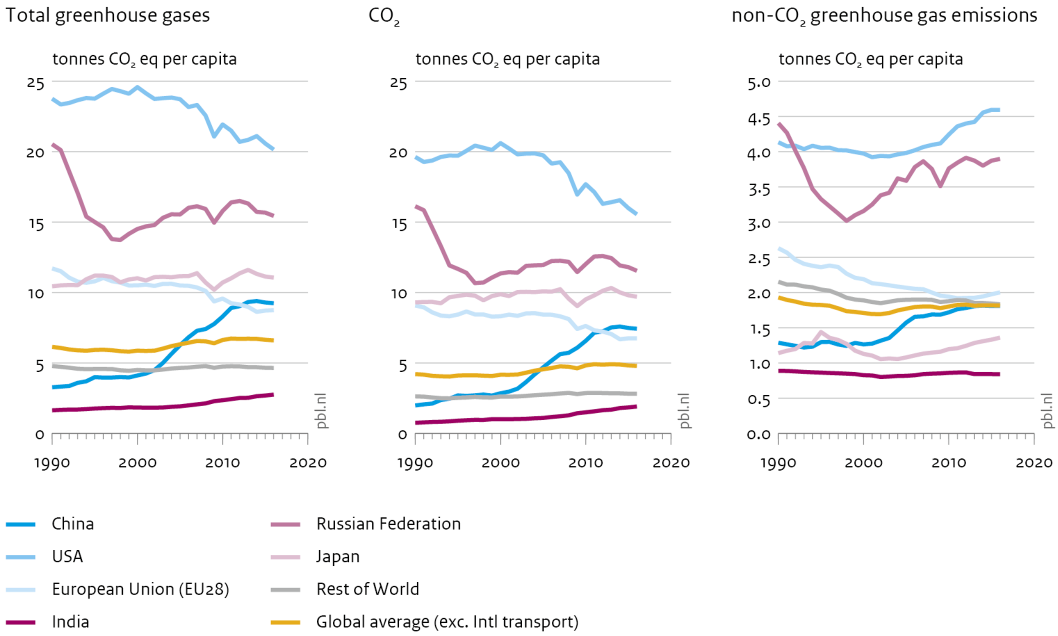
As discussed in Chapter 2, the emission trends of the largest countries and regions, apart from India, of which GHG emissions are rising, are relatively flat in 2016. In absolute values, the largest emitters are China, the United States, and the European Union, followed by India, the Russian Federation, and Japan. For non-CO_2 emissions only, India and the European Union switch rank.

After China's very rapid rise of its CO_2 emissions caused by the fast industrialisation that started in 2002, in 2005 China surpassed the United States as the world's largest emitting country. Since 2013 China's CO_2 emissions have been more than twice those of the United States (see Figure 2.5). However, for a proper perspective in comparisons between countries also the size of a country's activities should be accounted for. Therefore, the per capita emissions, and the emissions per USD of GDP, and their trends, are presented below, which allows for better comparison of level and trends between countries because it eliminates either population size or size of the economy of a country from the equation. Apart from that, it also provides reference values to assess in what direction emissions will progress if structural changes occur in population or economy of a country (or in the rest-of-world countries as a group).

Figure 3.2 shows emissions per capita for the five main emitting countries, the European Union, the rest of the world, and for the world average. Separate graphs are presented for total greenhouse gas emissions, for CO_2 only and for non-CO_2 greenhouse gas emissions. Except for India, all main emitters have per capita emission levels that are significantly higher than those for the rest of the world and the world average. China, in this measure, has rank 4, rather than rank 1, which it has for absolute emissions. Although CO_2 emissions in the United States have been steadily decreasing since 2000, from 20.6 tCO_2/cap to about 15.6 tCO_2/cap by 2016, it is the highest amount among the top 5 emitting countries and is only surpassed by three other G20 countries: Canada, Australia and Saudi Arabia. The United States, the Russian Federation, and Japan make up the top 3 for total and CO_2 emissions, while the United States, the Russian Federation, and the European Union form the top 3 for non-CO_2 emissions.

Figure 3.2

Emissions per capita

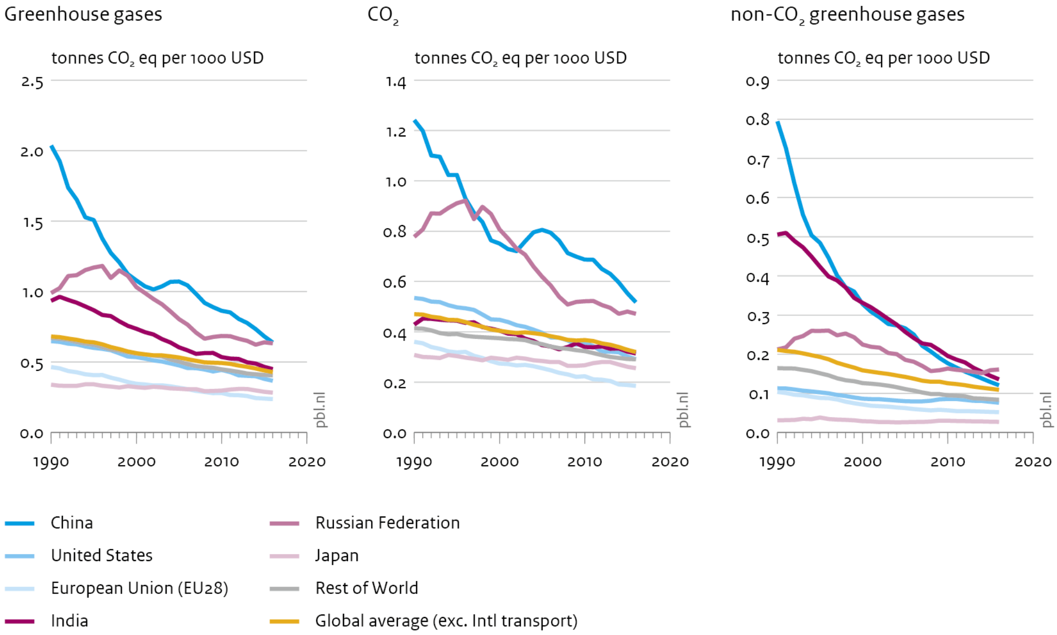


Source: EDGAR v4.3.2 (EC-JRC/PBL 2017); World Bank (2017); IEA (2017); BP (2017)

The emissions per USD of GDP (in 2011 prices and corrected for Purchasing Power Parity (PPP)) presented in Figure 3.3, show yet another image. Contrary to the per capita emissions, the top 5 countries and the European Union are not all above the world average when it comes to emissions per USD of GDP. In the United States, emissions per USD of GDP are virtually equal to the world average, while those in the European Union are the lowest per USD of GDP worldwide, closely follow by Japan. Emissions in China and the Russian Federation are the highest, and, especially for CO_2, significantly higher than the world average. The trend for all countries, except for the Russian Federation, is downward, including that for the world average. This is consistent with the Kaya decomposition of global CO_2 emissions in Figure 2.6, which shows that growing GDP not necessarily results in growth in total greenhouse gas emissions.

Figure 3.3

Emissions per US dollar of Gross Domestic Product (GDP, at PPP 2011 prices)



Source: EDGAR v4.3.2 (EC-JRC/PBL 2017); World Bank (2017); IEA (2017); BP (2017)

Appendix A provides in Tables A.2 and A.3 more details with 1990–2016 times series of per capita CO_2 emissions for the top 30 countries/regions and also a similar table with CO_2 emissions per USD of GDP.

In the remainder of this chapter we discuss the level and trends of emissions for the top-5 emitting countries and the European Union. We also show the relative trends of their CO_2 and non-CO_2 GHG emissions.

3.1 China

In 2016, according to our latest estimates, China's CO_2 emissions decreased by about 0.3% to about 10.5 Gt CO_2. This was mainly due to a 1.4% decline in coal consumption, partly compensated by increases in the consumption of natural gas and oil products of 8% and 3%, respectively (percentages in energy units, e.g. in PJ) (BP, 2017).

For 2017, statistics available mid November for the first 10 months shows that coal power *decreased* by 2.8% while total power generation increased by 2.5% and crude steel production increased by 2.8%, compared with the same months in 2016 (NBS, 2017c). When coal consumption would decline by 2.5% in total 2017 and the use of gas and oil products would increase by 9% and 4.5% (the average of the last five years), then China's CO_2 emissions would decrease by about 1%. This estimate is outside the uncertainty range of the GCP estimate of +3.5% (range of +0.7% to 5.4%) for 2017, which is based on data available mid September (Le Quéré et al., 2017).

In Figure 3.4, the Kaya decomposition for China illustrates the drivers behind the CO_2 emission trend. Looking at the 1990–2016 trend we see the following striking features. Already in the 1990s China showed a very large economic growth rate of almost 10% per year, according to official statistics. Because of the abundant domestic reserves of coal, China's economic development relied for the energy demand mainly on coal rather than oil or natural gas, thereby increasing its CO_2 intensity of energy use, which shows as the purple bars on top of the graph.

The very large *increases* shown for 2003 to 2007 coincide with the years of double digit annual GDP growth that occurred after it was admitted to the World Trade Organisation (WTO) in 2001. In 2003 and 2004 the growth of energy use was even higher than GDP growth, thus the two green bars on top of the GDP growth bars. In these years China's industrialisation took a higher gear with cement production in the top year soaring by 19% and steel production by 21%, essential for the development of new building for manufacturing and infrastructure for transportation of goods and people.

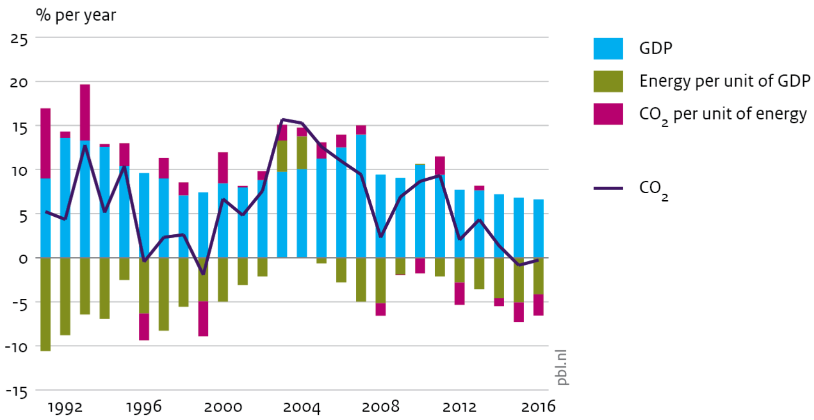
From the 1990s to 2010 China's annual CO_2 emissions per unit of energy *increased* since as coal consumption increases faster than other fossil fuels and more than non-fossil energy sources. However, since 2012, the growth of renewable power such as hydropower, wind and solar power, and nuclear power as well as the consumption of natural gas and oil products is higher than the growth in coal consumption, hence the CO_2 intensity per unit of energy consumption *decreased*, as did China's CO_2 emissions.

China's GDP has increased by 6.6% in 2016, while the population growth was only 0.5%. Thus, the CO_2 emissions have continued to decouple from economic growth in China and have even decreased marginally, by 0.3%. In 2016 the GDP growth rate, although still very high compared to many other countries, was lower than in recent years, assisting the decrease in emission growth. Since 2012 total primary energy supply in China increased by 10%, while the Gross Domestic Product (GDP) on PPP basis saw a growth of 31% in that period (an average of about 7%, per year). The energy intensity, resulting from structural changes of China's economy from energy-intensive industrial manufacturing, building and construction activities toward lower-energy economic activities, and national policies that also intervene with growth patterns in many parts of the economy, continues to decrease at a similar rate as in previous years. Energy efficiency improvement in China is important for reducing emissions of CO_2 and air pollutants. Investments in China account for more than a quarter of global total investments in energy efficiency (IEA, 2017b). However, the decrease in energy intensity has not become more pronounced in recent years, and therefore is not the main cause of the decrease in emissions.

Apart from decreasing GDP growth and continuing improvements in energy intensity of the economy, the main cause of the decrease in 2016 can be attributed to the CO_2 intensity of energy. This is related to a 1.4% decline in coal consumption offset by increases in the consumption of natural gas and oil products (BP, 2017), which is also shown and discussed below with Figure 3.6, for which we will discuss the developments in total primary energy supply in more detail.

Figure 3.4

Change in CO_2 emissions and their drivers, GDP and energy, based on Kaya decomposition for China

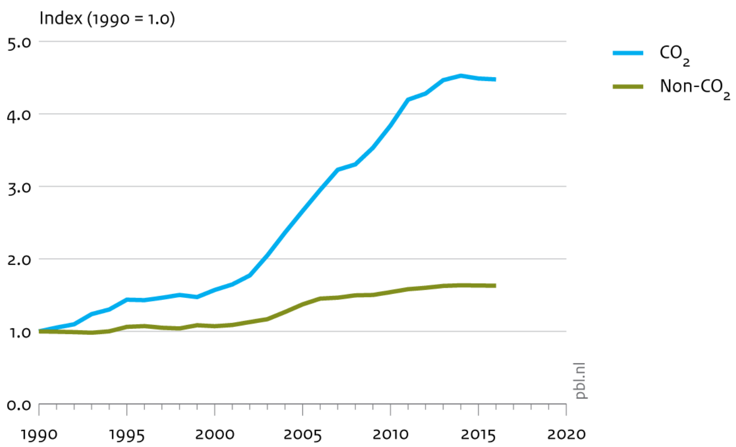


Source: EDGAR v4.3.2 CO2 FT2016 (EC-JRC/PBL 2017); World Bank (2017); IEA (2017); BP (2017)

In Figure 3.5, we compare the CO_2 trend to the trend in non-CO_2 emissions, indexed on the 1990 emission values. The CO_2 growth has been much steeper than the growth in non-CO_2 emissions, according to EDGAR v4.3.2 estimates. Since 1975, the annual growth in CO_2 emissions has exceeded that of non-CO_2 emissions in China. Similar to the CO_2 emissions, the non-CO_2 emissions in 2016 have

Figure 3.5

Trend on CO_2 and non-CO_2 for China



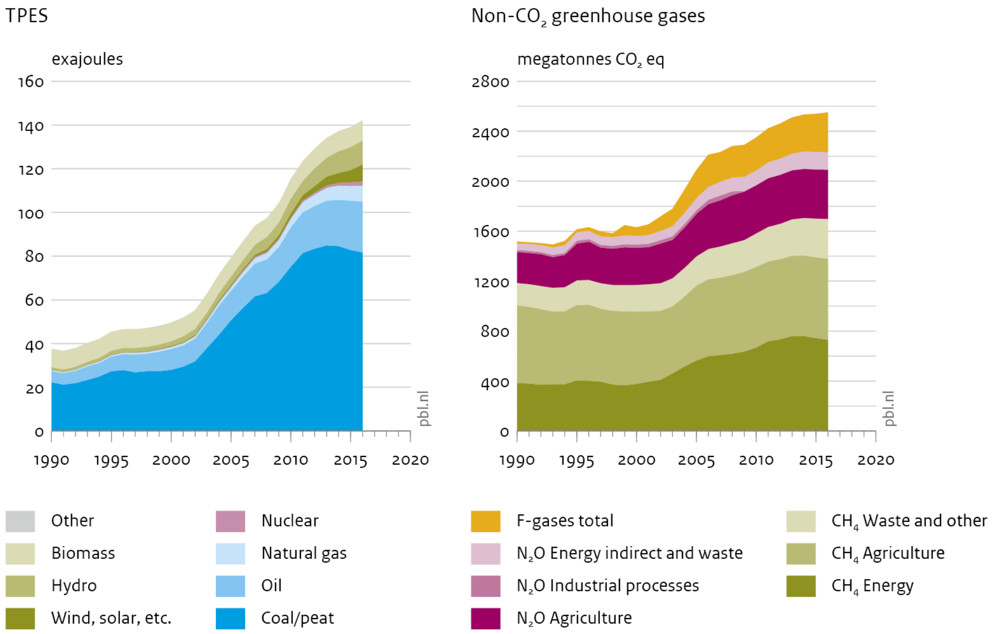
Source: EDGAR v4.3.2. (EC-JRC/PBL 2017); IEA (2017); BP (2017)

started a flatter trend in recent years. In 2016, non-CO_2 emissions have increased by a marginal 0.5%, not corrected for the leap year. F-gases have increased by 3.8%, but this is still a relatively small category. Methane emissions have stayed at the same level as in 2015, and N_2O emissions increased by 0.5%. Total greenhouse gas emissions in China have decreased by 0.1% in 2016.

The trend in total primary energy supply is shown in Figure 3.6 (left). As also observed in the Kaya decomposition, the recent decrease in emissions is mainly driven by decreases in coal consumption by about 2% in the last two years, partly offset by increases in the use of oil products of 6.3% and natural gas by 4.7% in 2016 (BP, 2017). The total fossil fuel consumption remained almost flat since 2013 (IEA, 2016; BP, 2017). The resulting increase in energy demand in 2016 compared to 2013 of about 6% was mostly met by increased use of renewable energy sources: wind and solar power as well as hydropower, the share of which increased by 4 percentage points to almost 20% in 2016.

Figure 3.6

Trend of Total primary Energy Supply (TPES) and non-CO_2 greenhouse gases in China



Note: Figures were calculated using a substitution method for nuclear, hydro and other non-biomass renewables as in BP 2017 (i.e. assuming 38% conversion efficiency)

Source: EDGAR v4.3.2. (EC-JRC/PBL 2017); IEA (2017); BP (2017)

Of total national CO_2 emissions from coal, oil and natural gas combustion, China has one of the highest shares of 81% CO_2 emissions from coal, only beaten by South Africa coal with 83%. Other large countries with high coal shares are Indonesia (81%) and South Korea (75%), which are all high in comparison with the global average of about 46% that stem from coal combustion. About half of China's CO_2 emissions are from power generation, virtually all from coal-fired power plants, about one-third from the manufacturing industry, almost all from coal combustion, and almost one-tenth from the residential and commercial sector (houses, offices and shops) (IEA, 2016).

In response to the increasingly low load factors of Chinese coal power plants (47.5% in 2016), the government of China has implemented new measures to restrict further expansion of coal-fired power capacity. These include suspension of new approvals in many provinces and halting the start of construction in several others, shut down of outdated coal plants, halting 'provincial self use plants' (e.g. aluminium smelters), and cancellation of planning and construction of 85 plants. This resulted in investments in new coal-fired power plants to drop by 25% in 2016 (IEA, 2017b). In addition, in China's 13th Five Year Plan a coal power capacity cap of 1,100 GW by the end of 2020 was announced (current capacity is 960 GW) (Shearer et al., 2017). This also means that a total of 150 GW of new coal power generation capacity construction will be halted or postponed from 2016 to 2020, the 13th Five-Year Plan period. In addition, 20 GW of outdated capacity will be shut down, and nearly 1,000 GW of coal power capacity will be upgraded to produce fewer emissions and use less energy (EIA, 2017f; Xinhua, 2017). The coal power cap of 1,100 GW means that on top of the present capacity of 960 GW and the 20 GW to be scrapped, still 160 GW of new coal power capacity may be added until the end of 2020 – or about 1 GW per week.

Addressing coal power overcapacity is getting more urgent by newly increased targets for wind and solar power capacity (Myllyvirta and Danqing, 2017). However, another issue that needs to be addressed in wind and solar power generation is to make better use of the renewable power that is generated. Presently, a large and growing proportion is going to waste. In 2016, the wind curtailment rate – the amount of wind power that could have been generated and used but wasn't – reached 17%, more than double what it was in 2014. Meanwhile China's solar curtailment rose by 50% in 2015 and 2016 (Boren, 2017).
In the last three years total power generation increased by 4.0%, 2.9% and 5.6%, respectively, resulting in a total increase of 23% since 2012. For 2017 the first 10 monthly statistics from the National Bureau of Statistics of China (NBS) from January to October show an increase of 2.5% in total power generation (NBS, 2017c). Power generation from renewable and nuclear energy increased by 42% since 2012. In 2016, hydropower and nuclear power generation increased by 5.6% and 24.9%, respectively, resulting in shares of 18.9% and 3.5% (BP, 2017). Although the shares of wind and solar power are increasing fast, currently they account for only 3.9% and 1.1% of total power generation, respectively (BP, 2017). In 2017, electricity production by fossil fuel power sources *decreased* by 2.8% in the first 10 months statistics (January to October) compared with the same months in 2016. Almost all of 'thermal' refers to coal power with a few percent natural gas. However, all other (i.e. zero-CO_2) power sources increased in these 10 months: hydropower was up 16.9%, nuclear power up 15.2%, wind power up %11.7% and solar power up by 35.7% (NBS, 2017c).

The manufacturing industries account for more than half of total electricity consumption. Of the energy-intensive industries, the production of crude steel, aluminium and ethylene increased in 2016 by 0.6%, 1.5% and 3.9% in 2016 and changed by -2.2%, +8.8% and +1.1% in 2015, respectively (NBS, 2017a,b). In 2017, production of these materials changed from January to October by +6.1%, -7.5% and 8.5%, respectively, compared with the same months in 2016 (NBS, 2017c). In the residential and commercial sectors, the demand for space heating, half of which is met by coal combustion, was about 4% higher in 2016 than in 2015 due to colder winter temperatures (based on heating degree days in 2015 and 2016, for the 21 largest cities). Since this affects only about 8% of CO_2 emissions the impact on 2-16 emissions is only 0.2 percentage points.

Although most of China's CO_2 emissions stem from fossil fuel combustion (86%), about 7% originate from the calcination of limestone in the chemical process of cement clinker production. Together with CO_2 emissions from other industrial uses of limestone such as lime production, around 9% of national CO_2 emissions stem from these calcination processes. Of other large countries, in Turkey, Egypt and Nigeria this share in total CO_2 emissions is also around 10%. The production of cement decreased 5.3% in 2015 and increased 2.3% in 2016. In 2017, cement production *decreased* by 3.1% in the first 10 months (statistics from January to October), compared with the same months in 2016 (NBS, 2017a,b,c).

The non-CO_2 emissions, shown in Figure 3.6 on the right, have increased only marginally in 2016, especially if you correct for the leap year. F-gases was the largest growing category, by 3.8%. The largest emission source of non-CO_2 emissions by far is coal mining, responsible for 27% of methane emissions. Energy-related methane emissions in general cover 43% of methane emissions, and have decreased by 1.9%. Methane emissions associated with waste handling (mainly landfills and wastewater) is the fastest growing source, of which emissions in 2016 increased by 3%. Agricultural methane emissions are another large source, covering 38% of methane emissions. Contrary to most countries, in which cattle are the main source of agricultural methane emissions, in China the largest agricultural source is rice cultivation, responsible for 21% of total methane emissions. Methane emissions from agriculture have remained at the same level as in 2015. N_2O emissions have only increased marginally in 2016. Its major source are synthetic and natural fertilisers. F-gas emissions are mainly due to the industrial production of halocarbons, resulting in HFC-23 emissions that make up over 70% of F-gas emissions (without accounting for additional abatement). Table 3.1.1 shows a snapshot for China of total greenhouse gas emissions per main source sector and gas in 2016.

Table 3.1.1 Emissions of CO_2 and other greenhouse gases in China in 2016

China	CO_2	Non-CO_2	CH_4	N_2O	F-gas
Total sectors (Mt CO_2 eq)	10483	2551	1698	537	316
Energy	9093	796	730	67	0
Industrial processes	1340	324	6	2	316
Agriculture	21	1042	649	394	0
Waste	1	336	312	24	0
Indirect and other	28	52	2	50	0

3.2 United States

In the United States, CO_2 emissions decreased in 2016 by 2.0% to 5.0 Gt CO_2. This was mainly due to an unprecedented 8.5% decrease in coal consumption, partly compensated by 0.8% increases in the consumption of both natural gas and oil products (BP, 2017). These percentages are very close to those reported by the U.S. Energy Information Administration, when taking into account that their numbers include fuel used for international transport (bunkers) (EIA, 2017a).

For 2017, available fuel statistics for the first 8 months shows that coal consumption was up 0.6%, oil products up 0.7% and natural gas down 5.2%, compared with the same months in 2016 (EIA, 2017g). However, the last third part of the year can significantly modify this, depending on the weather in the last four months from September to December (influencing the fuel demand for space heating, thereby affecting the demand for coal power and gas power). When fossil fuel consumption would change likewise in total 2017 then the US CO_2 emissions would increase by about 2%. This estimate is outside the uncertainty range of the GCP estimate of -0.4% (range of -2.7% to +1.0%) for 2017 which was based on a projection by the EIA (Le Quéré et al., 2017).

In Figure 3.7, the Kaya decomposition for the United States further illustrates the drivers behind the CO_2 emission trend. When looking at the annual change in CO_2 emissions (black line), we see that since 1990 in most years emissions increased up to 2005, resulting in an increase over this period of almost 18%, whereas since 2005 CO_2 emissions declined in most years to a level in 2016 that is 14% below the peak level of 2005. This is the combined impact of the change in total primary energy supply since 2005: decreases in coal (-9 EJ) and oil (-6 EJ) versus increases of natural gas (+6 EJ) and wind and solar (+3 EJ) (see the TPES trends in Figure 3.9 (left)).

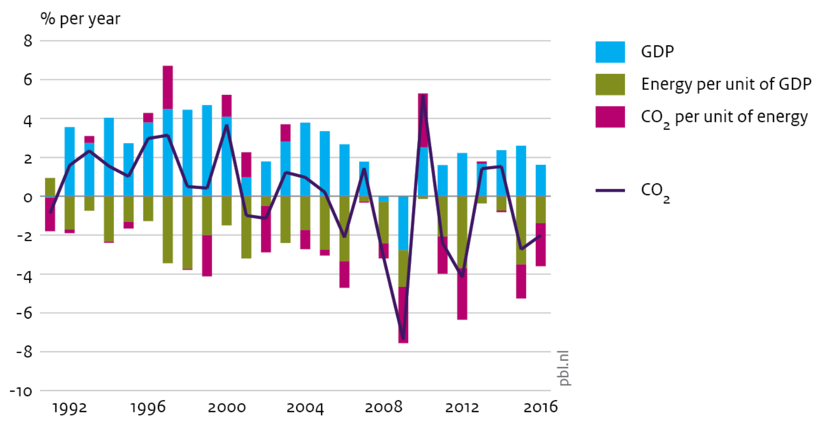
Part of the annual changes in CO_2 emissions can be explained by varying winter temperatures, with demand of fuel for space heating higher than normal in cold winters and lower in mild winters. Using the number of *Heating Degree Days* (HDD) as a proxy, that shows that the winter months of 1991 to 1997 were cold, 1993 and 1996 even very cold, so more fuel was used for space heating in these years – in very cold winters about 10% more. Other relatively cold winters were in 2003 and 2014, also resulting in more fossil fuels used and thus higher emissions. Conversely, years with mild winters were seen in 1998, 2006 and in recent years in 2012, 2015 and 2016. The winter months of 2012 and 2016 were relatively very warm, with space heating more than 11% lower than in normal winters. This explains part of the relative large or small increases of total energy use, show in Figure 3.7 as relatively large or small changes in the energy intensity of GDP.

When looking at the changes in CO_2 per unit of energy used, excluding the two recession years, we see that *increases* only occur in years before 2005 (*positive* purple bars), whereas in normal years after 2005 only *decreases* occur (*negative* purple bars). This mainly reflects the changes in the share of coal (notably coal-fired power plants) in the energy mix because that has the largest carbon content per unit of energy.

The rise, peaking in 2005 and fall of total CO_2 emissions in the United States mirrors very much the trend in coal consumption. Coal is mainly used for power generation. Since 2005 the domestic production of natural gas by hydraulic fracturing soared, which boosted the use of gas for space heating in the residential sector and for power generation. Interestingly, the use in these sectors is interrelated: in cold winters the demand for space heating increases and so does the gas price. Then, when natural gas prices are high, utilities that can switch between coal-fired and gas-fired power will use the most economic option and switch to coal-fired power plants. After the peak in 2007 of coal use for power generation, all years saw declining coal use, except in 2010 (recession) and 2013 (cold winter after very warm winter months in 2012). In recent years, the largest declines were in 2012, 2015 and 2016, by 11.7%, 18.3% and 8.3% respectively, due to the very warm winter months in these years and therefore low natural gas prices.

Figure 3.7

Change in CO_2 emissions and their drivers, GDP and energy, based on Kaya decomposition for the United States



Source: EDGAR v4.3.2 CO2 FT2016 (EC-JRC/PBL 2017); World Bank (2017); IEA (2017); BP (2017)

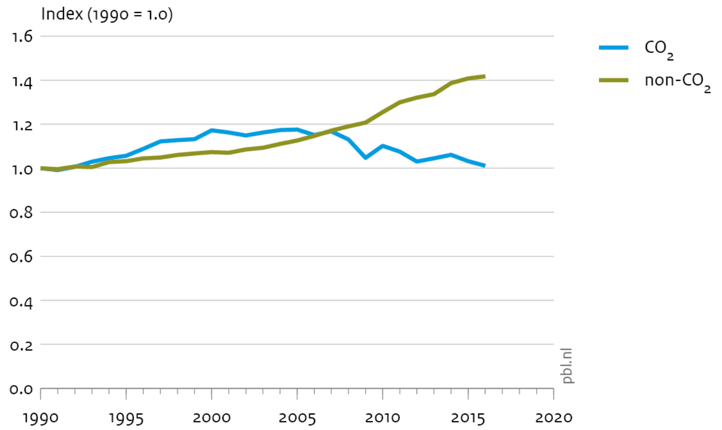
From this it can be concluded that the decreasing CO_2 emission trend since 2005 is the combined result of a lower GDP, with similarly lower energy intensity, and lower CO_2 intensity of energy due to the decline of coal power. GDP in 2016 increased by 1.6%, at a similar rate to that in 2013 and even 2011, but somewhat lower than the average over the past years. The CO_2 intensity of energy in 2016 decreased by 2.2%, mainly due to a decrease in coal consumption (notably coal power) as a result of low natural prices because of the very warm winter months, but also due to increases in the consumption of other energy sources: natural gas, oil products and wind and solar power (BP, 2017). This is also illustrated and further discussed below in Figure 3.9 (left).

In Figure 3.8 we compare the CO_2 trend to the trend in non-CO_2 emissions, indexed on the 1990 emission values. Contrary to the CO_2 emissions, the non-CO_2 emissions continue to show a rising trend. Total GHG emissions decreased by 1.4% in 2016. Non-CO_2 greenhouse gases in 2016 made up 23% of the total GHGs (excluding LULUCF), its highest share since 1990. As can be seen in Figure 3.9 (right) this can be attributed to the steady rise in F-gases since 1990, and partly to the rise in energy-related CH_4 (mainly from coal mining and natural gas production) between 2010–2013.

The trend in total primary energy supply is shown in Figure 3.9 (left). The 97% share of total CO_2 emissions stemming from fossil fuel combustion is the highest among the G20 countries. About 40% of CO_2 emissions are from power generation, of which about three quarters from coal-fired power plants and one quarter from natural-gas-fired plants**.** The demand for electricity has remained rather constant since 2005, but in 2016 the carbon intensity of the power sector decreased by 5%, for the second consecutive year (EIA, 2017c), as a result of coal being substituted with natural gas and renewable energy. Over the last ten years natural gas has displaced coal in the power generation mix of the nine Northeast states. Due to increased access to natural gas its share increased from 23% in 2006 to 41% in 2016 and the share of coal-fired power generation in these states declined from 31% to 11% over these years (EIA, 2017d). This can be attributed to a combination of low natural gas prices and policy (Clean Power Plan and the Mercury and Air Toxics Standards (MATS) (EIA, 2017e)). In 2016, for the first time, natural gas was the leading fuel in power generation, displacing coal as the leading fuel. Coal consumption decreased, in 2016, by 8.5%, while natural gas and oil consumption increased, marginally (~1%) (BP, 2017).

Figure 3.8

Trend of CO_2 and non-CO_2 for the United States



Source: EDGAR v4.3.2. (EC-JRC/PBL 2017); IEA (2017); BP (2017)

The increase in oil consumption in 2016 is consistent with the increase in CO_2 emissions from the transportation sector have increased in 2016 (EIA, 2017a,b). CO_2 emissions from road transport account for two thirds of total oil-combustion-related emissions, with fairly equal shares for the remaining emissions between the manufacturing industry, other domestic transport, the residential and commercial sector (i.e. buildings) and refineries (IEA, 2016).

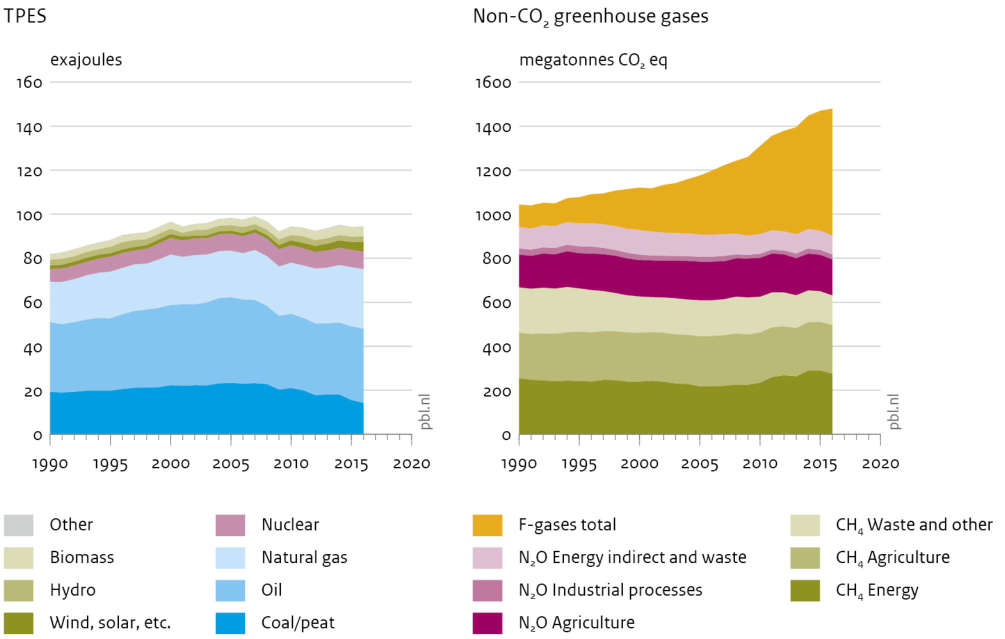
The increase in natural gas demand can be attributed to its increased consumption in the electricity sector — partly to substitute the decrease in coal-fired production (EIA, 2017a) and partly offset by a decrease in heating demand in the residential and commercial sector. In the United States, 2016 was recorded the second warmest year on record behind 2012 since records started in 1895. This resulted in relatively low number of Heating Degree Days (HDD) in these years, which are indicators for the demand for space heating (EIA, 2016b). Because heating degree days in the United States exceed cooling degree days by a factor of around 3, energy consumption in the residential and commercial sector is mainly the result of the number of heating degree days. The lower demand for space heating contributed to the decrease in CO_2 in 2016 by about 0.5 percentage points.

Apart from the 97% in CO_2 emissions from fossil-fuel combustion in the United States, half of the remaining 3% originates from industrial non-combustion processes, mainly from the production of chemicals such as ammonia and ethylene and from cement clinker production. These sources increased by about 2% in 2016 (USGS, 2017). Gas flaring is a relatively small source of CO_2 emissions; however, due to emission increases from oil and natural gas extracted by hydraulic fracturing, total CO_2 emissions from gas flaring increased by about two thirds since 2012.

Total CO_2 emissions have steadily declined since 2005, whereas non-CO_2 emissions have shown a steady rise since 2005 (Figure 3.9, right). The 0.7% increase in non-CO_2 GHG

Figure 3.9

Trend of Total primary Energy Supply (TPES) and non-CO_2 greenhouse gases in the United States



Note: Figures were calculated using a substitution method for nuclear, hydro and other non-biomass renewables as in BP 2017 (i.e. assuming 38% conversion efficiency)

Source: EDGAR v4.3.2. (EC-JRC/PBL 2017); IEA (2017); BP (2017)

emissions in 2016 was due to a significant increase (~6%) of F-gases, partly offset by the decrease in methane (-3%) and N_2O emissions (-1%). The F-gases trend is much steeper than the GDP trend, but we recall that those emissions are very uncertain.

Overall, in 2016 the increase of non-CO_2 emissions per USD of GDP is 0.5% and the increase in non-CO_2 emissions per capita is 1.4% (see also Figures 3.2 and 3.3). Methane emissions have, after an on average increasing trend since 2005, decreased in 2015 and 2016. This decrease can be attributed to decreases in methane emissions from energy (mainly reduction from coal mining, but also from oil and natural gas production) and from solid waste disposal, which are large categories of emissions. Emissions from energy constitute 43% of methane emissions, of which the largest categories are gas production, which contributes 19%, and flaring and venting from gas and oil production (another 14%). Agricultural emissions on the other hand have shown small increases and contribute 35% to methane emissions, of which non-dairy and dairy cattle in the United States are responsible for the majority, adding up to 25% of methane emissions. Over the past years, emissions from non-dairy cattle have shown a decrease of 1% to 2%, annually. Another fairly large agricultural source is rice cultivation, of which emissions have increased by two-digit growth rates yearly since 2013. However, they still contribute less than 2% of methane emissions, and emissions from this source have been this high before. Table 3.2.1 shows a snapshot for the United States of total greenhouse gas emissions per main source sector and gas in 2016.

Table 3.2.1 Emissions of CO_2 and other greenhouse gases in the United States in 2016

United States	CO_2	Non-CO_2	CH_4	N_2O	F-gas
Total sectors (Mt CO_2 eq)	5012	1480	632	273	575
Energy	4888	333	276	58	0
Industrial processes	108	598	1	22	575
Agriculture	11	385	221	163	0
Waste	0	143	134	9	0
Indirect and other	5	21	0	20	0

3.3 European Union

In 2016, total CO_2 emissions in the European Union (EU28) have increased by about 0.2% to 3.4 Gt CO_2. This flat trend was mainly due to an 8.7% decrease in coal consumption, compensated by increases in the consumption of natural gas and oil products of 7.4% and 2.1%, respectively (BP, 2017). When corrected for the extra day of the leap year 2016, the CO_2 trend would be slightly negative by 0.1%.

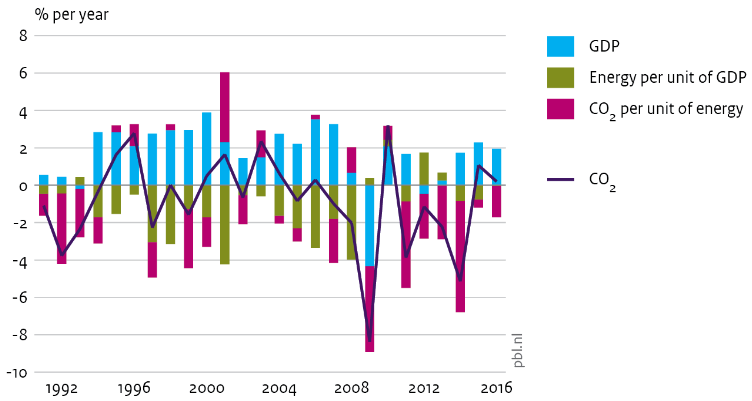
For 2017, available fuel statistics for the first 8 months shows that coal consumption was up 1.9%, oil products up 2.2% and natural gas up 8.8%, compared with the same months in 2016 (Eurostat, 2017c). However, the last third part can significantly modify this, depending on the weather in the last four months from September to December (influencing the demand for space heating and the wind and solar power produced, thereby affecting the demand for coal power and gas power). When fossil fuel consumption would change likewise in total 2017 then the European Union's CO_2 emissions would increase by about 3.7%. This estimate is outside the uncertainty range of the GCP estimate of -0.2% (range of -2.0% to +1.6%) for 2017 which is based on a projection of GDP and a simplified Kaya Identity (Le Quéré et al., 2017).

In Figure 3.10, the Kaya decomposition for the European Union illustrates the drivers behind the CO_2 emission trend. The declining CO_2 intensity of energy use in the 1990s is caused by the decrease of coal consumption in the new Member States (former Eastern European countries such as former Eastern Germany, Poland, the Czech Republic and Romania), where old and inefficient coal-fired power plants were phased out. In the United Kingdom the "Dash for Gas" in the 1990s meant a shift from coal power to new privately owned gas-fired power generation using natural gas produced in the British part of the North Sea. This decline of coal use shows in the figure as declining CO_2 intensity per unit of energy used and annually decreasing emissions, with an exception in 1995–1996 due to a very cold winter in 1996. In later years, coal power in the European Union is replaced by increasing wind and solar power, in particular in the United Kingdom, Germany and Italy. The large *increase* of CO_2 intensity of energy in 2001 is due to a very large *decline* in hydropower production and the large *decline* of CO_2 intensity in 2011 is also due to a unusual large *increase* of hydropower. From this we can see that the rather flat trend in CO_2 emissions since 1997 can be attributed to both a decrease in energy intensity of the economy in many years and a decrease in carbon intensity of energy (in most years) that together offset the continuing growth in GDP (apart from the recession years). Since 2007 the CO_2 intensity of total primary energy supply (in purple) has decreased significantly, with the exception of the recession years 2008 and 2010. The decrease in CO_2 intensity in 2016 was mainly due to an 8.7% decline in coal consumption, however, mostly off-set by increases in the consumption of natural gas and oil products that have a two-third share in total energy supply (see Figure 3.12 (left)), by 7.4% and 2.1%, respectively (BP, 2017). Only the recession years 2008 and 2009, and 2014, saw a similar or larger decline in coal consumption.

Furthermore, the years 2001 and 2010 stand out in the graph with increases in CO_2 intensity. These were years with very cold winters compared to other years as indicated by the high number of so-called Heating Degree Days (HDDs) and the large increases of HDDs compared to the previous year (the same applies to 1995 and 1996) (Eurostat, 2017a), affecting energy demand for space heating proportionally. In 2010 the 12% higher demand for space heating increased the CO_2 emissions in 2010 by about 2 percentage points. Likewise, the winter months of 2014 were rather mild, with 11% less HDDs than in 2013, whereas the winters of 2015 and 2016 were both colder compared to the previous year (3.4% and 4.2% lower HDDs, respectively). This effect caused 2014 emissions to be about 2 percentage points lower than normal and 2015 and 2016 CO_2 emissions to be about 0.6 percentage points higher than normal.

Figure 3.10

Change in CO_2 emissions and their drivers, GDP and energy, based on Kaya decomposition for the European Union (EU28)

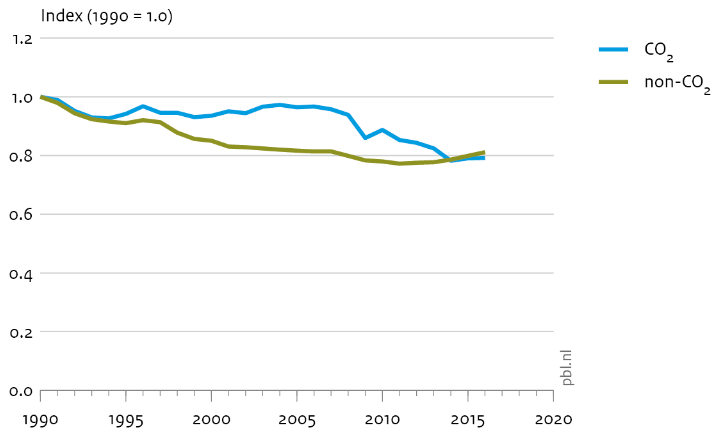


Source: EDGAR v4.3.2 CO2 FT2016 (EC-JRC/PBL 2017); World Bank (2017); IEA (2017); BP (2017)

In the European Union both CO_2 and non-CO_2 greenhouse gas emissions have decreased considerably since 1990, according to EDGAR 4.3.2 estimates, each by more than 20% and CO_2 emissions by 18% since 2004 (Figure 3.11). The trend for total greenhouse gas emissions is also negative, with a decrease of about 21% compared to 1990 according to EDGAR 4.3.2 estimates and by 24% according to official European Union data. Although the official reported non-CO_2 emissions of the European Union have decreased much faster than the EDGAR estimates, their share in total greenhouse gas emissions is less than one fifth, so this has limited impact on the trend in total greenhouse gas emissions.

Figure 3.11

Trend of CO_2 and non-CO_2 for the European Union (EU28)



Source: EDGAR v4.3.2. (EC-JRC/PBL 2017); IEA (2017); BP (2017)

The trend in total primary energy supply is shown in Figure 3.12 (left). In the European Union coal consumption has been steadily decreasing, mainly due to the phasing out of coal-fired power plants in several countries. However, while the United Kingdom has closed a significant amount of its coal power plant capacity, in the last decade Poland, Germany, Italy and the Netherlands have constructed new ones (Climate Analytics, 2017; CAN Europe, 2017). For the latter it should be mentioned that the Dutch government decided in October 2017 to close the five remaining (and relatively new) coal power plants by 2030 (Wynn, 2017; Darby, 2017). At present seven new plants and one new unit are currently under construction in the European Union: four stations and one new unit in Poland and three stations in Germany, Czech Republic and Greece, one in each country (Morton, 2017). Countries including the United Kingdom France, Portugal, Austria and Finland are phasing out coal and have policies in place to end its use in power generation (Shankleman et al., 2017). The countries that most contributed to the decline in coal consumption in 2016 are the United Kingdom – where coal consumption fell by more than 50% – and Spain and Germany with declines of 24% and 4%, respectively.

The United Kingdom, Germany and France contributed most to the large 7.4% increase in total natural gas consumption in the European Union in 2016, with respective increases of 13%, 9% and 9% (BP, 2017). In recent years only in 2010 the European Union saw a similar increase in natural gas use, which was strongly related to the very cold winter in that year (Eurostat, 2017b). The European Union was in 2016 still the largest producer of wind and solar power in the world, although the annual increase in wind power stalled last year (see also Figure 3.12 and Tables C.3 and C.4 in Appendix C). For China and the United States, the numbers two and three, the annual increase in wind power continued to increase.

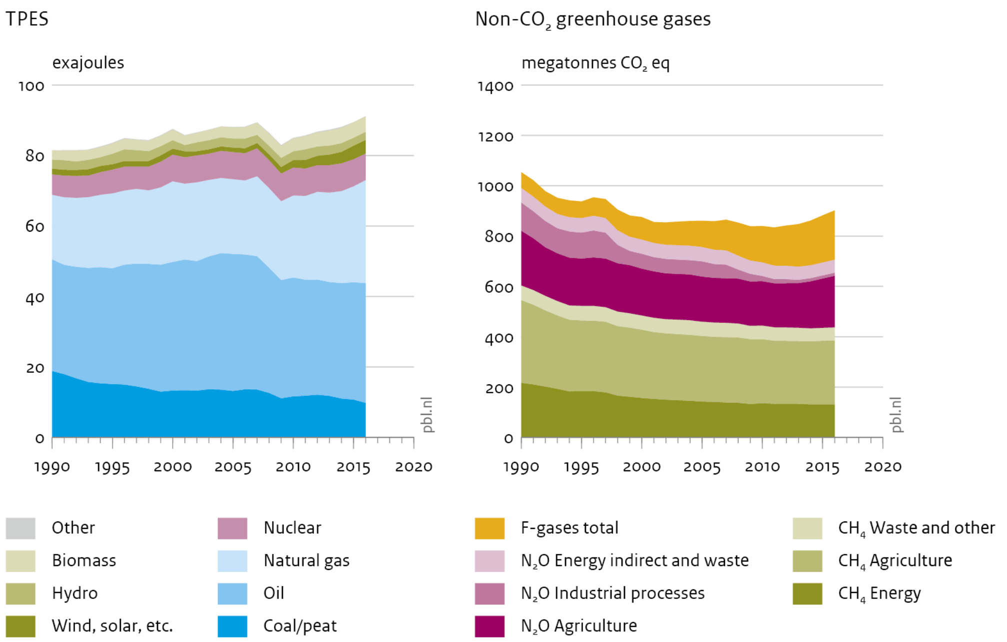
The different members of the European Union show very different trends. The United Kingdom strengthened the CO_2 emissions decrease from -4% in 2015 to -6% in 2016, while Spain weakened the CO_2 emissions increase from +7% in 2015 to +3% in 2016. Other countries changed completely from a significant increase in 2015 to a decrease in 2016, such as Bulgaria with +5% in 2015 to -6% in 2016. This was observed for several northern countries (which are more subject to cold winters): Finland, Denmark and Sweden changed their decrease in 2015 (of -10%, -8% and -3%) to significant increases in 2016 (of 4%, 5% and 4%, respectively).

Oil consumption has increased by 2.1% in 2016. Other energy consumption trends are nuclear energy (-2.0% per year), hydropower (+2.0% per year) and other renewable energy (0.8% per year). A fuel shift away from coal is generally observed: towards natural gas (such as in the United Kingdom), towards nuclear fuel (such as in Belgium and Sweden), and towards renewable energy (such as hydropower in France, Portugal and Romania). Even though no large increases in other types of renewable energy are observed, it should be noted that, by the end of 2016, Germany and Denmark were the world leaders for the per capita capacity of solar PV and wind power, respectively (REN21, 2017).

CO_2 emissions from non-combustion production processes have been significant, with a 6.5% share in the total. These emissions showed an increase of +3.2% per year in 2016, compared to 2015. The major contributors are cement and lime production and the metal industry, with respective shares of 2.4% and 0.6% in total greenhouse gas emissions. Cement and lime production emissions in 2016 were 10% higher than in 2015, representing a doubling of the increase observed in 2015. Non-combustion process emissions from the metal industry decreased by 1.8%, mainly because of the 5.2% decrease in pig iron production in 2016, compared to 2015.

Figure 3.12

Trend of Total primary Energy Supply (TPES) and non-CO_2 greenhouse gases in the European Union (EU28)



Note: Figures were calculated using a substitution method for nuclear, hydro and other non-biomass renewables as in BP 2017 (i.e. assuming 38% conversion efficiency)

Source: EDGAR v4.3.2. (EC-JRC/PBL 2017); IEA (2017); BP (2017)

In the European Union, 52% of the total greenhouse gases fall under the Emissions Trading System (EU ETS), and are almost all (50%) are emissions emitted by industrial and energy facilities, which are steadily reducing their emissions (2% are CO_2 emissions from aviation). In 2016 the EU ETS saw 2.9% decrease, compared to 2015, which is a larger reduction than in 2015 (when the reduction was only 0.7%). All these facilities present a continued effort in decreasing CO_2 emissions from combustion by 3.8% and process gases by 1.1% in 2016. In addition, the aviation sector with a 1.8% share in total GHG contributes to EU ETS emissions with growing importance since 2013, and with a 7.5% increase in 2016 compared to 2015.

The 'Clean Energy For All Europeans' package, more commonly referred to as the 'Winter Package' of 30 November 2016, wants the European Union to lead the clean energy transition (EC, 2016) and sets a 2030 reduction target for domestic GHG emissions of 40% compared to the 1990 level. This should be achieved by three measures: (1) an increase in energy efficiency of 30% in 2030 compared to the 2005 level, (2) leadership in renewable energy, with a 27% share of renewable energy consumed in the European Union by 2030, and (3) a fair energy deal for consumers, with transparent energy costs, easier switching between providers, and, for the European Union as a whole, a 35% reduction in the import bill for primary energy. Table 3.3.1 shows a snapshot for the European Union of total greenhouse gas emissions per main source sector and gas in 2016.

Table 3.3.1 Emissions of CO_2 and other greenhouse gases in the European Union in 2016

European Union	CO_2	Non-CO_2	CH_4	N_2O	F-gas
Total sectors (Mt CO_2 eq)	3432	1018	553	269	196
Energy	3232	160	131	29	0
Industrial processes	189	208	1	12	196
Agriculture	7	459	254	205	0
Waste	4	179	167	12	0
Indirect and other	0	11	0	11	0

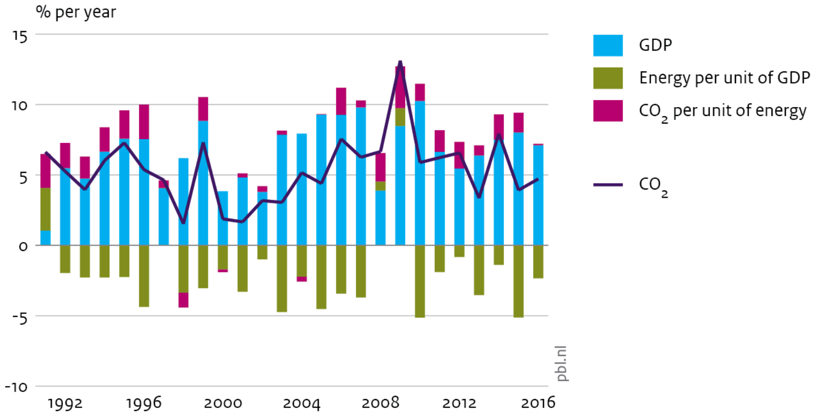
3.4 India

In 2016, India's CO_2 emissions increased by about 4.7% to about 2.5 Gt CO_2. This was mainly due to continuing GDP growth, paired with increases in fossil fuel consumption. The largest increases in per cent were seen in the consumption of natural gas and oil products of 9.5% and 8.6%, respectively. Coal consumption increased by 3.9% (BP, 2017).

In Figure 3.13, the Kaya decomposition for India illustrates the drivers behind the CO_2 emission trend. Looking at the 1990–2016 trends we see the following features. India's economy saw no recession in 2008, only a dent in the growth: with average annual growth of 6.7% before and 7.5% after 2008 and a 'low' of 3.9% in 2008. CO_2 emissions followed a similar pattern with an average annual growth of 4.7% before 2008 and 5.5% after 2009. Over the whole period the largest absolute increases were seen in coal consumption, with oil consumption a good second. Since 2009 coal use increased by 52%, while oil consumption increased 37%. The largest coal-fired power plant additions occurred in 1999, 2009 and 2014, as also visible in the figure as large increases of the CO_2 intensity and also larger CO_2 emissions. From this figure it can be deduced that the increase in CO_2 emissions is related to the strong annual GDP growth of 7.1%, while the population increased by 1.2% per year. The energy intensity of GDP has not decreased much, but the CO_2 intensity of energy has increased over time by 29% in 2016 compared tot 1990 due to the fast growth of coal consumption (see also Figure 3.15 (left)). Together, those trends result in significant growth in CO_2 emissions (see Figure 3.14).

Figure 3.13

Change in CO_2 emissions and their drivers, GDP and energy, based on Kaya decomposition for India

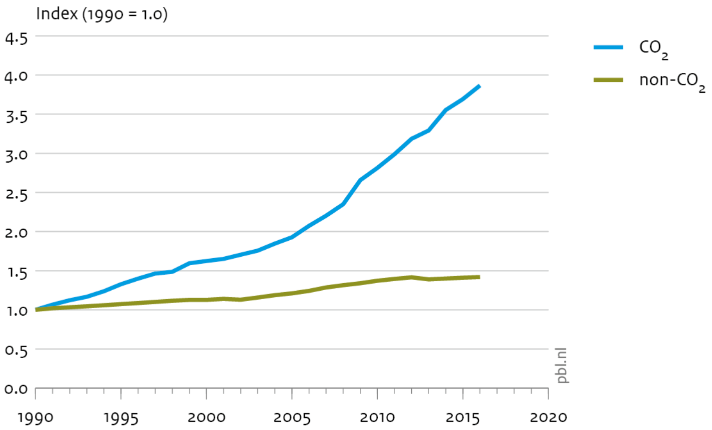


Source: EDGAR v4.3.2 CO2 FT2016 (EC-JRC/PBL 2017); World Bank (2017); IEA (2017); BP (2017)

In Figure 3.14 we compare the CO_2 trend to the trend in non-CO_2 emissions, indexed on the 1990 emission values. In contrast with many of the other main emitters, but mirroring the developments in China, in India the trend for non-CO_2 emissions is flatter than that for CO_2 emissions, with growth rates in 2016 of 1% for non-CO_2 emissions and 4.7% for CO_2 emissions. Overall, total GHG emissions increased by 3.5%, in 2016. In India, non-CO_2 emissions make up 31% of the total greenhouse gas emissions, the largest fraction of the main emitters. In fact, it has only been since 1995 that CO_2 emissions in India are higher than the non-CO_2 emissions according to EDGAR v4.3.2 estimates.

Figure 3.14

Trend of CO_2 and non-CO_2 for India

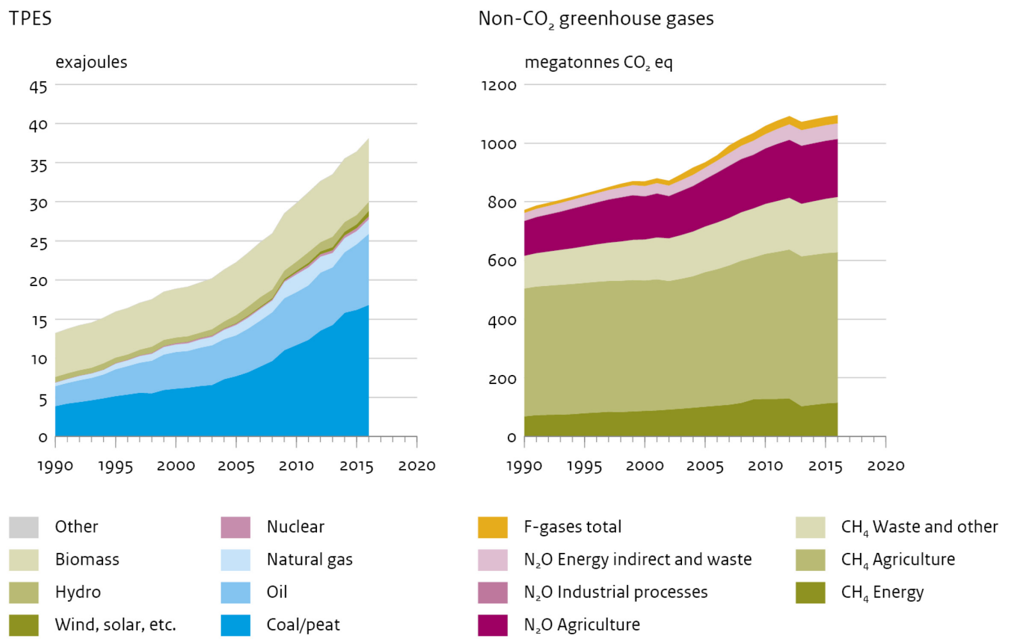


Source: EDGAR v4.3.2. (EC-JRC/PBL 2017); IEA (2017); BP (2017)

India's CO_2 emissions mainly stem from coal combustion, which has a share of 72% in total fossil fuel combustion emissions, with 25% from oil products (BP, 2017). The development of TPES is shown in Figure 3.15 (left). The largest percentage increases in 2016 are seen in the consumption of natural gas and oil products of 9.5% and 8.6%, respectively, and a 3.9% increase in coal consumption (BP, 2017). The production of new renewable energy increased by about 45% (BP, 2017). As illustrated by the graph, India has a very high share of traditional biomass fuels compared to the other large emitting countries.

Figure 3.15

Trend of Total primary Energy Supply (TPES) and non-CO_2 greenhouse gases in India



Note: Figures were calculated using a substitution method for nuclear, hydro and other non-biomass renewables as in BP 2017 (i.e. assuming 38% conversion efficiency)

Source: EDGAR v4.3.2. (EC-JRC/PBL 2017); IEA (2017); BP (2017)

In the last five years, India increased its power production from fossil fuel, surpassing European Union and Japan, reaching 1161 TWh in 2016, becoming the third largest fossil power producer in the world after China and the United States (see Table C.1 in Appendix C). In power generation from hydropower, wind, PV and biomass, India is in the top 10 of countries with shares in the global total, with shares vary between 3% and 4% (BP, 2017) (see Appendix C). The power sector is the largest coal consumer in India. After expansions in coal-fired power plants from 71 GW in 2007 to a total capacity of 212 GW in 2016, for the first time in the last decade, the coal power capacity under development decreased last year, due to policies and economic changes. According to ENDCOAL (2017), 452 GW coal plant capacity was cancelled over 2010–2017, 212 GW is operating of which 19 GW is newly installed capacity in 2016.

Also for India, addressing coal power overcapacity is getting more urgent. The load factor for national coal plants in India has declined from about 70% five years ago to about 60% on average at present, being at the limit of financial viability. Still, India is the second biggest player when it comes to coal power and has 45 coal power stations under construction, of which 19 are new plants and 26 expanded with more units (Morton, 2017). Modernisation of the power sector, considering also the quality of coal and emission control needs, will affect further developments and growth in India (Roychoudhury, 2016).

In 2016, in India, the renewable energy sector contributed 15% to the total installed capacity for electricity; thermal power contributed 69%, hydropower 14%, other renewable power 15% and nuclear energy 2%. With a target of achieving 40% of cumulative electric power from non-fossil fuel by 2030, increases in the share of clean energy are expected in the future (Government of India, 2017). Substantial increases could already be seen in 2016, compared to the preceding year, in wind power (37%) and solar PV power (82%) production (BP, 2017) (see also Appendix C).

The development of non-CO_2 greenhouse gas emissions is shown in Figure 3.15 (right). The pronounced dip in methane emissions from energy in 2013 is the result of a CDM project on methane recovery in coal mining. Methane from agriculture is by far the largest category of non-CO_2 emissions, but with growth of 0.1% in 2016, at the same time the slowest growing category. Within this category, 73% results from dairy and non-dairy cattle and buffalo livestock. Rice cultivation contributes 19% to the methane emissions. Methane emissions from energy-related sources increased with 2.3% in 2016. Overall, methane emissions increased by 0.8% in 2016. N_2O emissions increased by around 1.5%, and F-gases by 1.9%. Table 3.4.1 shows a snapshot for India of total greenhouse gas emissions per main source sector and gas in 2016.

Table 3.4.1 Emissions of CO_2 and other greenhouse gases in India in 2016

United States	CO_2	Non-CO_2	CH_4	N_2O	F-gas
Total sectors (Mt CO_2 eq)	2534	1113	818	264	31
Energy	2342	142	115	27	0
Industrial processes	164	32	0	1	31
Agriculture	13	716	513	203	0
Waste	0	202	188	14	0
Indirect and other	14	21	1	19	0

3.5 Russian Federation

In 2016, CO_2 emissions in the Russian Federation continued to decrease, for the fourth year in a row, by about 2.1% to about 1.66 Gt CO_2. This was mainly due to a 5.3% decline in coal consumption and a 3.0% decline in gas consumption, partly compensated by an increase in the consumption of oil products of 2.6% (BP, 2017). The relatively cold winter of 2016 reduced the CO_2 decrease by 1.0 percentage point, since the demand for space heating was about 10% higher in 2016 than in 2015 due to colder winter temperatures (based on heating degree days in 2015 and 2016 for the 13 largest cities) and space heating has a share of about 10% in total national CO_2 emissions.

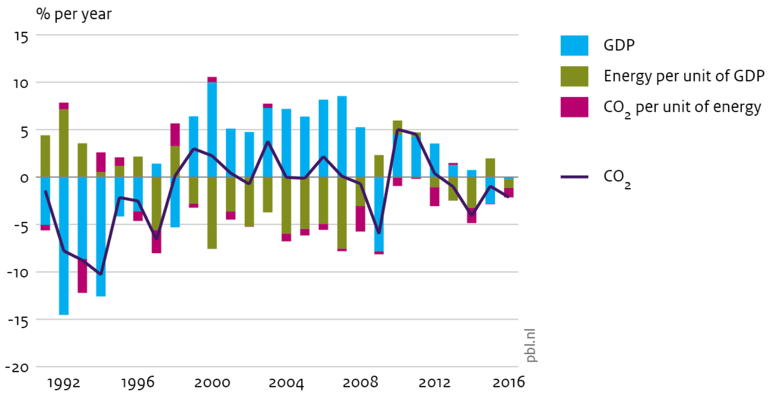
In Figure 3.16, the Kaya decomposition for the Russian Federation illustrates the drivers behind the CO_2 emission trend. After the breakdown of the Soviet Union, the 1990s were years that the Russian Federation saw large declines of GDP and in fossil fuel use. The largest decline was in the consumption of oil products from 1990 to 1998 by 54%, followed by coal with a decrease of 42% and natural gas with a decrease of 15%. GDP plummeted in these years by declining 7% per year on average, but since 1999 the Russian economy recovered and up to 2008 GDP saw annual increases of about 7% on average.

After the recession year 2009 up to 2014 GDP increased by about 3% per year. Since 2000, coal use decreased slowly by 14% in 2016, whereas oil products soared by 28% in 2016 and natural gas consumption increased by 11%, both compared to 2000. So there was a shift in the fossil fuel mix from coal to oil and natural gas. Further, since 2000 nuclear power increased by 50% and hydropower by 14%. After years of decline, from 1999 onward GDP increased again, only interrupted in the recession year 2009, up to 2014, after which GDP declined again. During the period of economic growth the CO_2 emissions only increased in some years: 1990, 2000, 2003 and 2010 to 2012. In other years decreasing energy intensity of GDP compensated the GDP growth. The years with CO_2 growth cannot be characterised by specific factors. Since 2000, in most years the consumption of oil products and natural gas increased whereas coal consumption varied, in some years increasing but most years decreasing. Sectors that saw the largest absolute annual changes since 2000 are power generation and gas flaring, followed by central heat production, industry and the residential and commercial sectors. However, the sectors that saw their CO_2 emissions increase since 2000 are power generation, industry, and road transport. Sectors with declining emissions over time are the residential and commercial sectors and gas flaring.

One of the main drivers in the Russian Federation, in contrast to China, is the *decrease* in GDP of 0.2% in 2016. Apart from the absence of GDP growth, the decrease in CO_2 emissions also results from a decrease in the CO_2 intensity of energy. The decreasing CO_2 intensity in 2016 can be explained by substitution of coal by oil in the fossil fuel mix and a 10% increase of hydropower (BP, 2017). This can also be seen in Figure 3.18 (left), for which we will discuss the developments in total primary energy supply below in more detail.

Figure 3.16

Change in CO_2 emissions and their drivers, GDP and energy, based on Kaya decomposition for the Russisan Federation

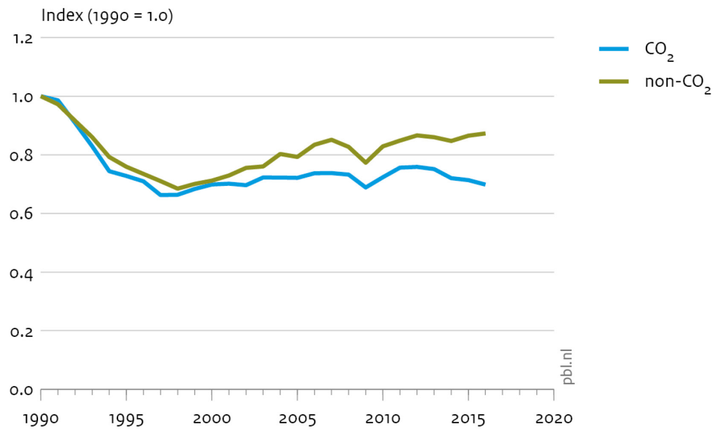


Source: EDGAR v4.3.2 CO2 FT2016 (EC-JRC/PBL 2017); World Bank (2017); IEA (2017); BP (2017)

In Figure 3.17, we compare the CO_2 trend to the trend in non-CO_2 emissions, indexed on the 1990 emission values. While the trend for CO_2 has been fairly flat since 1995, the non-CO_2 emissions have slowly increased. In 2016, the non-CO_2 emissions increased by 0.7%, part of which can be attributed to 2016 being a leap year. Overall, the trend for total greenhouse

Figure 3.17

CO_2 and non-CO_2 for the Russian Federation



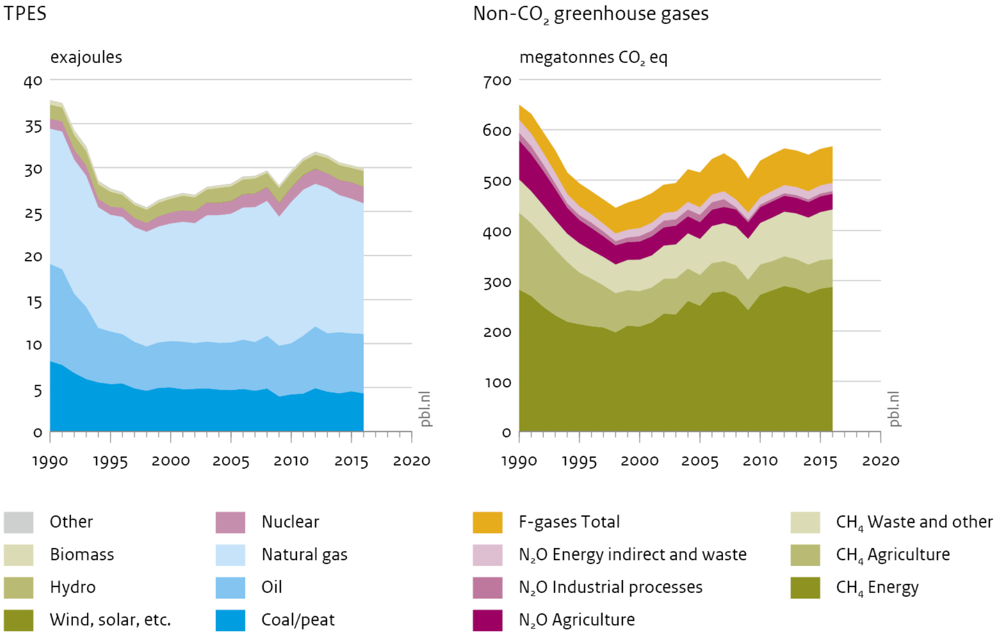
Source: EDGAR v4.3.2. (EC-JRC/PBL 2017); IEA (2017); BP (2017)

gas emissions remains negative, in 2016, by 1.4%. While emissions from agriculture for both CH_4 and N_2O have been steadily decreasing, in 2016 by 1.6%, methane emissions from waste (landfills and waste water) is a steeply growing category, in 2016 by 2.5%. Methane emissions from energy production steadily continue to increase, in 2016 by about 1.3%.

The decreasing trend that we have seen in the Kaya decomposition in Figure 3.16 is also reflected in the trend in TPES, as shown in Figure 3.18 (left). The decrease in CO_2 emissions in 2016 was mainly due to a decrease in the consumption of coal and gas by 5.3% and natural gas by 3.0%, part of which is offset by higher oil consumption, by 2.6% (BP, 2017). The net reduction in fossil fuel consumption amounts to -2.0%. Natural gas remains the Russian Federation's leading fuel with a share in total primary energy supply of 52%. The decrease in coal consumption was largely due to a higher output from hydropower plants (BP, 2017). Half of the coal is used by so-called auto-producers of electricity and heat: cogeneration by industries and companies for housing management (central heating and other services) (IEA, 2014). Renewable energy (excluding hydropower) still represents a negligible fraction of the fuel for primary energy supply (less than 0.02%). Nuclear power production increased in 2016 by 0.3%, compared to 2015, while a much larger increase of 9.8% was observed for energy from hydropower (BP, 2017). Oil production in the Russian Federation increased by 2.2% (above the 10-year average of 1.4%), but mainly for exports. In 2016, about 77% of the produced oil was exported, mainly to Europe and China.

Figure 3.18

Trend of Total primary Energy Supply (TPES) and non-CO_2 greenhouse gases in the Russian Federation



Note: Figures were calculated using a substitution method for nuclear, hydro and other non-biomass renewables as in BP 2017 (i.e. assuming 38% conversion efficiency)

Source: EDGAR v4.3.2. (EC-JRC/PBL 2017); IEA (2017); BP (2017)

The non-CO_2 emissions, shown in Figure 3.18 (right), have remained essentially flat in 2016, especially if you correct for the leap year. In 2016, the N_2O and F-gas emissions have decreased by a moderate 1%, but this is partly offset by a rise of about 1% in methane emissions. The major sources of methane emissions are related to energy (66%), and result from gas, oil, and coal production (mining) including venting and flaring activities. Its related emission trend somewhat follows the fossil trend in TPES as shown in the figure on the left. The next largest source is waste management, with 20%, most of which stems from solid waste disposal. Agriculture contributes about 13% to the methane emissions. N_2O is a relatively small emission category in the Russian Federation, compared to the other main emitters, as is also seen in Figure 3.1. The largest source of N_2O emissions before the 1990s was synthetic fertilisers, but this source has decimated since then, and overtaken by N_2O emissions from burning of crop residues. Around 2007, a steep drop in industrial N_2O emissions can be seen, which was due to a drop in emissions from nitric acid production. Table 3.5.1 shows a snapshot for the Russian Federation of total greenhouse gas emissions per main source sector and gas in 2016.

Table 3.5.1 Emissions of CO_2 and other greenhouse gases in the Russian Federation in 2016

Russian Federation	CO_2	Non-CO_2	CH_4	N_2O	F-gas
Total sectors (Mt CO_2 eq)	1662	561	442	52	68
Energy	1561	294	288	6	0
Industrial processes	101	74	0	6	68
Agriculture	0	85	56	29	0
Waste	0	101	98	3	0
Indirect and other	0	7	0	7	0

3.6 Japan

In 2016, Japan's CO_2 emissions continued to decrease for the third year in a row, by about 1.2% to about 1.24 Gt CO_2. This was mainly due to a 2.5% decline in the consumption of oil products and a 1.9% decline in natural gas consumption, whereas coal consumption did not change compared to 2015 (BP, 2017).

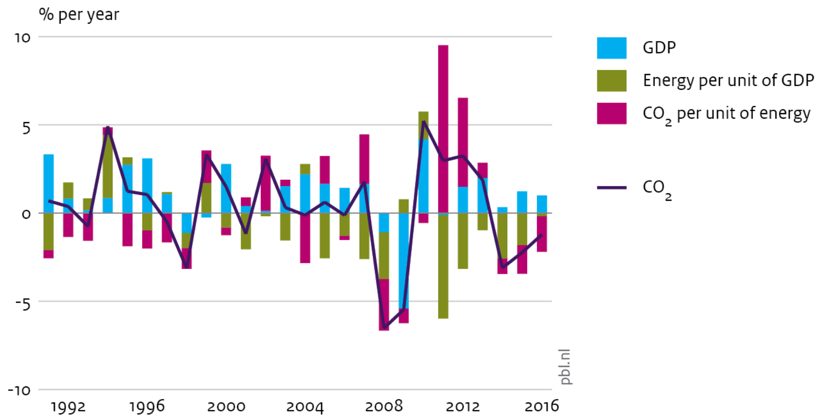
In Figure 3.19, the Kaya decomposition for Japan illustrates the drivers behind the CO_2 emission trend. Looking at the 1990–2016 trend we see the following features. In the years before the global recession years 2008 and 2009 Japan's economy saw small and varying growth rates of on average 1.3% per year and CO_2 emissions increased by 0.8% on average. In this period the years 1994, 1999, 2002 and 2008 saw the highest CO_2 growth, which can be explained by relatively large decreases in hydropower (1994 and 1999) or nuclear power (1999, 2002 and 2007). Conversely, the relatively large decrease in 1998 is due to the very warm winter months which showed in a decrease of oil products.

After the strong economic recovery in 2010, with increasing coal and gas consumption, two years with very cold winters followed, which explains part of the increasing CO_2 emissions in 2010 to 2012. In 2011 the Great East Japan Earthquake happened that triggered a very powerful tsunami that led to the Fukushima nuclear disaster. Subsequently, the operation of most other nuclear power plants, which together generated about one third of Japans power, was suspended for safety inspections and many of them are still not in operation. To compensate this, coal-fired and natural gas-fired power generation increased, thereby also increasing CO_2 emissions. Since 2013 Japan has increased renewable power production, in particular it quadrupled power generation by solar PV (see Table C.4 in Appendix C). In addition, in 2016 Japan has also restarted a few more of its 54 reactors (EIA, 2016). This also shows in Figure 3.19 as the negative purple bars in the last three years.

From this we can deduce that the main driver behind the CO_2 reduction is the decrease in CO_2 intensity of energy. The GDP in 2016 has increased by 1%, despite a declining population of 0.2%. The decrease in CO_2 intensity in 2016 was due to declining consumption of oil and gas, whereas coal consumption did not change compared to 2015 and wind power and nuclear power increased in 2016 (BP, 2017).

Figure 3.19

Change in CO_2 emissions and their drivers, GDP and energy, based on Kaya decomposition for Japan

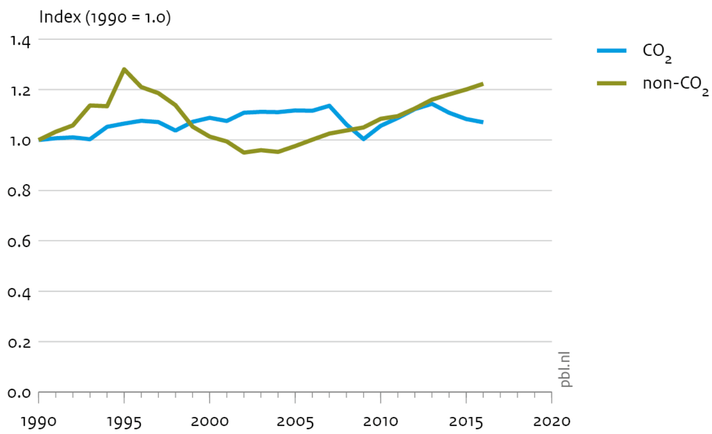


Source: EDGAR v4.3.2 CO2 FT2016 (EC-JRC/PBL 2017); World Bank (2017); IEA (2017); BP (2017)

In Figure 3.20 we compare the CO_2 trend to the trend in non-CO_2 emissions, indexed on the 1990 emission values. While emission levels for CO_2 are around the same as in 1990, non-CO2 emissions have started to steadily rise after 2004. However, the composition of the non-CO_2 emissions has changed in this period, as shown in Figure 3.21 (right), which is further discussed below. Contrary to the decrease in CO_2 emissions in 2016, the non-CO_2 emissions have increased by 1.9%.

Figure 3.20

Trend of CO_2 and non-CO_2 for Japan



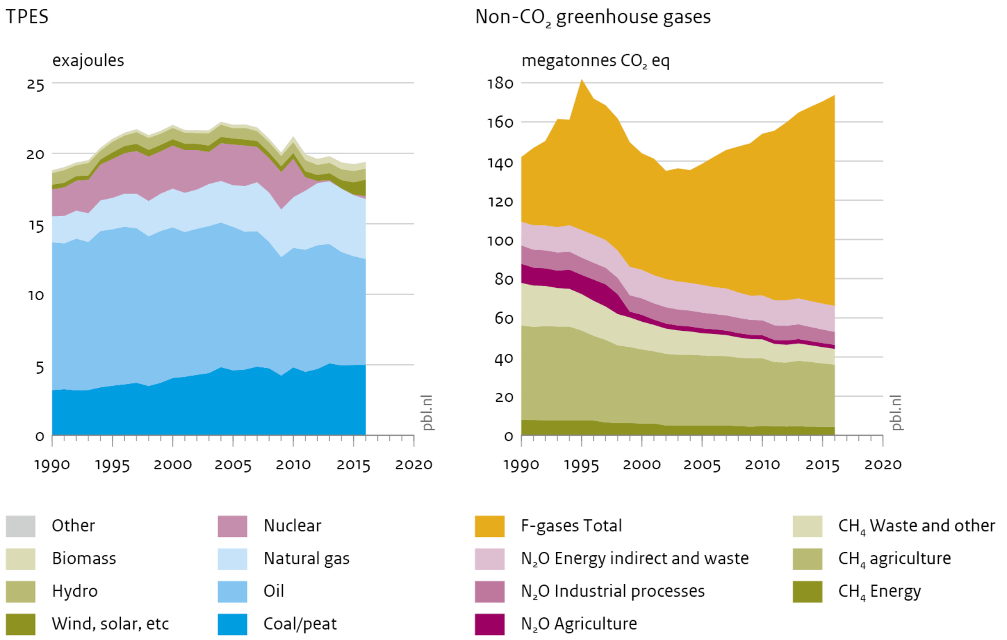
Source: EDGAR v4.3.2. (EC-JRC/PBL 2017); IEA (2017); BP (2017)

The trend in total primary energy supply is shown in Figure 3.21 (left). Coal consumption has levelled in 2016, while gas and oil consumption have decreased by 1.9% and 2.5%, respectively. Energy supply from nuclear sources has started up again in 2015, after the shut down of nuclear activities following the earthquake-induced Fukushima incident in 2011 (EIA, 2015). In 2013, Japan's Nuclear Regulation Authority (NRA) issued more stringent safety regulations to address issues dealing with tsunamis and seismic events, complete loss of station power and emergency preparedness. Applications for the restart of other reactors are under review by the NRA. However, some approved reactors face opposition from the public or politics that may delay or avert their restart (EIA, 2015).

Energy supply from solar and wind energy sources increased by 35.2%, and in 2016 had a share of 6% of TPES. Hydropower had a 4% share and biomass, geothermal and other renewables together add another 2.4% share. Total renewable power had a share of 12.4% in TPES. In 2016, TPES from fossil fuels decreased by 2.4 percent points to a share of 86.5% (BP, 2017).

Figure 3.21

Trend of Total primary Energy Supply (TPES) and non-CO_2 greenhouse gases in Japan



Note: Figures were calculated using a substitution method for nuclear, hydro and other non-biomass renewables as in BP 2017 (i.e. assuming 38% conversion efficiency)

Source: EDGAR v4.3.2. (EC-JRC/PBL 2017); IEA (2017); BP (2017)

The trends in non-CO_2 emissions are shown in Figure 3.21 (right). In 2016 they have increased by 1.9% due to an increase in F-gases by 4.2%. This is partly offset by reductions in methane and N_2O emissions of 2% and 1%, respectively. Contrary to most other countries, F-gases are the largest non-CO_2 emission category in Japan according to the EDGAR 4.2 FT2010 dataset, but we recall that those emissions are very uncertain and emissions up to 2016 are just based on extrapolation of the 2007-2010 trend. The EDGAR estimates suggest that the main sources of F-gas emissions are the use of HFC-125 and HFC-143a and the use of HFC134a for refrigeration and air conditioning. Of total methane emissions in 2016 over 70% is attributed to agriculture, of which rice cultivation is the predominant source. In 2016, Japan exported rice at a record level (Asian Nikkei Review, 2016). Table 3.6.1 shows a snapshot for Japan of total greenhouse gas emissions per main source sector and gas in 2016.

Table 3.6.1 Emissions of CO_2 and other greenhouse gases in Japan in 2016

Japan	CO_2	Non-CO_2	CH_4	N_2O	F-gas
Total sectors (Mt CO_2 eq)	1240	174	44	22	108
Energy	1160	11	4	7	0
Industrial processes	75	110	0	2	108
Agriculture	1	38	32	7	0
Waste	4	11	8	3	0
Indirect and other	0	4	0	4	0

Appendices

A. CO_2 emissions: per country, per capita, per USD of GDP

Table A.1 CO_2 emissions per country and group, 1990–2016[5] (unit: Gt CO_2)

CO_2 emissions per country/group, 1990–2016 [Gt CO_2]																											
1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Region**
2.34	2.46	2.57	2.90	3.05	3.37	3.35	3.43	3.52	3.45	3.68	3.86	4.15	4.80	5.53	6.23	6.91	7.56	7.74	8.27	8.99	9.82	10.02	10.46	10.60	10.51	10.48	**China**
4.96	4.91	4.99	5.10	5.18	5.24	5.39	5.56	5.59	5.61	5.81	5.76	5.69	5.76	5.82	5.83	5.70	5.79	5.60	5.19	5.46	5.33	5.11	5.18	5.26	5.11	5.01	**USA**
4.33	4.29	4.13	4.03	4.02	4.08	4.19	4.10	4.10	4.03	4.05	4.12	4.09	4.19	4.22	4.18	4.19	4.15	4.07	3.73	3.84	3.70	3.65	3.57	3.39	3.42	3.43	**EU28**
0.38	0.40	0.39	0.37	0.36	0.37	0.39	0.38	0.40	0.40	0.39	0.40	0.40	0.40	0.40	0.40	0.39	0.39	0.39	0.37	0.38	0.35	0.35	0.35	0.32	0.32	0.33	France
1.00	0.98	0.93	0.92	0.91	0.90	0.93	0.90	0.89	0.86	0.86	0.87	0.86	0.85	0.86	0.82	0.84	0.81	0.82	0.76	0.80	0.78	0.79	0.81	0.77	0.77	0.78	Germany
0.42	0.42	0.42	0.41	0.41	0.43	0.43	0.43	0.44	0.45	0.45	0.45	0.46	0.48	0.49	0.49	0.49	0.48	0.46	0.41	0.42	0.41	0.39	0.36	0.34	0.36	0.36	Italy
0.16	0.16	0.16	0.17	0.17	0.17	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.18	0.18	0.17	0.17	0.17	0.17	0.17	0.18	0.16	0.16	0.16	0.15	0.16	0.16	Netherlands
0.36	0.36	0.35	0.34	0.33	0.35	0.37	0.36	0.33	0.32	0.31	0.31	0.29	0.30	0.31	0.31	0.32	0.32	0.32	0.30	0.32	0.32	0.31	0.30	0.29	0.29	0.30	Poland
0.23	0.23	0.24	0.23	0.24	0.25	0.24	0.26	0.27	0.29	0.31	0.31	0.32	0.33	0.35	0.36	0.35	0.37	0.34	0.30	0.28	0.28	0.27	0.25	0.24	0.26	0.25	Spain
0.58	0.58	0.57	0.56	0.55	0.54	0.56	0.54	0.54	0.54	0.54	0.56	0.54	0.55	0.55	0.55	0.55	0.54	0.53	0.47	0.49	0.45	0.46	0.45	0.41	0.39	0.37	United Kingdom
0.66	0.70	0.74	0.76	0.81	0.87	0.92	0.96	0.97	1.04	1.06	1.08	1.12	1.15	1.21	1.26	1.36	1.44	1.54	1.74	1.84	1.96	2.09	2.16	2.33	2.42	2.53	**India**
2.38	2.35	2.16	1.97	1.77	1.73	1.69	1.58	1.58	1.63	1.66	1.67	1.66	1.72	1.72	1.72	1.75	1.76	1.74	1.64	1.72	1.80	1.81	1.79	1.71	1.70	1.66	**Russian Federation**
1.16	1.17	1.17	1.16	1.22	1.23	1.25	1.24	1.20	1.24	1.26	1.25	1.28	1.29	1.29	1.29	1.29	1.32	1.23	1.16	1.22	1.26	1.30	1.32	1.28	1.25	1.24	**Japan**
1.54	1.59	1.64	1.68	1.77	1.85	1.91	1.97	1.98	2.01	2.17	2.17	2.21	2.22	2.28	2.31	2.32	2.40	2.43	2.39	2.46	2.51	2.53	2.51	2.50	2.50	2.50	**Other OECD G20**
0.28	0.28	0.28	0.29	0.29	0.30	0.31	0.32	0.34	0.35	0.36	0.37	0.38	0.39	0.41	0.41	0.41	0.43	0.43	0.43	0.42	0.43	0.42	0.41	0.41	0.42	0.41	Australia
0.55	0.56	0.58	0.58	0.62	0.66	0.65	0.65	0.68	0.68	0.73	0.73	0.74	0.72	0.73	0.72	0.70	0.71	0.72	0.68	0.69	0.69	0.69	0.70	0.70	0.68	0.68	Canada
0.29	0.31	0.32	0.31	0.33	0.32	0.33	0.34	0.36	0.36	0.38	0.38	0.38	0.39	0.39	0.41	0.42	0.44	0.43	0.43	0.45	0.46	0.48	0.47	0.45	0.45	0.44	Mexico
0.27	0.29	0.31	0.34	0.37	0.40	0.43	0.45	0.38	0.42	0.48	0.49	0.49	0.49	0.51	0.51	0.52	0.53	0.54	0.55	0.59	0.61	0.61	0.60	0.60	0.60	0.60	South Korea
0.15	0.15	0.16	0.16	0.16	0.18	0.19	0.20	0.21	0.20	0.23	0.21	0.22	0.23	0.24	0.25	0.27	0.30	0.30	0.30	0.31	0.33	0.34	0.32	0.35	0.35	0.37	Turkey
0.92	0.95	0.98	1.02	1.07	1.13	1.20	1.26	1.30	1.31	1.34	1.34	1.37	1.44	1.50	1.54	1.60	1.67	1.75	1.74	1.84	1.86	1.90	1.96	2.07	2.07	2.08	**Other G20 countries**
0.11	0.11	0.11	0.12	0.12	0.12	0.13	0.14	0.14	0.15	0.14	0.13	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.18	0.19	0.19	0.19	0.19	0.20	0.20	0.20	Argentina
0.22	0.22	0.23	0.23	0.24	0.26	0.28	0.30	0.31	0.32	0.33	0.34	0.34	0.33	0.35	0.35	0.36	0.37	0.39	0.37	0.42	0.44	0.45	0.48	0.50	0.49	0.46	Brazil
0.16	0.17	0.18	0.20	0.21	0.24	0.25	0.27	0.28	0.29	0.29	0.32	0.32	0.35	0.36	0.36	0.38	0.40	0.40	0.41	0.42	0.43	0.44	0.45	0.49	0.50	0.53	Indonesia
0.17	0.17	0.19	0.20	0.21	0.22	0.23	0.23	0.24	0.25	0.26	0.27	0.28	0.30	0.29	0.31	0.32	0.34	0.36	0.39	0.42	0.44	0.45	0.46	0.50	0.51	0.52	Saudi Arabia
0.27	0.26	0.26	0.27	0.27	0.29	0.30	0.31	0.32	0.30	0.31	0.29	0.31	0.34	0.36	0.37	0.38	0.40	0.42	0.40	0.41	0.39	0.38	0.40	0.41	0.39	0.39	South Africa
18.29	18.42	18.38	18.63	18.89	19.50	19.90	20.10	20.23	20.33	21.04	21.25	21.57	22.57	23.56	24.35	25.13	26.08	26.10	25.85	27.37	28.24	28.41	28.94	29.15	29.00	28.95	**G20**
1.67	1.69	1.65	1.56	1.49	1.51	1.50	1.50	1.47	1.52	1.58	1.62	1.68	1.77	1.85	1.94	2.01	2.10	2.14	2.03	2.13	2.21	2.21	2.25	2.21	2.15	2.22	**Other big countries**
0.09	0.09	0.09	0.10	0.09	0.10	0.10	0.11	0.12	0.12	0.12	0.13	0.14	0.14	0.15	0.17	0.18	0.19	0.20	0.20	0.21	0.22	0.23	0.21	0.21	0.21	0.22	Egypt
0.20	0.22	0.24	0.24	0.27	0.28	0.29	0.30	0.30	0.33	0.35	0.36	0.38	0.40	0.43	0.47	0.50	0.53	0.54	0.56	0.57	0.58	0.59	0.61	0.64	0.63	0.64	Iran
0.25	0.26	0.27	0.23	0.21	0.18	0.16	0.14	0.14	0.13	0.13	0.13	0.14	0.16	0.17	0.18	0.21	0.22	0.26	0.23	0.24	0.27	0.25	0.26	0.24	0.23	0.23	Kazakhstan
0.06	0.07	0.07	0.07	0.08	0.09	0.10	0.11	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.18	0.18	0.20	0.21	0.19	0.21	0.21	0.22	0.23	0.24	0.25	0.27	Malaysia
0.07	0.08	0.08	0.08	0.07	0.08	0.09	0.09	0.08	0.08	0.09	0.10	0.09	0.09	0.09	0.09	0.08	0.07	0.08	0.07	0.08	0.09	0.08	0.08	0.08	0.08	0.08	Nigeria
0.13	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.23	0.24	0.24	0.25	0.26	0.27	0.28	0.28	0.27	0.26	0.27	0.27	0.27	0.27	0.28	0.27	0.28	Taiwan
0.09	0.10	0.11	0.13	0.14	0.16	0.18	0.18	0.16	0.17	0.17	0.18	0.19	0.20	0.22	0.22	0.23	0.23	0.24	0.23	0.24	0.25	0.26	0.27	0.26	0.27	0.27	Thailand
0.79	0.74	0.65	0.56	0.47	0.46	0.39	0.38	0.36	0.36	0.36	0.36	0.36	0.38	0.36	0.35	0.35	0.36	0.35	0.29	0.31	0.32	0.31	0.31	0.27	0.22	0.23	Ukraine
1.87	1.85	1.79	1.80	1.83	1.89	1.94	2.03	2.05	2.05	2.13	2.19	2.25	2.30	2.38	2.49	2.56	2.64	2.78	2.83	2.96	2.99	3.08	3.12	3.20	3.32	3.40	**Remaining countries**
0.63	0.64	0.67	0.67	0.69	0.72	0.74	0.76	0.79	0.82	0.85	0.82	0.85	0.86	0.94	1.00	1.05	1.09	1.10	1.05	1.12	1.15	1.09	1.11	1.13	1.16	1.18	**International transport**
22.45	22.59	22.49	22.66	22.90	23.61	24.07	24.40	24.54	24.73	25.59	25.88	26.35	27.51	28.74	29.77	30.75	31.92	32.12	31.77	33.59	34.58	34.79	35.42	35.69	35.63	35.76	**Total**

[5] Available for all countries on http://edgar.jrc.ec.europa.eu/overview.php?v=CO2ts1990-2016

Table A.2 CO_2 emissions per capita per country and group, 1990–2016 (unit: tonnes of CO_2 per person)

CO_2 emissions per capita per country/group, 1990–2016 [tonnes of CO_2 per person]																											
1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Region**
1.99	2.06	2.12	2.37	2.47	2.70	2.67	2.71	2.76	2.69	2.85	2.97	3.18	3.65	4.19	4.69	5.17	5.63	5.72	6.08	6.57	7.15	7.25	7.52	7.59	7.49	7.43	**China**
19.62	19.27	19.37	19.62	19.73	19.71	20.06	20.43	20.28	20.12	20.61	20.22	19.80	19.86	19.88	19.74	19.15	19.25	18.47	16.96	17.69	17.13	16.30	16.41	16.55	15.99	15.56	**USA**
9.08	8.95	8.59	8.37	8.32	8.44	8.66	8.45	8.44	8.29	8.32	8.43	8.35	8.52	8.54	8.43	8.43	8.31	8.12	7.41	7.63	7.32	7.23	7.06	6.69	6.75	6.75	**EU28**
6.61	6.99	6.76	6.39	6.27	6.39	6.61	6.44	6.86	6.72	6.60	6.67	6.57	6.63	6.59	6.61	6.41	6.27	6.19	5.86	5.99	5.49	5.44	5.52	5.00	5.04	5.12	France
12.68	12.32	11.58	11.41	11.20	11.13	11.45	11.03	10.94	10.54	10.51	10.71	10.52	10.40	10.48	10.08	10.26	9.95	10.10	9.38	9.88	9.63	9.71	9.92	9.39	9.37	9.47	Germany
7.41	7.38	7.34	7.22	7.11	7.54	7.46	7.52	7.72	7.84	7.91	7.87	7.96	8.24	8.37	8.34	8.22	8.05	7.78	6.89	7.03	6.86	6.58	6.03	5.74	5.97	6.03	Italy
10.43	10.83	10.62	10.87	10.83	10.90	11.42	10.82	10.85	10.45	10.51	10.76	10.77	10.85	10.94	10.65	10.28	10.32	10.45	10.01	10.61	9.84	9.74	9.64	9.17	9.49	9.62	Netherlands
9.45	9.42	9.14	8.76	8.62	9.16	9.53	9.25	8.58	8.31	8.03	7.94	7.65	7.92	8.04	8.00	8.35	8.39	8.27	7.89	8.41	8.26	7.97	7.85	7.54	7.55	7.76	Poland
5.75	5.93	6.12	5.75	5.99	6.28	6.01	6.47	6.65	7.16	7.48	7.39	7.72	7.77	8.02	8.23	7.90	8.08	7.29	6.37	6.03	6.02	5.82	5.28	5.25	5.60	5.43	Spain
10.07	10.19	9.93	9.63	9.53	9.37	9.65	9.23	9.26	9.14	9.23	9.43	9.10	9.28	9.23	9.14	9.08	8.82	8.51	7.56	7.73	7.06	7.19	6.97	6.31	6.01	5.59	United Kingdom
0.75	0.79	0.81	0.83	0.86	0.91	0.94	0.96	0.96	1.01	1.01	1.01	1.02	1.04	1.07	1.10	1.17	1.22	1.29	1.43	1.50	1.57	1.65	1.69	1.80	1.85	1.91	**India**
16.12	15.84	14.58	13.29	11.93	11.68	11.40	10.67	10.71	11.07	11.36	11.45	11.41	11.89	11.93	11.95	12.24	12.26	12.18	11.45	12.02	12.56	12.59	12.45	11.92	11.80	11.54	**Russian Federation**
9.30	9.33	9.34	9.24	9.67	9.76	9.84	9.78	9.45	9.75	9.88	9.75	10.04	10.05	10.03	10.08	10.06	10.24	9.57	9.04	9.51	9.80	10.13	10.32	10.01	9.81	9.70	**Japan**
5.93	6.05	6.15	6.19	6.42	6.60	6.73	6.84	6.78	6.80	7.24	7.18	7.22	7.17	7.28	7.28	7.25	7.41	7.39	7.18	7.28	7.34	7.32	7.16	7.06	6.98	6.90	**Other OECD G20**
16.21	16.11	16.10	16.15	16.29	16.67	17.04	17.38	18.28	18.58	18.70	19.16	19.51	19.77	20.32	20.28	19.76	20.37	20.13	20.01	18.94	18.99	18.31	17.88	17.26	17.61	17.20	Australia
20.03	19.84	20.36	20.33	21.32	22.35	21.91	21.78	22.63	22.23	23.69	23.55	23.72	22.74	22.87	22.37	21.41	21.50	21.69	20.09	20.13	19.84	19.79	19.82	19.69	18.99	18.63	Canada
3.39	3.61	3.58	3.43	3.60	3.37	3.47	3.55	3.69	3.59	3.71	3.64	3.65	3.68	3.69	3.81	3.85	3.93	3.82	3.73	3.82	3.84	3.96	3.83	3.65	3.58	3.46	Mexico
6.25	6.76	7.11	7.71	8.22	8.84	9.32	9.72	8.24	8.94	10.10	10.32	10.18	10.21	10.57	10.53	10.70	10.81	10.99	11.13	11.98	12.28	12.14	12.01	11.88	11.89	11.89	South Korea
2.77	2.77	2.80	2.87	2.82	3.02	3.24	3.36	3.35	3.26	3.59	3.22	3.33	3.46	3.51	3.62	3.96	4.29	4.27	4.14	4.26	4.44	4.53	4.27	4.48	4.47	4.63	Turkey
2.21	2.23	2.26	2.31	2.39	2.48	2.59	2.70	2.72	2.72	2.73	2.70	2.71	2.82	2.90	2.92	3.00	3.10	3.21	3.14	3.29	3.29	3.31	3.37	3.52	3.48	3.47	**Other G20 countries**
3.25	3.33	3.38	3.38	3.55	3.51	3.81	3.88	3.94	3.98	3.87	3.57	3.33	3.56	3.95	4.03	4.25	4.38	4.65	4.40	4.54	4.59	4.52	4.38	4.60	4.62	4.58	Argentina
1.44	1.47	1.47	1.49	1.52	1.61	1.71	1.80	1.82	1.84	1.90	1.89	1.87	1.81	1.89	1.88	1.90	1.96	2.05	1.89	2.13	2.20	2.26	2.37	2.47	2.39	2.23	Brazil
0.88	0.94	0.96	1.04	1.09	1.19	1.24	1.35	1.34	1.40	1.39	1.47	1.48	1.60	1.60	1.59	1.67	1.71	1.68	1.72	1.75	1.76	1.78	1.79	1.91	1.93	2.03	Indonesia
10.29	10.27	10.75	11.01	11.60	11.53	11.93	11.88	12.23	12.23	12.57	12.78	12.99	13.23	12.61	12.83	13.10	13.43	14.05	14.70	15.37	15.52	15.60	15.50	16.09	16.24	16.02	Saudi Arabia
7.14	6.83	6.72	6.62	6.62	6.79	6.92	7.18	7.19	6.68	6.72	6.32	6.54	7.06	7.46	7.61	7.66	7.98	8.39	7.83	7.85	7.41	7.25	7.42	7.48	7.10	6.97	South Africa
4.91	4.87	4.80	4.81	4.82	4.92	4.96	4.96	4.94	4.92	5.04	5.04	5.07	5.25	5.43	5.56	5.69	5.85	5.80	5.70	5.98	6.11	6.10	6.17	6.16	6.08	6.03	**G20**
4.50	4.47	4.30	4.00	3.78	3.78	3.68	3.65	3.52	3.59	3.66	3.72	3.79	3.95	4.06	4.19	4.29	4.41	4.44	4.14	4.28	4.36	4.30	4.30	4.17	3.99	4.06	**Other big countries**
1.57	1.56	1.57	1.55	1.47	1.53	1.61	1.68	1.73	1.78	1.73	1.88	1.89	1.90	2.03	2.23	2.31	2.42	2.45	2.47	2.50	2.56	2.59	2.34	2.26	2.23	2.29	Egypt
3.59	3.88	4.08	4.03	4.53	4.55	4.67	4.79	4.69	5.09	5.28	5.42	5.59	5.84	6.19	6.61	7.01	7.41	7.47	7.66	7.63	7.65	7.74	7.94	8.11	7.92	8.00	Iran
15.15	15.80	16.15	13.86	12.64	11.35	10.08	8.86	9.26	8.58	8.75	8.58	9.42	10.35	11.21	11.90	13.24	13.84	16.11	14.14	14.94	15.94	14.66	15.28	13.78	12.85	12.89	Kazakhstan
3.05	3.54	3.61	3.82	4.01	4.21	4.68	4.89	4.70	5.03	5.38	5.47	5.80	6.05	6.54	6.87	7.02	7.55	7.89	6.97	7.32	7.41	7.38	7.80	8.07	8.13	8.54	Malaysia
0.72	0.77	0.83	0.78	0.70	0.73	0.82	0.80	0.70	0.68	0.74	0.77	0.68	0.70	0.66	0.66	0.57	0.51	0.51	0.46	0.50	0.53	0.49	0.48	0.44	0.45	0.44	Nigeria
6.16	6.55	6.88	7.33	7.68	8.04	8.44	9.04	9.46	9.78	10.57	10.72	11.03	11.39	11.71	11.97	12.27	12.32	11.73	11.08	11.79	11.71	11.69	11.75	11.75	11.56	11.75	Taiwan
1.63	1.79	1.94	2.17	2.41	2.70	3.00	3.03	2.64	2.73	2.70	2.82	2.97	3.08	3.34	3.44	3.47	3.53	3.54	3.42	3.61	3.69	3.80	3.93	3.84	3.89	3.94	Thailand
15.31	14.33	12.58	11.00	9.13	9.05	7.79	7.55	7.27	7.32	7.33	7.37	7.44	7.99	7.64	7.52	7.61	7.83	7.51	6.23	6.75	7.09	6.93	6.76	5.98	4.83	5.25	Ukraine
1.52	1.47	1.38	1.37	1.35	1.37	1.38	1.41	1.39	1.36	1.39	1.39	1.40	1.41	1.43	1.46	1.48	1.49	1.54	1.54	1.58	1.56	1.58	1.57	1.57	1.60	1.61	**Remaining countries**
																											International transport
4.21	4.17	4.09	4.06	4.04	4.11	4.13	4.13	4.10	4.08	4.17	4.16	4.18	4.31	4.45	4.55	4.65	4.76	4.73	4.63	4.83	4.91	4.88	4.91	4.89	4.83	4.79	**Total**

Table A.3 CO_2 emissions per USD of GDP per country and group, 1990–2016 (unit: kg CO_2 per 1,000 USD of GDP [PPP, 2011 prices])

CO_2 emissions per USD of GDP per country/group, 1990–2016 [kg CO_2 per 1,000 USD of GDP]																											
1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Region**
1241	1198	1101	1096	1023	1023	930	873	836	763	751	729	721	759	795	805	794	762	713	699	687	686	650	630	596	553	518	**China**
536	532	521	519	506	498	494	488	469	450	448	440	427	420	409	396	378	377	366	348	358	343	322	321	318	302	291	**USA**
361	355	340	333	322	319	321	305	296	283	274	272	266	269	263	255	247	237	231	221	224	211	210	205	191	189	185	**EU28**
218	229	219	209	201	202	207	198	205	195	185	185	180	182	177	175	167	161	159	156	157	142	141	143	129	129	130	France
404	375	348	348	336	329	336	319	310	292	283	284	279	278	277	265	259	243	244	239	242	227	229	233	218	214	213	Germany
240	235	232	230	222	229	224	221	223	224	218	214	217	225	227	225	218	212	207	195	196	190	187	175	166	171	171	Italy
325	332	322	328	319	314	319	292	281	260	252	254	255	258	256	245	230	224	223	223	234	214	215	214	201	205	204	Netherlands
916	985	935	866	811	808	793	724	642	595	549	536	506	505	487	467	460	431	407	378	389	364	346	336	312	301	301	Poland
245	247	253	241	246	252	235	245	242	251	252	242	249	247	251	253	236	236	214	195	186	188	187	172	168	174	163	Spain
376	386	375	356	340	327	330	307	299	287	280	280	265	262	255	247	241	231	227	213	215	195	198	189	167	157	144	United Kingdom
429	453	452	448	446	445	436	438	419	413	405	393	391	373	364	347	342	331	340	354	340	339	342	333	334	321	314	**India**
777	807	871	870	892	911	921	848	897	868	807	771	731	707	659	619	585	539	509	519	521	523	507	495	472	481	472	**Russian Federation**
308	300	299	296	308	303	297	293	287	297	293	289	297	294	287	284	280	280	265	265	267	275	280	280	270	261	255	**Japan**
434	440	440	430	436	446	437	426	418	409	416	416	408	399	390	378	365	363	361	363	355	345	337	323	312	303	296	**Other OECD G20**
566	573	577	562	551	549	546	541	551	539	528	536	531	528	528	518	498	504	489	487	460	457	432	417	398	402	387	Australia
638	654	673	662	672	693	675	650	656	618	632	623	615	585	577	552	521	518	524	506	497	480	476	470	459	443	432	Canada
269	281	274	257	263	266	263	256	258	248	247	247	251	252	246	249	244	245	239	249	246	241	243	235	222	215	206	Mexico
538	533	534	547	541	536	531	528	478	469	490	483	446	437	433	417	405	389	386	389	395	392	380	367	353	345	337	South Korea
243	245	240	232	243	245	249	244	241	247	259	250	248	247	232	222	229	240	239	247	237	226	223	197	200	191	196	Turkey
243	236	236	237	237	241	246	250	263	268	262	261	263	265	260	253	252	249	248	246	244	234	231	230	238	235	235	**Other G20 countries**
300	277	255	244	245	252	263	251	248	262	260	253	268	266	274	260	256	245	252	256	243	234	235	225	245	242	248	Argentina
140	142	145	144	141	145	154	158	162	166	167	167	162	157	157	153	150	148	148	139	147	147	149	154	161	163	159	Brazil
190	193	189	195	193	199	195	204	237	250	240	248	243	253	245	233	235	230	215	214	207	199	192	186	191	186	189	Indonesia
242	217	225	240	258	262	270	271	276	293	292	308	331	313	284	282	288	298	301	330	338	320	314	313	322	320	318	Saudi Arabia
737	728	750	747	740	752	748	770	780	718	704	654	662	703	719	706	680	680	700	671	661	612	594	601	605	574	570	South Africa
471	468	460	458	450	450	443	430	423	410	405	400	396	399	398	393	386	381	372	371	373	370	361	356	346	333	323	**G20**
589	578	554	521	501	494	467	459	451	449	438	438	429	424	406	406	397	385	382	360	353	352	347	345	329	315	316	**Other big countries**
265	267	263	259	239	242	248	250	252	250	234	250	250	249	260	279	275	274	263	258	253	261	264	238	228	221	222	Egypt
353	345	358	362	420	418	410	423	413	447	446	453	438	426	438	454	461	452	456	463	437	428	469	497	493	495	475	Iran
1175	1376	1480	1390	1437	1389	1212	1031	1082	964	890	768	771	781	780	763	773	750	853	749	747	753	672	672	591	553	556	Kazakhstan
289	315	302	299	294	288	299	298	318	328	330	341	350	353	364	370	365	365	376	347	347	339	327	336	333	326	333	Malaysia
238	261	286	271	248	264	292	284	246	245	259	264	232	222	159	159	130	112	109	94	97	102	92	87	78	80	82	Nigeria
394	391	383	385	379	375	373	379	382	373	380	394	386	386	375	366	357	338	321	309	299	287	281	278	268	262	264	Taiwan
246	251	254	265	275	288	306	321	307	307	294	299	299	292	300	298	288	280	278	271	268	273	263	266	259	255	251	Thailand
1451	1483	1440	1466	1573	1768	1679	1666	1620	1620	1517	1384	1318	1282	1086	1033	969	919	858	833	861	854	829	805	757	675	713	Ukraine
320	324	312	310	304	302	298	297	289	282	280	278	280	279	268	263	253	246	247	247	247	240	236	229	228	230	229	**Remaining countries**
																											International transport
472	471	462	458	449	448	440	429	421	410	405	400	396	399	395	391	383	377	369	366	368	364	354	349	340	329	320	**Total**

B. Greenhouse gas emissions: total, CH_4, N_2O, F-gases

Table B.1 Total greenhouse gas emissions per country and group, 1990–2016 (unit: Gt CO_2 eq)

Total greenhouse gas emissions per country/group, 1990–2016 [Gt CO_2 eq]																											
1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Region**
3.86	3.98	4.08	4.38	4.55	4.98	4.99	5.01	5.10	5.05	5.27	5.51	5.82	6.52	7.39	8.23	9.05	9.78	10.02	10.54	11.32	12.23	12.47	12.95	13.12	13.04	13.01	**China**
6.00	5.95	6.04	6.15	6.25	6.30	6.46	6.63	6.67	6.68	6.90	6.86	6.80	6.87	6.94	6.96	6.86	6.96	6.81	6.40	6.70	6.61	6.43	6.52	6.65	6.53	6.43	**USA**
5.59	5.52	5.31	5.19	5.16	5.22	5.34	5.24	5.19	5.10	5.11	5.16	5.13	5.21	5.23	5.19	5.20	5.15	5.05	4.69	4.81	4.65	4.61	4.53	4.36	4.41	4.43	**EU28**
0.52	0.55	0.54	0.52	0.51	0.53	0.54	0.52	0.54	0.53	0.52	0.53	0.53	0.53	0.53	0.53	0.52	0.52	0.52	0.50	0.51	0.48	0.48	0.48	0.46	0.47	0.48	France
1.23	1.20	1.14	1.12	1.11	1.10	1.13	1.09	1.06	1.02	1.02	1.03	1.01	1.00	1.00	0.97	0.98	0.95	0.97	0.90	0.94	0.92	0.93	0.95	0.91	0.91	0.92	Germany
0.51	0.51	0.50	0.50	0.49	0.52	0.51	0.52	0.53	0.54	0.54	0.54	0.55	0.57	0.58	0.57	0.56	0.56	0.54	0.49	0.50	0.49	0.47	0.44	0.42	0.43	0.44	Italy
0.22	0.22	0.22	0.22	0.22	0.23	0.23	0.22	0.23	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.21	0.21	0.21	0.20	0.22	0.20	0.20	0.20	0.19	0.20	0.20	Netherlands
0.49	0.48	0.47	0.45	0.45	0.47	0.48	0.47	0.44	0.42	0.41	0.40	0.39	0.40	0.40	0.40	0.42	0.42	0.41	0.39	0.41	0.41	0.40	0.39	0.38	0.39	0.40	Poland
0.29	0.30	0.31	0.29	0.30	0.32	0.31	0.33	0.34	0.36	0.38	0.38	0.40	0.41	0.42	0.44	0.43	0.44	0.41	0.37	0.36	0.36	0.35	0.32	0.32	0.34	0.34	Spain
0.76	0.77	0.75	0.73	0.72	0.71	0.73	0.71	0.71	0.69	0.70	0.71	0.68	0.69	0.69	0.68	0.68	0.66	0.65	0.59	0.60	0.56	0.57	0.55	0.51	0.49	0.47	United Kingdom
1.43	1.49	1.53	1.57	1.63	1.70	1.76	1.81	1.83	1.91	1.93	1.96	1.99	2.04	2.12	2.20	2.32	2.43	2.55	2.78	2.90	3.03	3.18	3.23	3.42	3.52	3.65	**India**
3.03	2.97	2.75	2.53	2.28	2.22	2.16	2.04	2.02	2.08	2.12	2.14	2.15	2.22	2.23	2.22	2.29	2.30	2.27	2.15	2.26	2.34	2.37	2.34	2.26	2.26	2.22	**Russian Federation**
1.29	1.30	1.31	1.31	1.37	1.39	1.40	1.42	1.37	1.40	1.41	1.39	1.42	1.43	1.42	1.43	1.43	1.45	1.37	1.30	1.37	1.41	1.45	1.48	1.44	1.42	1.40	**Japan**
2.21	2.27	2.34	2.39	2.49	2.59	2.66	2.73	2.75	2.81	3.00	3.01	3.03	2.98	3.08	3.09	3.14	3.23	3.24	3.21	3.27	3.41	3.45	3.37	3.40	3.41	3.42	**Other OECD G20**
0.50	0.51	0.51	0.51	0.51	0.52	0.52	0.53	0.56	0.60	0.63	0.64	0.64	0.59	0.64	0.62	0.64	0.65	0.63	0.64	0.61	0.71	0.70	0.62	0.63	0.66	0.65	Australia
0.72	0.72	0.75	0.76	0.80	0.83	0.83	0.83	0.85	0.85	0.91	0.90	0.92	0.89	0.91	0.90	0.88	0.89	0.90	0.86	0.87	0.87	0.88	0.90	0.92	0.89	0.89	Canada
0.44	0.47	0.47	0.47	0.50	0.50	0.52	0.54	0.57	0.56	0.58	0.58	0.59	0.60	0.61	0.63	0.65	0.68	0.68	0.68	0.70	0.71	0.73	0.73	0.71	0.71	0.70	Mexico
0.32	0.35	0.37	0.40	0.43	0.46	0.49	0.51	0.45	0.49	0.55	0.57	0.55	0.55	0.58	0.58	0.59	0.59	0.60	0.61	0.66	0.67	0.67	0.66	0.66	0.66	0.66	South Korea
0.23	0.24	0.25	0.26	0.26	0.28	0.30	0.31	0.31	0.31	0.34	0.31	0.32	0.34	0.34	0.36	0.39	0.42	0.42	0.42	0.44	0.46	0.47	0.46	0.49	0.50	0.52	Turkey
1.96	2.01	2.07	2.12	2.20	2.26	2.33	2.40	2.42	2.43	2.46	2.50	2.56	2.69	2.77	2.84	2.91	3.00	3.10	3.08	3.23	3.26	3.32	3.37	3.51	3.53	3.55	**Other G20 countries**
0.28	0.28	0.28	0.29	0.30	0.29	0.31	0.30	0.30	0.31	0.31	0.30	0.30	0.32	0.33	0.34	0.35	0.36	0.37	0.35	0.36	0.35	0.35	0.35	0.37	0.38	0.38	Argentina
0.65	0.68	0.69	0.72	0.75	0.78	0.79	0.81	0.83	0.84	0.86	0.88	0.90	0.93	0.97	0.99	0.99	1.01	1.04	1.01	1.09	1.11	1.13	1.14	1.18	1.17	1.15	Brazil
0.43	0.45	0.47	0.49	0.49	0.52	0.54	0.56	0.56	0.57	0.57	0.59	0.60	0.64	0.65	0.66	0.69	0.72	0.72	0.76	0.78	0.80	0.82	0.83	0.87	0.89	0.92	Indonesia
0.24	0.25	0.25	0.26	0.29	0.29	0.30	0.31	0.32	0.32	0.33	0.34	0.36	0.38	0.37	0.39	0.41	0.43	0.45	0.48	0.51	0.53	0.55	0.57	0.60	0.62	0.63	Saudi Arabia
0.35	0.35	0.35	0.35	0.36	0.37	0.39	0.41	0.42	0.40	0.40	0.39	0.40	0.43	0.46	0.47	0.48	0.50	0.53	0.50	0.51	0.49	0.49	0.50	0.51	0.50	0.50	South Africa
25.37	25.48	25.42	25.65	25.93	26.66	27.10	27.27	27.34	27.47	28.21	28.53	28.90	29.95	31.20	32.16	33.19	34.31	34.41	34.17	35.87	36.95	37.27	37.80	38.15	38.11	38.12	**G20**
2.59	2.62	2.59	2.48	2.40	2.39	2.38	2.34	2.25	2.27	2.32	2.37	2.43	2.56	2.67	2.77	2.86	2.95	3.00	2.88	3.01	3.09	3.12	3.16	3.13	3.06	3.13	**Other big countries**
0.14	0.15	0.15	0.16	0.15	0.16	0.17	0.17	0.18	0.19	0.18	0.20	0.20	0.21	0.23	0.25	0.26	0.28	0.29	0.29	0.30	0.31	0.32	0.29	0.29	0.29	0.30	Egypt
0.37	0.40	0.42	0.40	0.45	0.45	0.46	0.47	0.45	0.48	0.50	0.51	0.53	0.57	0.61	0.65	0.69	0.73	0.74	0.76	0.77	0.78	0.79	0.81	0.84	0.84	0.86	Iran
0.35	0.36	0.37	0.32	0.29	0.25	0.23	0.20	0.20	0.18	0.19	0.18	0.20	0.22	0.24	0.25	0.28	0.29	0.33	0.30	0.32	0.34	0.35	0.36	0.35	0.33	0.34	Kazakhstan
0.09	0.10	0.11	0.12	0.12	0.13	0.15	0.15	0.15	0.16	0.17	0.18	0.19	0.20	0.22	0.23	0.24	0.26	0.27	0.25	0.26	0.27	0.27	0.29	0.31	0.32	0.33	Malaysia
0.33	0.34	0.36	0.36	0.35	0.36	0.39	0.36	0.32	0.30	0.31	0.32	0.29	0.31	0.30	0.31	0.29	0.28	0.28	0.27	0.28	0.30	0.30	0.30	0.29	0.29	0.29	Nigeria
0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.22	0.23	0.25	0.26	0.27	0.28	0.29	0.29	0.30	0.30	0.29	0.28	0.30	0.29	0.29	0.30	0.30	0.29	0.30	Taiwan
0.20	0.22	0.23	0.24	0.26	0.27	0.29	0.30	0.27	0.28	0.28	0.29	0.30	0.31	0.34	0.35	0.35	0.36	0.37	0.36	0.39	0.39	0.40	0.41	0.40	0.40	0.40	Thailand
0.95	0.89	0.79	0.70	0.59	0.58	0.50	0.48	0.45	0.45	0.44	0.44	0.45	0.47	0.45	0.44	0.44	0.45	0.43	0.37	0.39	0.41	0.40	0.39	0.35	0.29	0.31	Ukraine
4.11	4.08	4.07	4.12	4.17	4.26	4.34	4.43	4.47	4.48	4.58	4.64	4.72	4.89	5.02	5.21	5.33	5.48	5.71	5.77	5.98	6.06	6.17	6.27	6.38	6.57	6.70	**Remaining countries**
0.65	0.66	0.70	0.70	0.72	0.75	0.77	0.80	0.82	0.86	0.89	0.85	0.89	0.90	0.99	1.04	1.09	1.14	1.14	1.10	1.17	1.19	1.14	1.15	1.18	1.21	1.23	**International transport**
32.72	32.84	32.78	32.94	33.23	34.06	34.59	34.84	34.88	35.08	36.00	36.40	36.94	38.30	39.87	41.18	42.47	43.88	44.26	43.91	46.02	47.29	47.71	48.37	48.84	48.94	49.18	**Total**

Table B.2 CH_4 emissions per country and group, 1990–2016 (unit: Mt CO_2 eq)

CH_4 emissions per country/group, 1990–2016 [Mt CO_2 eq]																											
1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Region**
1185	1176	1162	1147	1153	1207	1210	1184	1170	1169	1170	1176	1184	1223	1307	1399	1458	1478	1504	1529	1583	1634	1660	1695	1706	1701	1698	**China**
668	662	666	663	670	663	656	651	642	632	627	624	622	619	613	609	609	614	626	622	625	645	645	632	654	651	632	**USA**
805	793	769	749	732	727	724	717	697	687	676	662	655	645	635	624	619	612	602	587	583	572	568	563	558	556	553	**EU28**
77	78	77	75	75	75	75	74	73	73	73	73	72	71	70	70	69	69	70	68	68	66	66	66	65	65	66	France
143	137	130	125	121	119	115	110	105	102	98	94	91	88	85	82	78	77	76	73	71	70	69	69	68	67	66	Germany
54	54	52	51	52	52	53	54	53	53	54	51	52	50	48	47	46	46	45	45	45	43	43	42	41	40	39	Italy
37	37	37	36	35	35	34	33	32	31	30	29	27	26	26	25	24	24	24	24	24	23	23	23	22	21	21	Netherlands
103	98	94	91	90	89	87	86	78	75	70	69	68	68	66	67	68	67	66	64	65	65	66	66	66	66	66	Poland
36	37	37	36	37	37	38	39	40	41	41	42	43	43	43	43	43	44	43	44	43	42	42	42	42	43	43	Spain
128	129	127	124	119	122	122	122	119	117	113	109	107	102	96	93	89	85	80	75	72	69	66	63	60	58	56	United Kingdom
617	626	632	637	643	650	656	662	666	672	673	680	677	688	700	717	731	746	765	779	794	804	815	795	803	811	818	**India**
502	478	450	421	393	374	360	347	332	341	342	350	370	372	394	383	409	415	408	384	415	426	437	434	426	437	442	**Russian Federation**
78	77	76	75	75	72	69	66	62	60	58	56	55	54	53	52	52	51	50	49	49	47	46	47	46	45	44	**Japan**
462	466	473	483	485	486	494	505	499	514	531	525	519	489	504	497	514	518	507	508	504	544	550	521	543	546	545	**Other OECD G20**
150	151	149	147	145	145	140	141	144	159	170	172	169	135	152	138	153	147	135	138	128	170	172	132	137	144	141	Australia
107	110	117	122	126	118	126	126	118	122	125	119	120	120	121	122	120	120	118	116	117	115	117	125	138	131	131	Canada
114	111	110	114	113	118	121	127	127	121	121	121	120	122	122	123	126	130	135	133	134	132	130	132	132	132	131	Mexico
39	38	37	36	36	36	37	37	36	36	37	37	35	35	36	36	37	37	36	36	37	36	37	36	36	36	36	South Korea
52	55	61	64	64	69	71	74	74	76	77	76	74	75	73	77	79	83	84	84	88	89	94	97	100	103	105	Turkey
803	820	839	851	873	867	874	869	857	853	855	873	897	939	962	982	990	996	1013	1016	1040	1050	1070	1075	1087	1094	1099	**Other G20 countries**
139	132	133	138	143	129	135	125	118	120	121	123	124	132	132	132	134	133	131	125	116	112	115	116	117	117	118	Argentina
328	342	352	362	376	388	380	382	387	389	391	404	423	442	462	470	466	464	468	468	486	485	487	484	489	492	494	Brazil
207	219	231	235	221	218	225	224	216	212	208	211	214	219	222	227	236	245	253	267	279	289	301	305	309	309	308	Indonesia
66	64	59	52	69	66	67	68	65	60	63	64	64	72	71	75	77	77	81	77	80	85	89	90	91	96	98	Saudi Arabia
63	64	63	64	65	66	67	70	71	71	71	72	73	74	75	78	77	78	80	79	79	79	80	80	80	80	80	South Africa
5120	5098	5067	5027	5024	5047	5044	5001	4926	4928	4931	4946	4979	5028	5168	5263	5382	5430	5475	5474	5594	5722	5791	5762	5823	5841	5830	**G20**
766	774	781	769	759	739	747	701	636	611	609	607	596	636	647	664	671	670	677	673	692	704	736	736	742	730	733	**Other big countries**
38	41	43	46	46	47	47	46	42	44	42	44	46	49	50	55	58	59	61	60	57	59	60	58	60	59	59	Egypt
148	153	152	139	155	145	145	140	124	119	122	119	121	138	141	148	154	154	155	159	164	167	163	163	174	178	185	Iran
83	80	80	75	64	54	50	47	42	41	41	39	44	44	49	51	55	54	57	57	60	59	88	87	91	90	93	Kazakhstan
27	29	29	37	36	36	38	39	40	38	38	37	38	39	43	45	45	45	46	45	43	45	45	49	51	52	53	Malaysia
241	249	254	260	252	260	281	246	214	193	194	196	173	191	189	188	180	176	173	166	174	180	183	180	179	176	176	Nigeria
11	11	11	11	11	11	11	11	11	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Taiwan
96	100	101	96	99	96	95	98	93	95	94	95	96	95	99	102	103	108	110	113	121	117	122	122	115	108	101	Thailand
120	112	110	104	96	90	81	76	71	70	68	66	68	71	67	66	66	64	66	63	63	66	65	66	62	56	56	Ukraine
1765	1751	1803	1829	1863	1888	1903	1898	1896	1905	1917	1919	1932	2007	2051	2121	2168	2212	2286	2293	2353	2396	2424	2473	2499	2543	2579	**Remaining countries**
8	8	9	9	9	9	10	10	11	10	11	11	11	11	12	13	13	13	13	12	12	12	12	12	13	13	13	**International transport**
7659	7632	7660	7634	7655	7682	7704	7610	7468	7454	7468	7483	7517	7682	7879	8062	8233	8325	8451	8452	8652	8835	8965	8983	9076	9126	9155	**Total**

Table B.3 N_2O emissions per country and group, 1990–2016 (unit: Mt CO_2 eq)

N_2O emissions per country/group, 1990–2016 [Mt CO_2 eq]																											
1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Region**
317	322	328	324	337	385	394	375	383	397	394	395	419	418	440	467	498	518	526	506	505	518	522	528	532	534	537	**China**
274	274	283	285	295	296	304	304	304	303	302	298	295	296	300	299	297	296	286	281	285	283	277	277	279	275	273	**USA**
388	372	355	346	351	349	358	354	323	305	302	298	296	296	296	297	289	288	270	260	251	245	245	243	251	260	269	**EU28**
62	62	59	60	60	61	64	63	51	47	45	45	44	43	43	43	41	41	41	40	40	38	39	39	43	46	50	France
67	66	67	64	67	65	67	64	48	45	44	44	43	43	43	42	42	42	44	40	39	38	39	39	40	41	42	Germany
28	28	28	27	27	28	28	28	28	28	28	28	28	26	26	25	20	20	19	18	18	18	18	17	17	17	17	Italy
13	13	14	14	14	14	14	13	13	13	13	12	12	14	14	14	16	15	9	9	9	9	9	8	9	9	9	Netherlands
26	25	25	25	25	26	26	27	26	26	26	26	25	27	27	27	27	27	26	23	23	23	23	23	25	27	30	Poland
22	22	20	21	21	22	23	24	24	25	25	24	24	25	24	24	23	23	22	22	21	20	20	21	22	23	24	Spain
53	53	47	43	44	42	43	42	42	32	30	28	28	28	27	26	25	25	25	23	23	23	23	23	24	24	25	United Kingdom
146	151	156	160	166	170	175	180	184	187	182	185	180	187	193	201	211	221	227	231	238	246	251	252	257	261	264	**India**
119	115	105	94	79	74	72	66	62	60	63	65	65	65	63	63	63	63	54	52	51	53	53	52	51	52	52	**Russian Federation**
31	31	31	31	33	33	34	34	32	26	27	25	25	25	25	25	24	24	23	22	22	22	23	23	23	22	22	**Japan**
182	181	187	193	201	215	217	222	228	246	257	258	250	222	246	230	248	247	238	248	240	290	294	261	272	281	283	**Other OECD G20**
71	70	70	70	70	70	66	65	70	87	96	96	91	59	78	61	76	70	58	62	52	98	99	62	74	82	84	Australia
38	37	38	38	41	42	44	42	37	35	35	33	33	34	35	34	35	34	34	33	34	35	37	40	40	39	39	Canada
37	36	39	42	50	60	62	70	73	75	79	82	83	87	90	92	94	99	103	109	110	112	112	112	113	114	115	Mexico
9	10	12	13	13	14	15	16	16	16	18	18	13	12	13	13	13	12	12	13	13	13	13	12	12	12	12	South Korea
28	27	29	30	27	30	30	30	31	32	31	29	29	30	31	30	31	31	31	31	32	32	33	35	34	33	33	Turkey
217	220	229	233	242	247	247	249	258	256	259	269	281	295	299	306	305	318	315	311	329	327	328	319	331	340	349	**Other G20 countries**
35	34	35	34	36	36	37	36	38	39	41	46	45	49	47	49	51	53	52	47	51	50	48	51	55	57	60	Argentina
99	101	106	111	118	121	116	120	125	125	126	131	140	150	155	158	156	165	162	159	175	174	175	166	171	175	179	Brazil
58	58	61	60	61	63	65	63	65	63	64	64	67	67	68	69	69	71	72	75	75	75	76	74	76	78	80	Indonesia
6	6	7	7	6	6	6	7	6	7	7	7	7	7	8	7	8	8	7	7	7	8	8	8	8	8	8	Saudi Arabia
19	19	21	21	21	21	23	23	24	23	21	21	23	22	22	23	22	22	21	21	22	21	21	21	21	21	21	South Africa
1675	1665	1675	1667	1703	1769	1799	1784	1774	1780	1786	1793	1811	1804	1863	1887	1935	1975	1938	1910	1922	1985	1993	1956	1995	2024	2048	**G20**
143	142	145	140	136	132	130	131	130	129	130	133	139	139	155	154	155	163	158	152	159	159	159	154	154	154	155	**Other big countries**
11	12	13	14	13	15	16	16	17	16	17	18	18	19	21	21	22	22	23	23	25	25	25	21	21	20	20	Egypt
21	21	23	22	23	23	24	26	26	26	26	27	26	27	39	36	36	41	34	31	31	30	30	28	28	28	28	Iran
21	21	22	20	19	17	16	14	13	12	12	13	17	14	15	15	16	15	16	15	16	15	15	14	15	15	15	Kazakhstan
8	8	8	8	8	8	8	9	10	9	10	9	10	10	11	11	11	11	12	12	12	12	12	12	13	13	14	Malaysia
19	20	20	21	21	21	22	23	24	24	25	26	25	26	26	28	28	28	28	28	29	30	31	33	32	33	34	Nigeria
4	4	4	4	5	5	5	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	Taiwan
15	15	16	17	18	17	17	17	17	18	17	17	18	18	18	18	17	20	20	22	22	22	22	23	22	22	21	Thailand
44	41	38	32	29	25	22	22	19	18	19	19	20	20	19	20	20	21	20	17	18	19	18	18	18	17	17	Ukraine
449	446	448	454	459	466	474	484	502	503	513	518	522	551	559	576	570	594	604	604	618	626	619	628	633	651	662	**Remaining countries**
19	20	21	21	21	22	22	23	24	25	26	24	25	26	28	30	32	33	33	32	34	35	32	32	32	33	33	**International transport**
2286	2273	2288	2280	2320	2389	2426	2422	2430	2436	2454	2468	2497	2520	2605	2647	2692	2765	2733	2698	2734	2805	2803	2770	2814	2862	2898	**Total**

Table B.4 F-gas emissions per country and group, 1990–2016 (unit: Mt CO_2 eq)

F-gas emissions per country/group, 1990–2016 [Mt CO_2 eq]																											
1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Region**
15	16	15	13	15	22	32	24	28	39	30	82	68	85	115	139	185	225	257	238	252	256	263	271	280	288	296	**China**
98	101	102	103	102	102	108	118	131	140	161	179	192	195	216	226	246	267	290	312	330	357	399	428	457	485	514	**USA**
64	66	62	64	60	63	66	66	73	75	82	84	89	83	88	93	98	104	113	121	131	136	144	152	160	169	177	**EU28**
9	9	11	12	13	17	14	9	10	11	13	13	15	15	16	17	17	17	19	20	22	23	25	26	28	30	31	France
13	13	14	15	13	13	14	15	17	18	18	18	20	19	19	20	22	24	26	28	30	29	30	31	32	33	34	Germany
6	6	5	5	4	4	5	5	8	8	9	10	10	11	12	11	12	12	13	14	15	17	18	19	20	21	22	Italy
11	11	7	8	8	8	9	8	9	9	10	9	9	5	4	4	4	4	5	5	5	5	6	6	6	6	7	Netherlands
1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	3	3	3	4	3	3	3	3	3	3	Poland
6	8	7	7	8	8	7	8	8	8	9	7	9	8	8	9	10	10	11	12	13	13	14	15	15	16	16	Spain
6	7	6	7	7	6	9	9	9	9	10	10	10	10	11	11	11	12	13	14	15	15	16	17	18	19	20	United Kingdom
8	10	10	11	10	10	9	9	9	10	13	13	16	16	16	20	24	18	18	26	24	26	28	28	29	29	30	**India**
28	29	29	39	40	44	42	45	45	48	51	54	58	58	56	57	65	69	70	75	76	67	72	72	71	70	69	**Russian Federation**
27	29	33	39	43	55	54	77	69	69	67	63	59	59	55	58	57	62	66	71	74	78	82	86	91	95	99	**Japan**
32	35	32	34	32	33	32	33	40	43	43	52	50	46	54	53	54	61	65	66	69	69	74	76	80	83	87	**Other OECD G20**
5	6	6	5	5	4	3	3	3	3	4	4	5	5	5	6	7	7	8	9	9	10	10	11	11	12	12	Australia
16	16	14	15	14	15	15	15	16	17	18	19	20	20	21	23	23	25	27	28	29	30	33	35	37	39	41	Canada
4	4	3	4	2	3	3	3	6	6	5	7	6	5	6	6	6	9	12	11	11	12	13	13	14	15	15	Mexico
5	6	7	7	8	8	8	9	13	14	14	20	17	13	18	15	13	14	12	12	12	10	9	9	9	8	9	South Korea
2	2	3	3	3	3	2	2	2	2	2	2	3	3	3	4	5	5	6	7	7	7	8	8	9	9	10	Turkey
17	18	18	18	16	15	14	13	12	12	12	10	10	10	11	13	15	16	17	19	19	19	20	21	21	22	22	**Other G20 countries**
3	3	3	3	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	Argentina
9	9	10	10	10	10	9	9	7	7	7	6	6	5	6	8	9	10	10	11	12	11	12	12	12	13	13	Brazil
2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Indonesia
2	2	2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	3	Saudi Arabia
1	1	2	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	4	4	4	South Africa
289	303	300	321	319	345	359	386	408	434	458	538	542	552	611	659	743	821	897	928	975	1008	1082	1134	1188	1242	1296	**G20**
8	9	9	10	10	9	8	8	9	9	10	11	13	13	15	17	17	17	19	20	21	19	20	20	20	21	21	**Other big countries**
2	2	2	2	2	2	2	2	3	2	2	3	3	3	3	3	3	3	4	4	4	4	4	4	4	5	5	Egypt
2	2	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	Iran
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	Kazakhstan
0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Malaysia
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	Nigeria
2	2	2	2	2	2	2	2	3	4	4	5	7	6	8	8	8	7	8	9	9	7	8	7	7	7	6	Taiwan
1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	2	Thailand
0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Ukraine
29	31	31	29	24	21	19	18	19	20	20	21	24	26	26	28	32	35	38	41	45	44	45	47	50	52	56	**Remaining countries**
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**International transport**
326	342	341	360	353	375	386	412	435	463	488	571	579	591	652	704	793	874	954	990	1041	1071	1148	1201	1259	1314	1372	**Total**

C. Recent trends in electricity production: fossil, renewable, nuclear

Table C.1 Fossil fuel power production, 2010–2016 (unit: TWh)

Fossil fuel power production in top 25 countries and the European Union 2010–2016 [TWh]										
Country	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Increase 2016**	**Increase 2016 [%]**	**Share in 2016**
China	3352	3838	3897	4224	4242	4245	4386	141	3.3%	26.9%
United States	3114	3014	2998	2967	2972	2947	2871	-76	-2.6%	17.6%
India	772	828	893	925	1025	1081	1161	81	7.5%	7.1%
European Union	973	1003	1023	1002	1005	983	997	14	1.4%	6.1%
Japan	747	829	979	954	931	876	819	-57	-6.6%	5.0%
Russian Federation	697	712	721	698	702	697	703	6	0.8%	4.3%
Germany	388	382	388	390	368	368	375	8	2.1%	2.3%
South Korea	338	351	368	384	367	361	368	6	1.7%	2.3%
Saudi Arabia	240	250	272	284	312	328	330	2	0.7%	2.0%
Iran	216	225	234	235	255	260	266	7	2.6%	1.6%
Mexico	224	237	246	246	241	251	256	5	1.8%	1.6%
South Africa	245	247	244	240	237	231	227	-3	-1.4%	1.4%
Indonesia	143	161	178	190	203	210	223	13	6.4%	1.4%
Taiwan	198	203	201	201	209	213	221	9	4.1%	1.4%
Australia	229	226	220	214	215	218	215	-3	-1.2%	1.3%
United Kingdom	294	264	252	234	210	185	184	-1	-0.6%	1.1%
Turkey	155	171	174	171	199	178	183	5	2.9%	1.1%
Italy	225	220	207	178	159	174	179	5	2.9%	1.1%
Egypt	129	134	146	150	155	165	171	6	3.6%	1.0%
Thailand	149	141	155	156	160	164	164	0	-0.2%	1.0%
Poland	147	150	145	147	139	142	144	2	1.2%	0.9%
Malaysia	112	111	117	125	129	128	137	9	6.8%	0.8%
United Arab Emirates	94	99	106	110	116	127	136	9	7.4%	0.8%
Canada	136	139	130	128	129	137	132	-5	-3.6%	0.8%
Vietnam	64	60	62	67	82	102	115	12	12.2%	0.7%
Spain	144	148	149	118	111	126	111	-15	-11.7%	0.7%
Other countries	2051	2049	2110	2137	2148	2203	2244	41	1.9%	13.7%
Global total	14603	15189	15594	15873	16015	16116	16323	206	1.3%	100.0%

Source: BP (2017)

Note: ‘Other countries’ includes all countries not explicitly listed (including other EU countries)

Table C.2 Hydropower production, 2010–2016 (unit: TWh)

Hydropower production in top 20 countries and the European Union 2010–2016 [TWh]										
Country	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Increase 2016**	**Increase 2016 [%]**	**Share in 2016**
China	711	688	863	910	1051	1114	1163	48	4.3%	28.9%
Canada	351	376	380	392	383	378	388	11	2.8%	9.7%
Brazil	403	428	415	391	373	360	384	25	6.8%	9.6%
European Union	378	314	337	371	375	341	348	7	2.0%	8.6%
United States	257	316	274	267	256	246	262	15	6.2%	6.5%
Russian Federation	168	165	165	179	175	170	187	17	9.8%	4.6%
Norway	117	120	142	128	135	137	143	6	4.4%	3.6%
India	109	132	116	132	139	133	129	-4	-3.4%	3.2%
Japan	87	81	76	78	80	84	80	-4	-4.6%	2.0%
Turkey	52	52	58	59	41	67	67	0	0.0%	1.7%
Sweden	67	67	79	61	64	75	62	-13	-17.2%	1.5%
Venezuela	77	83	82	83	74	76	61	-15	-19.8%	1.5%
Vietnam	28	41	53	57	60	57	61	3	6.0%	1.5%
France	64	46	60	70	62	54	60	5	9.5%	1.5%
Colombia	41	48	48	44	45	45	47	2	5.2%	1.2%
Italy	51	46	42	53	59	46	41	-5	-10.0%	1.0%
Austria	38	34	44	42	41	37	40	3	7.1%	1.0%
Argentina	41	40	37	41	41	42	38	-4	-9.2%	1.0%
Spain	42	31	21	37	39	28	36	8	27.7%	0.9%
Switzerland	36	32	38	38	37	38	34	-3	-8.5%	0.9%
Pakistan	29	31	29	31	32	32	34	2	5.5%	0.8%
Other countries	672	645	657	703	699	683	706	23	3.4%	17.6%
Global total	3441	3502	3677	3797	3886	3903	4023	120	3.1%	100.0%

Source: BP (2017)

Note: 'Other countries' includes all countries not explicitly listed (including other EU countries)

Table C.3 Wind power production, 2010–2016 (unit: TWh)

Wind power production in top 10 countries and the European Union 2010–2016 [TWh]										
Country	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Increase 2016**	**Increase 2016 [%]**	**Share in 2016**
European Union	149	179	206	235	251	302	301	-1	-0.4%	31.3%
China	45	70	96	141	156	186	241	55	29.7%	25.1%
United States	96	121	142	170	183	193	229	36	18.8%	23.8%
Germany	38	49	51	52	57	79	77	-2	-2.3%	8.1%
Spain	44	42	49	54	52	49	49	0	-0.9%	5.1%
India	20	25	30	34	33	33	45	12	36.8%	4.7%
United Kingdom	10	16	20	28	32	40	38	-3	-7.0%	3.9%
Brazil	2	3	5	7	12	22	33	11	52.2%	3.4%
Canada	9	11	14	17	21	25	27	3	10.7%	2.8%
France	10	12	15	16	17	21	21	0	-2.0%	2.2%
Italy	9	10	13	15	15	15	18	3	18.7%	1.8%
Other countries	60	78	92	112	130	166	183	17	10.1%	19.0%
Global total	341	437	527	644	709	828	960	131	15.9%	100.0%

Source: BP (2017)

Note: 'Other countries' includes all countries not explicitly listed (including other EU countries)

Table C.4 Solar power production, 2010–2016 (unit: TWh)

Solar power production in top 10 countries and the European Union 2010–2016 [TWh]										
Country	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Increase 2016**	**Increase 2016 [%]**	**Share in 2016**
European Union	23	46	71	85	97	108	112	3	3.2%	33.5%
China	1	3	4	8	24	39	66	28	71.9%	19.9%
United States	3	5	9	16	29	39	57	17	44.0%	17.1%
Japan	4	5	7	13	24	37	50	13	35.2%	14.9%
Germany	12	20	26	31	36	39	38	-1	-1.4%	11.5%
Italy	2	11	19	22	22	23	23	0	-0.2%	6.9%
Spain	7	9	12	13	14	14	14	0	-2.3%	4.1%
India	0	1	1	3	4	7	12	5	81.8%	3.6%
United Kingdom	0	0	1	2	4	8	10	3	36.1%	3.1%
France	1	2	4	5	6	7	8	1	11.7%	2.5%
Australia	1	2	2	4	5	6	7	1	20.1%	2.1%
Other countries	4	8	14	22	29	39	48	10	25.0%	14.5%
Global total	34	65	100	138	196	256	333	77	30.0%	100.0%

Source: BP (2017)

Note: 'Other countries' includes all countries not explicitly listed (including other EU countries)

Table C.5 Power production from biomass, geothermal, others, 2010–2016 (unit: TWh)

Power production from biomass, geothermal, and other renewables in top 10 countries and the European Union 2010–2016 [TWh]										
Country	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Increase 2016**	**Increase 2016 [%]**	**Share in 2016**
European Union	129	138	153	162	173	185	187	2	1.3%	33.4%
United States	75	76	77	81	84	84	85	1	1.0%	15.1%
China	25	28	30	37	45	60	73	13	21.8%	13.1%
Germany	34	37	43	46	48	50	52	1	2.6%	9.2%
Brazil	32	32	35	40	46	49	51	2	3.9%	9.1%
United Kingdom	12	13	15	18	23	29	30	0	0.7%	5.3%
Japan	22	21	22	23	24	24	27	3	12.5%	4.7%
Italy	15	16	18	23	25	26	26	0	0.7%	4.6%
India	12	14	14	15	15	17	16	-1	-5.0%	2.9%
South Korea	3	6	7	7	11	12	12	0	0.2%	2.1%
Finland	11	11	11	12	12	11	12	0	4.2%	2.1%
Other countries	137	144	154	156	164	174	179	5	2.9%	31.9%
Global total	376	399	427	459	497	536	562	25	4.7%	100.0%

Source: BP (2017)

Note: 'Other countries' includes all countries not explicitly listed (including other EU countries)

Table C.6 Nuclear power production, 2010–2016 (unit: TWh)

Nuclear power production in top 10 countries and the European Union 2010–2016 [TWh]										
Country	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Increase 2016**	**Increase 2016 [%]**	**Share in 2016**
United States	849	832	810	831	839	839	848	9	1.0%	32.4%
European Union	916	907	883	877	877	857	840	-18	-2.0%	32.1%
France	428	442	425	424	436	437	403	-34	-7.8%	15.4%
China	74	86	97	112	133	171	213	42	24.8%	8.1%
Russian Federation	170	173	178	173	181	195	197	1	0.6%	7.5%
South Korea	149	155	150	139	156	165	162	-3	-1.6%	6.2%
Canada	90	93	94	103	107	101	103	2	1.8%	3.9%
Germany	141	108	99	97	97	92	85	-7	-7.8%	3.2%
Ukraine	89	90	90	83	88	88	81	-7	-7.6%	3.1%
United Kingdom	62	69	70	71	64	70	72	1	2.0%	2.7%
Sweden	58	60	64	66	65	56	63	6	11.4%	2.4%
Other countries	656	544	393	394	375	361	391	30	8.3%	14.9%
Global total	2766	2652	2472	2492	2541	2575	2617	41	1.6%	100.0%

Source: BP (2017)

Notes: ‘Other countries’ includes all countries not explicitly listed (including other EU countries)

Power data in this table are for gross power production: it includes electricity required for primary pumps to run the reactor and the rest of the plant, which is about 5% of total gross electricity produced (WNA, 2016)

D. Methodology for non-CO_2 emission estimates 2013–2016

Non-CO_2 emissions constitute a substantial fraction of the global greenhouse gas emissions. For climate policies this refers to methane (CH_4), nitrous oxide (N_2O) and the F-gases HFCs, PFCs, SF_6 and NF_3. Currently, there is no literature that provides worldwide estimates of the non-CO_2 emissions for very recent years (e.g. up to last year) that is based on detailed activity data and trends in emission factors. In order to monitor the trend in global greenhouse gas emissions, reliable and independent data, is paramount. PBL and EC-JRC aim to provide such data by maintaining a database that keeps track of activities that result in greenhouse gases on a country level (EC-JRC/PBL, 2017). From these activities, the resulting CO_2 emissions are calculated annually (up to last year), based on the most up-to-date international statistics for energy consumption and industrial production related to CO_2 emissions (fossil fuels and limestone uses). This year, also the non-CO_2 greenhouse gas emissions behave been calculated, mainly based on the EDGAR database version 4.3.2, in order to provide an independent estimate of global total greenhouse gas emissions for all countries, thus filling the vacuum in knowledge on the status quo of recent emission trends. The focus of our analysis in this report is on the top-6 emitting countries (including the European Union) and the world total.

Version 4.3.2 of the EDGAR database, which comprises the 1970-2012 period for CO_2, CH_4 and N_2O emissions, is used as a basis. Here, we briefly describe the set-up of this database and the hybrid methodology that is applied to arrive at estimates for non-CO_2 greenhouse gas emissions (non-CO_2 emissions in short) in subsequent years, from 2013 up to and including 2016.

In 2017 the EDGAR database has been fully updated to include comprehensive activity and emission factor data up to 2012, and where available until later years. Also, activity data back to 1970 have been updated with revised international statistics, when applicable. For greenhouse gases, the methodology and data sources of the 2006 IPCC guidelines for inventories was used (IPCC, 2006). For more details on the update from the previous version 4.2 FT2010 to version 4.3.2, see Janssens-Maenhout et al. (2017a). The former was used in the Fifth Assessment report of Working Group III of the Intergovernmental Panel on Climate Change (IPCC, 2014). Most physical activity data is available on a country level in international statistics (notably for energy, industrial production and agriculture) and default IPCC emission factors are used to the available level of detail of the statistics in order to arrive at the emissions. Similar to our fast track nethod for the CO_2 emission estimates (Olivier et al., 2016), for years after 2012 we apply a fast track method using proxy data – combined with trend extrapolation for years where proxy data was not available for all the years 2013 up to 2016. For all sources where statistical data up to 2016 was lacking, we extrapolated data from three recent years. This section describes the hybrid fast-track and extrapolation method used for estimating the non-CO_2 emissions and summarises the changes in estimated recent emissions due to the update from EDGAR v4.2 FT2010 to EDGAR v4.3.2.

Greenhouse gases and activity data

The non-CO_2 greenhouse gases are categorised in three main gases: methane (CH_4), nitrous oxide (N_2O) and the fluorinated gases (so-called F-gases). The fluorinated gases taken into account are PFCs, HFCs, SF_6 and NF_3, which are reported annually by industrialised countries under the UN Framework Convention on Climate Change (UNFCCC, 2011). Below we summarise the largest source categories per gas, showing their CRF sector/category code as in the revised UNFCCC reporting guidelines (between brackets) (UNFCCC, 2011)[6].

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[6] The new UNFCCC reporting guidelines mainly follow the 2006 IPCC guidelines, except for that the last three main sectors numbers have been shifted one down: now 3 for Agriculture, 4 for LULUCF, 5 for Waste and 6 for Other, since Sector 2 Industrial processes now includes Product Use (formerly Sector 3) and for reporting purposes Agriculture and LULUCF remain separated CRF sectors (3 and 4).

Methane (CH_4)
Activities that mainly determine CH_4 emissions are:
- coal production (1B1)
- oil production (venting of unused associated gas) and transport (1B2a)
- gas production, transport and distribution (1B2b)
- livestock (ruminants) (3A)
- manure management (3B)
- rice cultivation (3C)
- landfills (5A)
- waste water (5C)

We note that for landfills methane is often recovered, as it is for coal mining and waste water treatment.

Nitrous oxide (N_2O)
Activities that mainly determine N_2O emissions are:
- adipic acid production (2B2)
- nitric acid production (2B3)
- animal waste management (3B)
- direct soil emissions from fertilisers (synthetic and animal manure) (3D11, 3D12)
- animal manure in pasture/range/paddock (3D13)
- indirect N_2O from agriculture (from direct soil emissions) (3D2)
- indirect N_2O from NO_x and NH_3 from other activities (such as fuel combustion) (6)

Generally industrial N_2O emissions are not proportional to the trend in activity, since these emissions are often abated (2B2, 2B3).

F-gases
Activities that mainly determine F-gas emissions are:
- aluminium production (by-product CF_4, C_2F_6) (2C3)
- HCFC-22 production (by-product HFC-23) (2B9)
- HFC use (HFCs), the largest being HFC-134a (2F)
- PFC use (PFCs) (2F)
- semiconductor manufacturing (mostly use of PFCs and SF_6) (2E1)
- manufacturing of Gas Insulated-Switchgear (GIS), containing SF6 (2G1)
- electricity sector (SF_6 from the use of GIS equipment) (2G1)

We note that in HCFC-22 production, by-product HFC-23 emissions are often abated.

Data sources and methodology used for estimating 2013–2016 emissions

For CH_4 emissions not for all sources recent statistics are available. For landfills recent international statistics (amount of municipal waste produced, fraction deposited in landfills and its organic fraction) are not available on a global level. The same holds for statistics on waste water generation and handling (% Biochemical Oxygen Demand (BOD), fractions to sewer, wastewater treatment plants, raw discharge and other handling systems).
However, for most of these sources the trends tend to change very slowly. However, for most of these sources the trends tend to change very slowly.

For N_2O emissions, recent statistics at global level are not available for the industrial production sources, animal waste management systems and for indirect emissions from nitrogen emissions from fuel combustion sources.

For F-gas emissions the international statistical basis, also for older years, is much worse than for the other greenhouse gases. Apart from primary aluminium production, which emits PFCs as a by-product, no global international statistics are available for the use of different fluorinated gases, neither for production of these gases per country or the global total, nor for consumption. An exception is SF_6, for which in the past surveys have been made of the sales by SF_6 manufacturers. The last such survey was conducted by RAND in 2000 and covered production and sales per main category. However, data from Russian and Chinese manufacturers were not included.

Except for the sources for which no international statistics for the activity data exist, the following data sources were used as proxy for the activity levels for main sources of methane and nitrous oxide (with revised CRF sector/2006 IPCC category code between brackets):

- IEA for CO_2 from fossil-fuel combustion of coal, oil products and natural gas per country (presently up to 2014) and BP for consumption of coal, oil and natural gas (for extrapolating from 2014 to 2016 (1A) [same table as in the Fast Track for CO_2 emissions]
- IEA for biomass (non-CO_2) (1A4bx)
- BP for fossil fuel production (1B1, 1B2a, 1B2b)
- FAO for animal numbers (3A, 3B)
- FAO for rice cultivation, fertiliser use and savannah burning (3C, 3D, 3E)
- GFED4.1s emissions for large-scale biomass burned (4 forest fires)
- CRF trends for waste and waste water emissions (5A, 5C) (see Box D.1)
- CRF trends for industrial processes (2B2, 2B3, 2B9) (see Box D.1)
- CRF and CDM for amounts of greenhouse gas recovery or abatement (1B1, 2B2, 2B3, 2B9, 5A) (see Box D.1)

In Tables D.1 and D.2 the CH_4 and N_2O sources are listed for which proxy data were used, and the sources and years covered by this proxy data. For data that is not available in international statistics (e.g. when data were not yet available through 2016 and for other, smaller sources) trend extrapolation was used. The fraction of sources in 2012 covered by these proxies are 81% and 87% for CH_4 and N_2O, respectively.

Box D.1 Data submitted to the UN Climate Convention: CRF and CDM

Industrialised countries ('Annex I countries') annually report their NIRs for the UNFCCC and also submit emission tables in so-called CRF data (UNFCCC, 2017). These *Common Reporting Format* data are detailed spreadsheets with annual data per source category: emissions, activity data and so-called implied emission factors). This data set is limited to the Annex I countries, but covers all years from 1990 to, presently, 2015. Four of the six largest emitting countries are included in this group: United States, European Union, Russian Federation and Japan. Where international statistics are lacking, such as for several industrial products, the trend in the CRF activity data can be used for a fast track estimate of these sources and for this group of countries. Moreover, in case of emissions abatement (such as N_2O and HFC-23 from industrial processes) the net emission trend may be used as proxy for estimating the actual net emissions trend.

In the case of developing countries, such as China and India, which do not annually submit CRF data the statistics of the above-named activities are used in combination with emission factors, in order to estimate recent non-CO_2 emissions for those countries. In addition, for these countries statistics from CDM projects (annual data up to 2016) can be used in order to adjust emissions to include emission reductions by these projects (e.g. CH_4 recovery from mines and landfills, N_2O abatement, HFC-23 destruction). These *Clean Development Mechanism* (CDM) projects are officially registered activities in developing countries, each with a detailed description of contents and time schedule and accounting of the emission reductions by CDM credits (tonnes CO_2 eq per year). Key information is regularly updated by UNEP DTU Partnership (formerly UNEP Risø Centre) in the so-called CDM-pipeline and is presently available up to and including 2016 (UNEP DTU Partnership, 2017).

Apart from IEA (available up to 2014 or 2015) and BP (available up to 2016), FAO statistics are mostly available up to 2014, thus requiring trend extrapolation for 2015 and 2016 emissions of these sources of non-CO_2 gases.

For F-gas emissions, which have a relatively small contribution to total national greenhouse gas emissions in most cases and have not been updated up to 2012 in v4.3.2, we used trend extrapolation for all years.

Revisions in emissions by switching from EDGAR v4.2 FT2010 to v4.3.2

The downward revisions in global CO_2 emissions in EDGAR 4.3.2 FT2016 for recent years (2010 and beyond) compared to the numbers in last year's report are due to regular annual statistical revisions of fossil fuel consumption in IEA and BP statistics (notably of BP coal consumption in 2015 in Indonesia (also in 2014), India, China and the United States), resulting in the trend in global total coal consumption in 2015 to be revised from -1.8% to -2.7%, which is equivalent to -0.15 Gt CO_2). Also revisions, corrections and some full updates occurred, including emission factors (for example for cement clinker), for several other sources (gas flaring, cement production, solvent use, ammonia production, urea and lime application). All updates and statistical revisions together have resulted in 0.6 Gt lower CO_2 emissions in 2015 compared to last year's assessment (Olivier et al., 2016).

Similarly, substantial revisions occurred in net CO_2 emissions from LULUCF when comparing net emissions in Houghton and Nassikas (2017) with the global CO_2 data in last year's global carbon budget compiled by the Global Carbon Project (GCP), and also in this years global carbon budget (Le Quéré et al., 2016, 2017). In addition, this year we also included the relatively small contribution by CH_4 and N_2O emissions from large-scale biomass burning (forest, other vegetation and peat) to the total net LULUCF emissions of greenhouse gases.

By switching from EDGAR 4.2 FT2010 (1970–2010) to version 4.3.2 for CH_4 and N_2O for 1970–2012, global methane emissions excluding LULUCF were revised downward in recent years by about 4% or 0.3 Gt CO_2 eq, mainly as a result of revisions in CH_4 emissions from coal production, gas transmission and distribution, venting of associated gas, and industrial wastewater in EDGAR 4.3.2. For N_2O emissions excluding LULUCF, the global total for recent years was revised upward by 5% in 2010, mainly from increases in N_2O emissions from industrial processes and product use (sector 2), N_2O from soils (3D) and indirect N_2O emissions from other NO_x and NH_3 emissions (sector 6) (Janssens-Maenhout et al., 2017a). Including the changes in CO_2 emissions total greenhouse gas emissions are now about 1 Gt CO_2 eq lower, for recent years, than described in the previous UNEP Gap Report published in 2016.

Quality and completeness of data

Globally, the main sources for non-CO_2 emissions are covered with global international statistics on activity data for all sources except for the production of many chemicals (adipic acid, nitric acid, HCFC-22), the use of F-gases, amounts of waste annually dumped in landfills and the amount of industrial waste water (degradable organic compounds therein). For industrialised countries for which CRF data is available, we have compared the data from our own estimates with those reported by the countries. From that comparison we conclude that for various gases, sources and countries, the data from the national CRF reports can be substantially different from that calculated using EDGAR data (Olivier et al., 2010).

Table D.1 Global CH_4 emissions: proxies and data sources used to estimate 2013-2016 emissions (1996 IPCC codes)

Global CH_4 emissions: proxies and data sources used to estimate 2013–2016 emissions							
CH_4 2012	**IPCC code**	**IPCC category** (as in 1996 Guidelines)	**Share 2012**	**Proxy code**	**Proxy**	**Source**	**Years**
0.2	1An	Fossil fuel combustion	1.2%	1A	1A-CO2	IEA+BP	12-14-16
		Except:					
0.0	1A1c1	Fuel combustion coke ovens	0.0%	2C1	steel	USGS+WSI	12-14-16
0.0	1A1c2	Blast furnaces (pig iron production)	0.0%	2C1	steel	USGS+WSI	12-14-16
0.0	1Anx	Fuel combustion (biomass)	0.1%	trend			
		Except:					
0.0	1A1cx4	Fuel comb. charcoal production (biomass)	0.0%	1B1b3x	ch prod	IEA	12-14
0.0	1A4bx	Residential (biomass)	2.8%	1A4x	fw cmb	IEA	12-14
0.0	1A4c1x	Agriculture and forestry (biomass)	0.0%	1A4x	fw cmb	IEA	12-14
38.0	1B1a1	Hard coal mining (gross)	10.5%	1B1	IEA+BP	IEA+BP	12-15-16
-3.4	1B1a1r	Methane recovery from coal mining	-0.9%			CDM+CRF	12-16; 12-15
0.8	1B1b1	Fuel transformation coke ovens	0.2%	2C1	steel	USGS+WSI	12-14-16
4.5	1B1b3x	Fuel transformation charcoal production	1.3%	1B1b3x	ch prod	IEA	12-14
8.2	1B2a1	Oil production	2.3%	1B2a1	IEA+BP	IEA+BP	12-15-16
0.0	1B2a2	Oil transmission	0.0%	1B2a2	pro+imp	IEA	12-15
0.2	1B2a3-l	Tanker loading	0.1%	1B2a3-l	exp	IEA	12-15
25.0	1B2b1	Gas production	6.9%	1B2b1	IEA+BP	IEA+BP	12-15-16
5.8	1B2b3	Gas transmission	1.6%	1B2b3	pro+exp	IEA	12-15
22.9	1B2c	Venting and flaring during oil and gas production	6.3%	1B2c	1B-CO2	NOAA	12-15
0.0	1C1	International air transport	0.0%	1A	1A-CO2	IEA+BP	12-14-16
0.1	1C2	International marine transport (bunkers)	0.0%	1A	1A-CO2	IEA+BP	12-14-16
18.3	4A1-d	Dairy cattle	5.1%	4A1d	FAO	FAO	12-14
59.1	4A1-n	Non-dairy cattle	16.3%	4A1n	FAO	FAO	12-14
26.7	4An..	Other ruminants (sheep, goats, etc.)	7.4%	4A..	FAO	FAO	12-14
2.4	4B1-d	Manure Management: Dairy Cattle (confined)	0.7%	4A1d	FAO	FAO	12-14
2.0	4B1-n	Manure Management: Non-Dairy Cattle (confined)	0.6%	4A1n	FAO	FAO	12-14
7.5	4Bn..	Manure Management: Other (confined)	2.1%	4A..	FAO	FAO	12-14
37.7	4C	Rice cultivation	10.4%	4C	FAO	FAO	12-14
9.3	4E	Savannah fires	2.6%			FAO	12-14
29.1	6A1	Managed waste disposal on land	8.0%		trend+	CDM+CRF	12-16; 12-15

Table D.2 Global N_2O emissions: proxies and data sources used to estimate 2013-2016 emissions (1996 IPCC codes)

Global N_2O emissions: proxies and data sources used to estimate 2013–2016 emissions							
N_2O 2012	IPCC code	IPCC category (*as in 1996 Guidelines*)	Share 2012	Proxy code	Proxy	Source	Years
210.1	1A1a	Public Electricity Generation	2.6%	1A	1A-CO2	IEA+BP	12-14-16
525.0	1An	Fossil fuel combustion (other)	6.6%	1A	1A-CO2	IEA+BP	12-14-16
		Except:					
10.0	1A1c1	Fuel combustion coke ovens	0.0%	2C1	steel	USGS+WSI	12-14-16
0.9	1A1c2	Blast furnaces (pig iron production)	0.0%	2C1	steel	USGS+WSI	12-14-16
5.9	1Anx	Fuel combustion (biomass)	0.4%	trend			
		Except:					
5.3	1A1cx4	Fuel comb. charcoal production (biomass)	0.0%	1B1b3x	ch prod	IEA	12-14
2.2	1A4bx	Residential (biomass)	2.8%	1A4x	fw cmb	IEA	12-14
0.7	1A4c1x	Agriculture and forestry (biomass)	0.0%	1A4x	fw cmb	IEA	12-14
6.1	1B1b3x	Fuel transformation charcoal production	0.1%	1B1b3x	IEA	IEA	12-14
0.3	1B2a1	Oil production	0.0%	1B2a1	IEA+BP	IEA+BP	12-15-16
2.9	1B2c	Venting and flaring during oil and gas production	0.0%	1B2c	1B-CO2	NOAA	12-15
13.5	1C1	International air transport	0.1%	1A	1A-CO2	IEA+BP	12-14-16
15.8	1C2	International marine transport (bunkers)	0.2%	1A	1A-CO2	IEA+BP	12-14-16
290.4	2B2	Nitric acid production	2.9%	trend+		CDM+CRF	12-16; 12-15
363.7	2B3	Adipic acid production	3.7%	trend+		CDM+CRF	12-16; 12-15
35.1	2B5f	Caprolactam production	0.4%	trend+		CDM+CRF	12-16; 12-15
39.9	4B1-d	Manure Management: Dairy Cattle (confined)	0.4%	4A1d	FAO	FAO	12-14
145.5	4B1-n	Manure Management: Non-Dairy Cattle (confined)	1.5%	4A1n	FAO	FAO	12-14
152.9	4B2	Manure Management: Other (confined)	1.5%	4A..	FAO	FAO	12-14
1,635.5	4D11	Synthetic Fertilizers	16.5%	4D11	FAO	FAO	12-14
347.9	4D12	Animal Manure Applied to Soils	3.5%	4D12	tr 4B (sum of 10)		
289.7	4D13	Direct soil emissions	2.9%				
314.4	4D14	Crop Residue	3.2%				
329.8	4D15	Cultivation of Histosols	3.3%		(FAO: constant)	FAO	(constant)
2,071.5	4D2	Pasture, Range and Paddock Manure	20.9%	4D2	tr 4B (sum of 10)		12-14
708.2	4D3a	Indirect N2O: Atmospheric Deposition-agricult. (4D)	7.1%	4D3a	tr 4D1(sum of 5)		12-14
355.0	4D3b	Indirect N2O: Leaching and Run-Off-agriculture	3.6%	4D3a	tr 4D1(sum of 5)		12-14
771.9	4E	Savannah fires	7.8%		FAO	FAO	12-14

We note that the estimated uncertainty range in non-CO_2 emissions, both in the national CRF data and as calculated using EDGAR data, is much larger than that for CO_2 emission estimates for which uncertainties are generally between 2% to 5%, with exceptions up to 10%.

The emissions calculated per country by EDGAR (mostly using international statistics and IPCC default emission factors) and in national inventories (often using more detailed methods and country-specific emission factors) can differ substantially. However, in general total emissions per gas of a country are still within the uncertainty range of total emissions (e.g. 30% to 50% for CH_4 and about 50% for N_2O or 100% including indirect emissions), however uncertainties for F-gas emissions from the *use* of these gases are in the range of 100% or more.

For a comparison of the EDGAR v4.3.2 emissions of CO_2, CH_4 and N_2O with other estimates we refer to Maenhout et al. (2017a), who conclude that the CO_2 and CH_4 emissions correspond well with those in other studies, taking into account their differences such as sources and years covered, number of fuel types and methodologies used. For all non-CO_2 gases, we refer to UNEP (2012), where in Appendix 1 a comparison was made between global total emissions per gas in EDGAR 4.2 FT2010 and estimates for global emissions and their trend based on inverse modelling of the trend in global concentrations and excluding an amount allocated to natural sources, which corresponded well[7].

When aggregating total emissions from industrialised countries (i.e. Annex I countries excluding Turkey), total EDGAR v4.3.2 emissions of CH_4 and N_2O are in 2012 only 8% and 3% lower than the countries reported to the UN Climate Convention. In comparison total CO_2 emissions differ by only a percent whereas for the total F-gases the EDGAR estimates for total Annex I countries are about twice the amount reported by countries, which is primarily caused by differences in HFC emissions.

For the top 5 countries and the European Union the trends that are deduced from total emissions for both CH_4 and for N_2O are summarised in Table D.3 and compared to trends reported in national estimates. Especially in the methane emissions, differences are large, especially in the case of the Russian Federation and Japan, and also the trend in the data can be quite different, as is the case for the United States and Japan. For Japan, the 1990 methane estimate from EDGAR is almost double that from CRF, mostly as a result of fugitive emissions from oil and natural gas (1B2), rice cultivation (3C), wastewater treatment (6C), and waste incineration (6B). For Japan’s 2012 emissions the difference is smaller, albeit still large. For China and India no comparison can be made because of missing data for the these years.

For the same countries and for the total Annex I group of countries we also compared CO_2 emissions and total greenhouse gas emissions for their value and trend in EDGAR v4.3.2 and as reported in national estimates (Tables D4.a and D4.b). For CO_2 emissions the differences in values and trends as presented in Table D.4.a are smaller than for the non-CO_2 GHG emissions in Table D.3, with the exception of the Russian Federation, where differences are much larger, in particular for 1990, which is an inherently uncertain year due to the turbulent changes in the economy and society at large. Note that the EDGAR group uses the fuel statistics as compiled by the IEA for calculation of fossil-fuel related combustion emissions for all substances, including CO_2. Differences in fuel statistics of IEA and those used by the countries themselves will also show in differences of the CO_2 emission trends. As expected, for total Annex I countries the differences in CO_2 emissions are smaller, as differences of countries tend to average out.

[7] The downward revisions in global CO_2 emissions in EDGAR 4.3.2 for recent years compared to last year’s report (Olivier et al., 2016) are due to regular annual statistical revisions of fuel consumption in IEA and BP statistics as well as revisions, corrections and some full updates, including emission factors, for several other sources (gas flaring, cement production, solvent use, ammonia production, urea and lime application). Apart from these revisions in CO_2 emissions, global methane emissions were also revised downward in recent years by about 4%, mainly as a result of major revisions in emissions from coal, oil and gas production and transmission in EDGAR 4.3.2 (Janssens-Maenhout et al., 2017a).

For total greenhouse gas emissions the differences are presented in Table D.4.b. This table shows the combined effect of differences in emissions of CO_2 (Table D.4.a) and non-CO_2 greenhouse gases (Table D.3), with a large weight for the CO_2 emissions which are by far the largest fraction. For the total for Annex I countries, the largest difference in total greenhouse gas emissions is in the estimate of 1990 emissions, which is also a mark of the large difference in the Russian CO_2 emissions.

Table D.3 Trend in EDGAR CH_4 and N_2O emissions and comparison with CRF data

Trend in EDGAR v4.3.2 CH_4 and N_2O emissions in 1990–2012 for top-6 countries and EU28 and comparison with national inventories (CRF data)

	CH_4			N_2O		
Country	**trend EDGAR**	**trend CRF**	**EDGAR-CRF (percentage points)**	**trend EDGAR**	**trend CRF**	**EDGAR-CRF (percentage points)**
United States	-3%	-14%	11%	3%	-3%	6%
European Union	-30%	-34%	4%	-3%	-38%	35%
Russian Federation	-13%	-9%	-4%	-45%	-45%	0%
Japan	-41%	-25%	-16%	-28%	-32%	4%
China	40%	-	-	65%	-	-
India	32%	-	-	-71%	-	-

Table D.4.a Trend in EDGAR CO_2 emissions and comparison with CRF data

Trend in EDGAR v4.3.2 CO2 emissions in 1990-2012 for top-5 countries, EU28 and total Annex I and comparison with national inventories (CRF data)

	EDGAR 1990 (Gt)	EDGAR 2012 (Gt)	EDGAR trend (%)	EDGAR/CRF 1990 (%)	EDGAR/CRF 2012 (%)	CRF trend (%)	EDGAR-CRF trend (% points)
United States	4.96	5.11	3.1%	**-3.3%**	**-4.8%**	4.7%	**-1.6%**
European Union	4.33	3.65	-15.7%	**-2.8%**	**-2.2%**	-16.3%	**0.6%**
Russian Federation	2.38	1.81	-24.1%	**-8.1%**	**4.5%**	-33.3%	**9.1%**
Japan	1.16	1.30	12.3%	**0.1%**	**0.2%**	12.2%	**0.1%**
Annex I *	14.70	13.75	-6.5%	**-2.8%**	**-1.4%**	-7.9%	**1.4%**
China	2.34	10.02	328.0%	-	-	-	-
India	0.66	2.09	218.4%	-	-	-	-

* Including Turkey, excluding Kazakhstan

Table D.4.b Trend in EDGAR greenhouse gas emissions and comparison with CRF data

Trend in EDGAR v4.3.2 total greenhouse gas emissions in 1990-2012 for top-5 countries, EU28 and total Annex I and comparison with national inventories (CRF data)

	EDGAR 1990 (Gt)	EDGAR 2012 (Gt)	EDGAR trend (%)	EDGAR/CRF 1990 (%)	EDGAR/CRF 2012 (%)	CRF trend (%)	EDGAR-CRF trend (% points)
United States	6.00	6.49	8.1%	**-5.7%**	**-0.7%**	2.6%	**5.5%**
European Union	5.59	4.63	-17.2%	**-1.0%**	**1.4%**	-19.1%	**1.9%**
Russian Federation	3.03	2.37	-21.9%	**-19.6%**	**-12.3%**	-28.3%	**6.5%**
Japan	1.30	1.46	12.3%	**2.5%**	**5.2%**	9.4%	**2.9%**
Annex I *	18.51	17.61	-4.9%	**-5.3%**	**0.1%**	-10.1%	**5.2%**
China	3.86	12.48	223.5%	-	-	-	-
India	1.43	3.18	122.7%	-	-	-	-

* Including Turkey, excluding Kazakhstan

We note that due to the large uncertainties in estimating emissions from fugitive sources (1B) and from waste and wastewater (5A and 5C), recalculations may be made by countries of these sources as part of their emission inventory improvement programme. These revisions may result in large changes in both values and trends of officially reported emissions data. As an example, Table D.4 shows for the United States, Russian Federation and the European Union the differences in the last four subsequent submissions of their officially reported greenhouse gas emissions for CH_4 fugitive emissions from oil and natural gas operations (CRF/IPCC categories 1B2a and 1B2b).

For the United States in particular, annual CH_4 emission estimates from oil operations (1B2a) changed substantially (Table D.5). This was caused almost exclusively by similarly large changes in the CH_4 emissions from oil production (1B2a2) in 2016 . For natural gas operations, the changes in percentage are smaller, although absolute changes can also be large (such as in 2016). Here, the changes were caused mainly by a very large upward revision of CH_4 emissions of natural gas production (2B2a2) in 2016 and by a very large downward revision of gas transmission (1B2b4) and gas distribution (1B2b5) in 2016. In the case of the Russian Federation, also in particular annual CH_4 emissions from oil operations (1B2a) changed substantially: a decrease of 54% in the whole time series (Table D.4). In this case the main cause was a 89% downward revision of the CH4 emissions from natural gas production (2B2a2) for the whole time series. For the European Union the largest changes were found in CH_4 emissions from natural gas operations. Here the changes were mainly caused by revisions of the underlying emissions of gas transmission (1B2b4) and gas distribution (1B2b5) (Table D.5).

These data show that officially reported national emissions for non-CO_2 gases can be subject to large revisions, thereby changing emission levels and emission trends in the national greenhouse gas inventory. For this reason it can be expected that the independently developed EDGAR v4.3.2 will also show similar differences when compared to officially reported data for totals of CH_4 and N_2O such as presented in Table D.3.

Apart from substantial differences found in fugitive CH_4 emissions from oil and natural gas production (1B2a,b) also significant changes may be found in CH_4 emissions from coal production (1B1), from manure management (3B) and from waste (6A) and wastewater (6C). However, in most cases these differences will be within the uncertainty in non-CO_2 emissions estimated for these datasets.

In Table D.6 we show for the five of the largest emitting countries and the European Union how total national methane emissions have changed in 1990, 2012 and the trend in the last four years. For a single submission, national totals in 2012 can change up to 19% for Australia, 53% for Japan, 64% for the Russian Federation, and 13% for the United States. In some cases the recalculation, for maintaining consistency over time, also resulted in rather large changes in 1990 emissions (Australia up to 11%, Japan up to 26%, Russian Federation up to 54%).

Because of these changes in 1990 and 2012 the resulting trend may also substantially change in a subsequent submission (for these five cases from 2 percentage points via 5-, 7- and 9- to 13 percentage points).

Table D.5 Revisions in last four submissions from oil and gas operations (unit: Gg CH_4)

Revisions in the last four submissions of the methane emissions from oil and gas operations CRF data for IPCC sector 1B2 [kt CH_4]						
Country	**Submission**	**1990 data point**	**Revision**	**2012 data point**	**Revision**	**Trend 90-12**
United States	1B2a: Oil operation emissions					
	2014	1,704		1,511		-11%
	2015	1,261	-26%	931	-38%	-26%
	2016	1,550	23%	2,335	151%	51%
	2017	2,218	43%	1,858	-20%	-16%
United States	1B2b: Natural gas operation emissions					
	2014	7,450		6,186		-17%
	2015	7,165	-4%	6,176	0%	-14%
	2016	8,270	15%	6,906	12%	-16%
	2017	7,762	-6%	6,247	-10%	-20%
United States	1B2b2: Natural gas production emissions					
	2014	2,664		1,992		-25%
	2015	2,380	-11%	1,989	0%	-16%
	2016	3,335	40%	4,442	123%	33%
	2017	2,826	-15%	4,274	-4%	51%
United States	1B2b4: Natural gas transmission and storage emissions					
	2014	2,343		2,071		-12%
	2015	2,343	0%	2,070	0%	-12%
	2016	2,343	0%	1,116	-46%	-52%
	2017	2,343	0%	1,116	0%	-52%
United States	1B2b5: Natural gas distribution emissions					
	2014	1,591		1,231		-23%
	2015	1,591	0%	1,226	0%	-23%
	2016	1,741	9%	457	-63%	-74%
	2017	1,741	0%	451	-1%	-74%
Russian Federation	1B2a: Oil operation emissions					
	2015	12,859		12,930		1%
	2016	12,859	0%	12,930	0%	1%
	2017	12,859	0%	12,930	0%	1%
Russian Federation	1B2b: Natural gas operation emissions					
	2015	12,814		12,637		-1%
	2016	5,912	-54%	5,846	-54%	-1%
	2017	5,912	0%	5,846	0%	-1%
Russian Federation	1B2b2: Natural gas production emissions					
	2015	7,319		7,216		-1%
	2016	805	-89%	793	-89%	-1%
	2017	805	0%	793	0%	-1%
European Union	1B2a: Oil operation emissions					
	2015	552		177		-68%
	2016	459	-17%	157	-11%	-66%
	2017	273	-40%	146	-7%	-46%
European Union	1B2b: Natural gas operation emissions					
	2015	1,890		1,186		-37%
	2016	1,818	-4%	1,059	-11%	-42%
	2017	1,838	1%	1,073	1%	-42%

Table D.6 Revisions in level and trend of total national CH_4 emissions in the last four submissions of countries to the UNFCCC (unit: Gg CH_4)

Changes in level and trend in total national CH_4 emissions in last four submissions to the UNFCCC [kt CH_4]						
Country	**Submission**	**1990 data point**	**Revision**	**2012 data point**	**Revision**	**Trend 90-12**
Australia	2014	5,713		5,517		-3%
	2015	5,077	-11%	4,450	-19%	-12%
	2016	4,751	-6%	4,032	-9%	-15%
	2017	4,797	1%	4,158	3%	-13%
European Union	2014	28,890		19,209		-34%
	2015	29,742	3%	18,966	-1%	-36%
	2016	29,380	-1%	18,792	-1%	-36%
	2017	29,136	-1%	19,079	2%	-35%
Japan	2014	1,546		954		-38%
	2015	1,943	26%	1,457	53%	-25%
	2016	1,943	0%	1,458	0%	-25%
	2017	1,769	-9%	1,319	-10%	-25%
Russia	2014	28,997		24,798		-14%
	2015	44,622	54%	40,737	64%	-9%
	2016	37,695	-16%	34,102	-16%	-10%
	2017	37,683	0%	34,012	0%	-10%
United States	2014	30,272		27,013		-11%
	2015	29,633	-2%	25,269	-6%	-15%
	2016	30,954	4%	28,576	13%	-8%
	2017	31,232	1%	26,643	-7%	-15%

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