TRENDS IN GLOBAL CO_2 EMISSIONS

2016 Report

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Trends in Global CO_2 emissions: 2016 report

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This CO_2 report 2016 is one in a series of annual publications by PBL Netherlands Environmental Assessment Agency and the European Commission's Joint Research Centre (JRC). After publishing web reviews in 2007 and 2008, the CO_2 report series started in 2009, providing up-to-date knowledge on the trend in global CO_2 emissions from fossil fuels and cement. CO_2 emission estimates were made by PBL and the JRC on the basis of energy consumption data for the 1970–2013 period, published by the International Energy Agency (IEA), and on 2014–2015 trends, published by BP. The estimations are also based on production data on cement, lime, ammonia and steel, as well as on emissions per country, from 1970 to 2012, from the Emissions Database for Global Atmospheric Research (EDGAR) version 4.3.2, which was developed jointly by the JRC and PBL. The greenhouse gas emissions of the EDGAR 4.2 FT2012 dataset have also been used for the global emissions overviews in the Emissions Gap Reports of the United Nations Environment Programme (UNEP) (2012–2016). All reports are available from http://edgar.jrc.ec.europa.eu/whats_new.php and http://www.pbl.nl/en/trends-in-global-co2-emissions.

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Contents

Summary and main findings

The year 2015 was a historic year. First, 2015 was the hottest year since records began in 1880. Moreover, the 16 warmest years recorded are in the 1998-2015 period. Second, top emitter China started to curb its carbon dioxide (CO_2) emissions in 2015. China and the United States reduced their emissions by 0.7% and 2.6%, respectively, compared to 2014. Emissions in the Russian Federation and Japan also decreased, by 3.4% and 2.2%, respectively. However, these decreases were counterbalanced by increases in India of 5.1%, in the European Union, where emissions increased by 1.3%, and by increased emissions in a large group of the smallest countries. Third, 2015 closed with the adoption of the landmark Paris Agreement on Climate Change by 194 countries and the European Union.

As a result of these changes in national emission totals, global CO_2 emissions from fossil fuel combustion, cement production and other processes decreased in 2015 by 0.1%. Taking into account the uncertainty in the trend we conclude that, in 2015, global CO_2 emissions for these sources stalled. This conclusion confirms that the slowdown in the growth in global CO_2 emissions from fossil fuel combustion in the last years was not random, but due to structural changes in the economy, global energy efficiency improvements and in the energy mix of key world players, as anticipated in previous CO_2 reports by Olivier et al. (2015, 2014). It also is in line with the assessments of the Global Carbon Project (GCP, 2016) and IEA announcement (2016a).

Stalling of global emissions in 2015

The stalling of global emissions is no surprise as the declining growth in annual emissions continued over the past three years: 2.0% in 2013; then 1.1% in 2014, and further down to -0.1% (±0.5%) in 2015. In 2013 and 2014, the slower emission growth was not so much a reflection of slower *global* GDP growth, which continued to increase by about 3%, but rather was associated with lower annual GDP growth in China of about 7%, down from a decade of official annual GDP growth figures of about 10%, on average, until 2013. However, in 2015 global CO_2 emissions became decoupled from GDP, as global GDP continued to grow by 3.0%. A more structural shift away from carbon-intensive activities, particularly in China but also in the United States and other countries, contributed considerably to this trend.

Changes in fossil fuel mix and renewable energy

Global primary energy consumption increased in 2015 by 1.0%, which was similar to 2014 but well below the 10-year average of 1.9%, even though fossil fuel prices fell in 2015 in all regions. In 2015, coal consumption *decreased*, globally, by 1.8%, while global oil and natural gas consumption increased by 1.9% and 1.7%, respectively. These shifts in fossil fuel consumption also affected the fuel mix. The largest decreases in coal consumption were seen in the United States and China, partly counterbalanced by increases in India and Indonesia. For oil consumption, the largest increases were in China, India and United States. The global increase in the use of natural gas was mainly due to increased consumption in the United States and the European Union, with smaller increases seen in Iran and China.
The production of nuclear energy increased by 1.3% and hydroelectricity by 1.0%; resulting in respective shares of 10.7% and 16.4% in total global power generation, and 4.4% and 6.8% in global primary energy consumption. In 2015, significant increases of 15.2% were observed in other renewable electricity sources, notably wind and solar energy. With double-digit growth for the 12th year in a row, these now provide almost 6.7% of global power generation, close to a doubling over the past five years (3.5% in 2010). Their share in 2015 increased to 2.8% of total global primary energy consumption, also doubling their share since 2010.

The remaining two thirds of global power generation was generated by fossil-fuel-fired power stations, which is 1 percentage point down from 2014 and the lowest share since 2002. The share of fossil fuel in global energy consumption was 86% in 2015.

The G20 and the six largest emitting countries (including the European Union)

In 2015, the five largest emitting countries and the European Union, which together account for two thirds of total global emissions, were: China (with a 29% share in the global total), the United States (14%), the European Union (EU-28) (10%), India (7%), the Russian Federation (5%) and Japan (3.5%). The 2015 changes within the group of 20 largest economies (G20), together accounting for 82% of total global emissions, varied widely, but, overall, the G20 saw a decrease of 0.5% in CO_2 emissions in 2015.

Coal-fired power plants caused one third of global emissions

Recent trends in the fossil-fuel mix, with shifts from coal to natural gas or vice versa, in the United States, China and European Union, are very relevant for the overall trend in CO_2 emissions. Globally, coal combustion was responsible for about 46% of CO_2 emissions from fossil-fuel combustion, with 31 percentage points emitted from coal-fired power plants. Among the top 4 emitting countries (including the European Union), coal-fired power plants also had large but variable shares in national CO_2 emissions: 48% for China, 31% for the United States, 28% for the European Union and 47% for India.
The energy industry continues to build new coal-fired power plants, at a relatively fast pace, even in countries that already have an overcapacity of electricity production. Utilisation rates decreased since 2005 in the top 4 countries (including the European Union) to around 50% to 55% and in India around 65%. In China, the average coal plant ran at about 49% of its capacity in 2015. Over the course of 2015, coal power plant construction activities in China increased by 21.7 GW, while this decreased overall in the rest of the world by 13.7 GW.

Structural changes towards less carbon-intensive activities in China

An important reason for the stalling of global CO_2 emissions is the change in the world's fossil-fuel use due to the structural change in the economy and in the energy mix of China. For the first time since 2000, China's CO_2 emissions decreased, by 0.7%, and its per capita CO_2 emissions went down by 1.2%. Although China, generally, in total, emits twice as many CO_2 emissions as the United States, its per capita CO_2 emissions (7.7 tonnes CO_2/cap) remain below half of those in the United States (16.1 tonnes CO_2/cap). While China's emissions over the 2002–2011 period, on average, increased by 10% per year, the recent average annual growth (between 2011 and 2015) was 3% per year. This reduced growth rate and even decline in emissions in 2015, was mainly due to a 1.5% decrease in coal consumption and a 1 percentage point increase in the share of non-fossil fuel in primary energy consumption. The latter was achieved by substantial increases, in 2015, in nuclear energy (29%), hydropower (5%) and other renewables, such as wind and solar energy (21%).

Decreasing CO_2 emissions in the United States

CO_2 emissions in the United States decreased considerably, in 2015, with 2.6%, which was mainly caused by a drop of 13% in coal consumption, representing the largest relative decrease in any fossil fuel in the United States over the past five decades. For the first time ever, the total kWhs produced by gas-fired plants in 2015 was almost equal to those produced by coal power in the United States.
The 12% decrease in energy-related CO_2 emissions over the last 10 years was mostly in the power sector, due to a shift from coal to natural gas used for electricity generation, whereas the demand for electricity has remained rather constant, since 2005. In addition, over the last decade, fuel consumption decreased also in other sectors, albeit to a lesser extent, contributing to the decline in CO_2 emissions since 2005.

Stagnating emission reduction in the European Union

After four years of decreasing annual emissions (on average by 3.1%), the European Union´s CO_2 emissions increased again, by 1.3%, in 2015. This was mainly due to an increase of 4.6% in natural gas consumption, mainly used in power generation and space heating, and an increase of 4% in diesel consumption in transport. Although power generation increased by 1.3% in 2015, the related CO_2 emissions decreased by 0.6%. This was due to a much larger share of 29% renewable electricity in total power generation in 2015 (mainly hydropower, wind and solar energy) and a decline of 1.8% in coal consumption in the European Union, where it was mainly used in the power sector. Coal consumption decreased in 2015 for the third consecutive year, renewable energy in the European Union increased by 15% (excluding hydropower). Although, in 2015, the amount of hydropower in the European Union declined by 10% due to less favourable weather conditions, the share of total renewable electricity increased by 7 percentage points to 29% of total electricity production.

Trends over the past decades

The annual growth rates of global CO_2 emissions continued to decrease between 2012 and 2015, after which they have levelled out. On a global level, there are also signs of an increased decoupling of CO_2 emissions and GDP growth. In 2015, global CO_2 emissions no longer increased without being coupled to a global economic recession, reflecting the emission reduction efforts of the major emitting countries, in particular China. After four years of relatively low growth rates, China's growth in energy consumption and physical industrial production has stalled over the first three quarters of 2016, while the share of renewable energy continued to increase. Thus, the slowdown of China's CO_2 emissions since 2012 reflects structural changes in the Chinese economy towards a less energy-intensive service and high value-added manufacturing industry, as well as towards a more low-carbon energy mix.

On a global scale, there has been a slowdown since 2012, which also reflects structural changes in the global economy, such as improvements in energy efficiency and the energy mix of the key global players. However, further mitigation of fossil-fuel use, and in particular of coal use, will be needed for large absolute decreases in global greenhouse gas emissions, which are necessary to substantially mitigate anthropogenic climate change, as was concluded in the Paris Agreement. Technically, these reductions are still feasible, but would need to be widely implemented very soon to be on a pathway under which global warming by the end of this century would remain limited to 2 °C above preindustrial global mean temperature.

How do these CO_2 trends relate to the Paris Agreement on climate change mitigation?

Further analysis may show the extent to which the recent national CO_2 trends estimated in this report are in keeping with the total national greenhouse gas emission trends as expected from analyses of the Cancun pledges for 2020, *Intended Nationally Determined Contributions* (INDCs) and *Nationally Determined Contributions* (NDCs) under the Paris Agreement and other country pledges for 2025 or 2030. By 15 December 2015, 187 countries and the European Union had submitted their INDCs, summarising their climate-related efforts after 2020 within the context of the Paris Agreement.

Introduction

This report presents the results of a trend assessment of global carbon dioxide (CO_2) emissions from fossil fuel and cement up to 2015, and updates last year's assessment (Olivier et al., 2015). This assessment focuses on the changes in annual CO_2 emissions from 2014 to 2015, and includes not only fossil-fuel combustion on which the BP (2016) reports are based, but also incorporates other relevant CO_2 emissions sources, including flaring of waste gas during gas and oil production, cement clinker production and other limestone uses, feedstock and other non-energy uses of fuels, and several other small sources. The report clarifies the CO_2 emission sources covered, and describes the methodology and data sources. For the years 2013 to 2015, more details are provided in Annex 1.

This assessment excludes CO_2 emissions from deforestation and logging, forest and peat fires, from the post-burn decay of remaining above-ground biomass, and from decomposition of organic carbon in drained peat soils. The latter mostly affects tropical non-OECD countries. These sources could add from 10% to 20% of CO_2 to global emissions, according to different authors (Van der Werf et al., 2009; Harris et al., 2012). However, these percentages are highly uncertain and show a large annual variability. Such variability is also one of the reasons why emissions and sinks from land use, land-use change and the forestry (LULUCF) sector are kept separate when reporting under the UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. This explains also that the emissions from the LULUCF sector are not included in this assessment. Information on recent emissions from forest and peat fires and post-burn emissions is being assessed by the Global Carbon Project (GCP), which has published comprehensive assessments of the global carbon budget, including all CO_2 sources and sinks (GCP, 2016; Le Quéré et al., 2015).

Chapter 2 presents a summary of recent CO_2 emission trends, per main country or region, including a comparison between emissions per capita and per unit of Gross Domestic Product (GDP), and of the underlying trend in fossil-fuel use and the use of non-fossil energy such as renewable energy. For a summary of recent trends in CO_2 emissions from fossil fuel production and other non-combustion sources of CO_2 we refer to Annex 2.
Chapter 3 focuses on the energy trends and shifts in the energy mix, with a special focus on fossil fuels, renewable energy and nuclear energy.

1.1 Methodology and data sources used

This report assesses the trend in global CO_2 emissions of fossil fuel use and industry processes but not from land-use change and forestry.
For global CO_2 emissions from 1970 to 2012, we use the EDGAR 4.3.2 dataset (EC-JRC/PBL, 2016) for greenhouse gases, because it covers all countries with a detailed sectorial breakdown and consistent time series.
This dataset provides greenhouse gas emissions per country for all anthropogenic sources identified by the IPCC (2006) (EC-JRC/PBL, 2016). The CO_2 emissions from fuel combustion in EDGAR are based on the International Energy Agency (IEA) energy statistics for fossil fuel consumption released in 2014 (IEA, 2014). However, for China we updated the energy statistics of China with IEA (2016) data because of the recently completed important revision, in particular of coal statistics (NBS, 2015c).
The core EDGAR 4.3.2 dataset on CO_2 emissions was extended to 2015 using a fast-track approach. For each country, the trend from 2012 onwards has been estimated with the trend in the appropriate activity data or with the approximating trend using related statistics as the estimator.
For the fuel combustion emissions that account for about 90% of total global CO_2 emissions, excluding those from forest and peat fires and related emissions, emissions per country for 2012 were divided into four main fuel types for

Box 1.1 Major changes compared to the trend report last year

This 2015 report largely follows the structure of last year's 2014 report. The main methodological changes are:

- This year, specifically *for China*, we used *the latest detailed energy balances for the 2000–2014* period, because these include the detailed NBS revisions for fossil fuels as implemented by the International Energy Agency (IEA, 2016c). Last year, we estimated the changes due to the major revision by China's National Bureau of Statistics (NBS, 2015c), notably in coal data for China, for the years 2000 to 2013. Moreover, we updated the statistics for *cement clinker production in China, through 2014*, affecting the emission factor for cement production.
- For *gas flaring*, we updated the amounts flared from 2012 to 2014, with new satellite data from NOAA (2016b), which includes more countries than NOAA's previous satellite data set, which covered 1994 to 2012 (NOAA, 2012b).
- The main textual changes can be found in the following sections:
- *We updated the group of top*-25 CO_2 emitting countries with a more recent ranking of both CO_2 emissions and GDP (on a Purchasing Power Parity (PPP) basis). We now use the G20 (group of twenty countries including the European Union), and the group of currently 35 member countries of the Organisation for Economic Co-operation and Development (OECD), thus including newer members such as Mexico, Hungary, Czech Republic, Poland, South Korea, Chili, Slovenia, Israel, Estonia, Latvia, and the Slovak Republic.
- Section 2.2, apart from the top-5 countries, now also discusses *more details on the top 6 to 10 countries*: South Korea, Canada, Brazil, Indonesia and Saudi Arabia.

This study provides CO_2 time series for the 1990–2015 period, per country, which are also available on http://edgar.jrc.ec.europa.eu/overview.php?v=CO2ts1990-2015

use as trend indicators. These fuel types are coal and coal products, oil products, natural gas, and other fuels (e.g. fossil-carbon containing waste oils). For each sector, the 2013–2015 trend was based on BP fossil fuel consumption data released in June 2016 (BP, 2016). In addition, these national oil consumption data were completed with biofuel and other fossil waste fuels, and with international shipping &aviation fuel from IEA bunker statistics with the BP (2016) oil consumption trend.
For the other emissions the CO_2 process emissions of each activity (production of steel and coke, of non-ferrous metals, of cement and lime) were estimated mainly with United States Geographical Survey (USGS, 2016), World Steel Association (WSA, 2016) trends. The USGS (2016) commodity statistics were also used for the trends in feedstock use and ammonia production. Only for the urea production data from IFA (2016) were used. For flaring we used the updated data of the US National Oceanic and Atmospheric Administration (NOAA, 2016b) for 2012-2014, whereas for 2015 we kept emissions equal to 2014.
EDGAR 4.3.2 includes CO_2 emission factors for cement production per tonne of cement produced, taking into account the decreasing share of clinker in cement.
These shares have been updated from 1990 onwards and extended from 2008 to 2012 with country-specific data for all countries annually reporting their emissions inventories to the United Nation Framework Convention on Climate Change (UNFCCC) (mostly OECD countries, Eastern European countries and Russia) and six other large countries, whereas regional estimates were used for the remaining countries. This is particularly significant for China where the clinker fraction continues to decline.
In addition to cement production, EDGAR 4.3.2 also includes other non-combustion industrial processes, such as the production of lime and soda ash and carbon used in metal production. All sources of CO_2 related to non-energy/feedstock uses of fossil fuels were estimated using the Tier 1 methods and data recommended by the 2006 IPCC guidelines for national greenhouse gas inventories (IPCC, 2006). Collectively, the other carbonate sources added about 30% to CO_2 emissions from global cement production in 2010. These process emissions are here addressed with more details than in the other global CO_2 data sets (CDIAC, GCP).

More details on the methodology and data sources are presented in Annex 1. Data quality and uncertainty in the data are discussed in Annex 3. The resulting CO_2 emissions for 2012 per country and for international transport have also been spatially distributed on a 0.1° x 0.1° grid using specific grid maps for various source types (e.g. locations of power plants, iron and steel plants, oil refineries, urban and rural population, oil and gas production, etc.) (see Figure 1.1). Gridded data can be used for verification, e.g. with inverse modelling.

For a comprehensiv assessment of the trends in all greenhouse gas emissions up to 2010, including CO_2 from forest fires and other land-use change and the non-CO_2 greenhouse gases such as methane and nitrous oxide, which contribute about one quarter to the global total CO_2 eq. greenhouse gas emissions, we refer to the

Box 1.2 Why do CO_2 emissions in this report differ from those in other data sets?

There are four main reasons why our CO_2 emissions from fossil fuel combustion and industrial processes differ from those reported by countries or from other international data sets:

- Different **activity data sources**, different **release dates** and different sources for the conversion factors used. Each of them may have different revisions included. For example, this year we incorporated the recent major revisions of China's fossil fuel statistics for 2000-2013, in particular coal, in our data set by using the latest IEA energy statistics (IEA, 2016c). Most of the current international datasets on energy use will not have included these revisions yet.
- Different conversion factors used (the **heat content** to convert e.g. from tonne to ktoe or to TJ). Sometimes, physical activities in statistics are converted to another unit for the application of preferred emission factors, for example from tonnes of coal to energy units (terajoules) for which conversion factors are established, such as TJ energy content per tonne of anthracite or per cubic metre of natural gas.
- **Country-specific emission factors** for key sources, versus international default factors, such as those recommended by the IPCC. Also, countries may use default values when representative country-specific data are missing or for small sources. The IPCC guidelines recommend for fuels to use emission factors expressed per unit of energy since these have less uncertainty than factors related to physical units (such as tonnes and m^3).
- In cases where the **fraction** of fuel carbon that is **not oxidised** during combustion is not very small, where representative country-specific values based on measurements are available, these fractions should be used, according to the IPCC guidelines (IPCC, 2006).
- **Different definitions** for specific emission sources. For fossil-fuel combustion, for example, CO_2 emissions related to coal and coke inputs in blast furnaces and coke ovens and carbon losses in these processes may be partly or fully reported under industrial processes or fugitive sources or under fuel combustion.

Also, the level of detail of the methodology used can be different: detailed fossil-fuel types or only aggregated ones (e.g. coal, oil products and natural gas), corrections made for non-energy uses of fuels (e.g. natural gas for ammonia production), and fuels used for international transport.

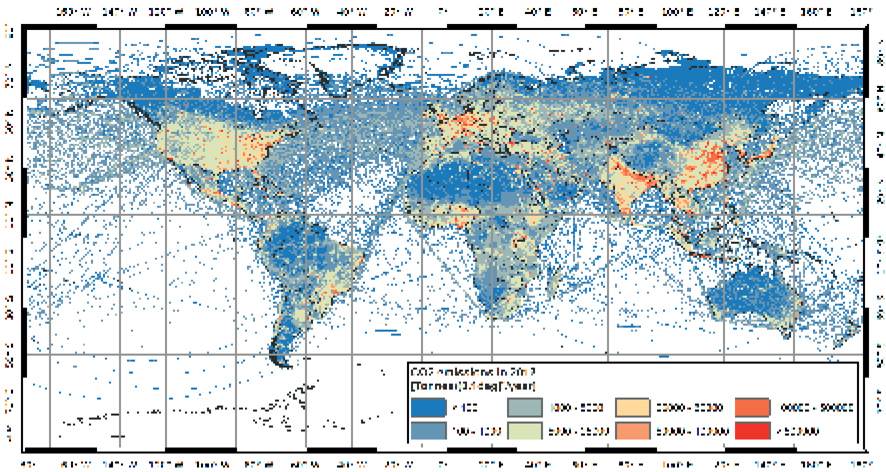
Another example is that of CO_2 emissions from the use of oil and gas for non-energy use, for example as chemical feedstock, which may be calculated with different methods and may be included under fossil-fuel combustion instead of under industrial processes. For example, BP does not make this distinction and includes these feedstock uses implicitly in their CO_2 emissions. Also the U.S. EIA (Energy Information Administration) includes these emissions in fossil-fuel CO_2 emissions.

Some international data sets, notably those of the EIA and BP, do not separate the use of so-called 'bunker' oil for international shipping and international aviation from a country's oil consumption and report those emissions as part of total national emissions.

Differences between official national CO_2 emissions are generally within 5% for OECD countries and around 10% for countries with less well-developed statistical systems (for details see Annex 3).

Figure 1.1

Global CO_2 emissions from fossil-fuel use and cement production, 2012



Source: EDGAR 4.3.2 (EC-JRC/PBL, 2016), notably for fossil-fuel combustion: IEA, 2014

Note: Lines across oceans and continents represent emissions from international shipping and aviation.

Fifth Assessment report of Working Group III 'Mitigating of Climate Change' of the IPCC (2014a) and the Emissions Gap Reports of UNEP (2014, 2015, 2016), for which data from EDGAR 4.2FT2010 and EDGAR 4.2FT2012, respectively, were provided. In addition, Part III of the IEA's energy statistics book on CO_2 emissions from fossil fuel combustion describes the greenhouse gas emissions data of EDGAR 4.2 FT2012, documented with references to data sources and methodologies (Olivier and Janssens-Maenhout, 2015).

TWO

Results

2.1 After a slowdown in growth, global CO_2 emissions stalled in 2015

The year 2015 was a historic year, which ended with the signing of the landmark Climate Change Agreement in Paris by 194 countries and the EU, at the COP21 (EC-CLIMA, 2016). In preparation of the Paris Agreement, countries submitted their Intended Nationally Determined Contributions ('INDCs'), outlining their post-2020 climate actions, and top emitters China and the United States set an example by effectively reducing their CO_2 emissions over 2015 by 0.7% and 2.6%, respectively, compared to 2014 levels. Also, emissions in the Russian Federation and Japan decreased by 3.4% and 2.2%, respectively. However, these decreases were compensated for by increases in India and the European Union of 5.1% and 1.3%, respectively, and in a large group of almost 200 smaller countries that, together, accounted for 9% of global CO_2 emissions. In 2015, this yielded a total amount in globally emitted CO_2 emitted of 36.2 billion tonnes – virtually the same level as in 2014 (Figure 2.1).
The calculated trend in the global total is -0.1%. Since global population growth is 1.2% per year, stalling of global emissions means per definition a 1.2% annual decrease in global per capita CO_2 emissions; 4.9 tonnes CO_2/cap in 2015 and 5.0 tonnes in 2014.

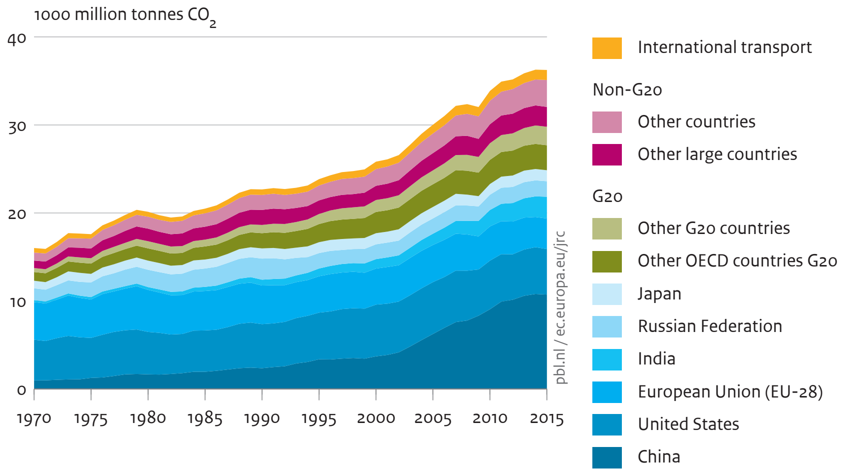
Stalling of global emissions

The stalling of global emissions is no surprise, as this is in line with the slowing trend in annual emission growth over the past three years, starting from 2.0% in 2013 to 1.1% in 2014 and further down to -0.1% in 2015. A similar trend of declining growth in global emissions could also be seen from 2010 to 2012, starting from 5.7% down to 0.7%. It is debatable whether the plateaued emission level will continue and results from structural changes (Jackson et al., 2016; Qi et al., 2016; Green and Stern, 2016). In 2009, a stronger global downward trend of -1.0% was recorded, compared to 2008 levels, but this was due to the global economic downturn. Now the stalling in emissions is not coupled with the GDP trend, as global GDP kept up with an annual growth of 3.0% in 2015 compared to 2014. A more structural change with a shift away from carbon-intensive activities, particularly in China but also in the United States, contributed considerably to this trend. The IEA estimates that in 2015 global investment in energy efficiency increased by 6% (IEA, 2016d). For more details see Section 3.1.

Changes in fossil fuel mix and renewably energy

Global primary energy consumption increased in 2015 by 1.0%, which was similar to 2014 but well below the 10-year annual average of 1.9%, even though fossil fuel prices fell in 2015 in all regions (BP, 2016). Coal consumption, globally, decreased in 2015 by 1.8%. Apart from the recession in 2009, these global annual changes represented the lowest growth levels since 1998. Global oil and natural gas consumption increased by 1.9% and 1.7%, respectively. These shifts in energy production and consumption had major effects on the fuel mix. The shift in the fossil fuel mix from coal to oil and natural gas, in part, resulted from lower regional fuel prices. The largest decreases in coal consumption were seen in the United States and China, partly counterbalanced by increases in India and Indonesia. For oil consumption, the largest increases were in China, India and United States.
The global increase in the use of natural gas was mainly due to increased consumption in the United States and the European Union, with smaller increases in Iran and China, partly compensated for by decreased natural gas use, in particular in the Russian Federation and the Ukraine, as well as in Japan and South Korea (BP, 2016).
Of the non-fossil fuel energy sources, nuclear energy increased by 1.3% and hydropower by 1.0%, resulting in respective shares of 4.4% and 6.8% in global primary energy consumption and 10.7% and 16.4% in total global power generation. Considerable efforts to increase other renewable power generation, notably wind and solar energy, resulted in a 15.2% increase in 2015, for the 12th consecutive year with double-digit growth, now providing almost 6.7% of global power generation,

Figure 2.1
Global CO_2 emissions per region from fossil-fuel use and cement production



Source: EDGAR v4.3.2 FT2015 (JRC/PBL 2016: IEA 2014 (suppl. with IEA 2016 for China, BP 2016, NBS 2016, USGS 2016, WSA 2016, NOAA 2016)

Note: Other OECD countries G20 include Australia, Canada, Mexico, South Korea and Turkey.
Other G20 countries include Argentina, Brazil, Indonesia, Saudi Arabia and South Africa, Turkey. Other large countries include Egypt, Iran, Kazakhstan, Malaysia, Nigeria, Taiwan, Thailand and the Ukraine.

up from 3.5% in 2010. In 2015 their share increased to 2.8% of the total primary energy consumption, a doubling since 2010 (BP, 2016).
Still, the remaining two thirds (66.2%) of global electricity are generated by fossil-fuel-fired power stations, which is a 0.9 percentage point down from 2014 and the lowest share since 2002. The share of fossil fuels in global primary energy consumption was 86% in 2015, calculated by using a substitution method for nuclear and renewable energy, assuming a 38% conversion efficiency (the average for OECD thermal power generation).

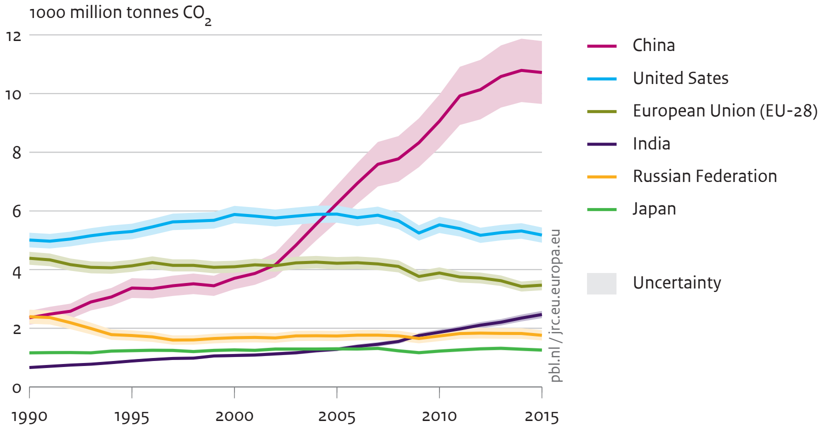
2015 by far the warmest year on record

As for the weather, the US National Oceanic and Atmospheric Administration (NOAA) recorded 2015 as the hottest year since records began in 1880. In addition, the 16 warmest years ever recorded are in the 1998–2015 period. The year 2015 was characterised by one of the strongest El Niños in history, and with record high ocean temperatures, globally (with annually averaged ocean surface temperature around the world of 0.74 °C higher than the average over the 20th century). The global land temperature for 2015 was 1.33 °C above the 20th century average, surpassing the previous records of 2007 and 2010 by 0.25%, the largest margin by which an annual global land surface temperature has been broken (NOAA, 2016a). Most regions experienced record high temperatures. Europe experienced relatively mild winter months in 2015, but saw 3% more so-called Heating Degree Days than the very mild winter in 2014. Heating Degree Days (HDDs) are an indicator of the demand for space heating (see Annex 4 for details) (EIA, 2016f). The United States and Russia benefited from a milder winter in 2015 than in 2014, and recorded 9% fewer HDDs that year (NOAA, 2016a). A drop in natural gas consumption can be associated with the 9% drop in demand for space heating in the United States and Russia, as well as in many other countries such as Canada, Japan and South Korea.

Changes in largest emitting countries

In summary, the six largest emitting countries/regions in 2015 were: China (with 29% share in the global total), the United States (14%), the European Union (EU-28) (10%), India (7%), the Russian Federation (5%) and Japan (3.5%) (Figure 2.2). Regional CO_2 emission trends differed strongly between countries, in particular, between the top six emitting countries and the European Union, which accounted for two thirds of total global emissions.
In China and the United States, emissions decreased (by 0.7% and 2.6%, respectively) after a slight increase (0.9%) in 2014, compared to 2013, whereas the European Union saw an increase (1.3%) in 2015, compared to 2014, after the large decrease in the previous year (5.4%). India's emission growth continued, with 5.1% in 2015, compared to 2014, while emissions continued to decrease in Russia and Japan (by 3.4% and 2.2%, respectively).
Of particular importance are large countries with emerging economies, such as India, which is still characterised by relatively low per capita CO_2 emissions of 1.9 tonnes CO_2/cap per year (17% higher than the

Figure 2.2
CO_2 emissions from fossil-fuel use and cement production in the top 5 emitting countries and European Union



Source: EDGAR v4.3.2 FT2015 (JRC/PBL 2016: IEA 2014 (suppl. with IEA 2016 for China, BP 2016, NBS 2016, USGS 2016, WSA 2016, NOAA 2016)

average per capita CO_2 emissions of the nearly 200 smallest and poorest countries, but still 60% below the global annual average of 4.9 tonnes CO_2/cap), in combination with a large population and relatively rapidly increasing human activities (also carbon-intensive ones). If India and the European Union were to continue their average annual change (6.8% increase per year for India and a decrease of1.9% per year for the European Union (averaged rates for 2006–2015)), then India would surpass the European Union by 2020. Indonesia (currently with a share of 1.4% of the global total) showed a 4.0% increase in emissions in 2015, compared to 2014.

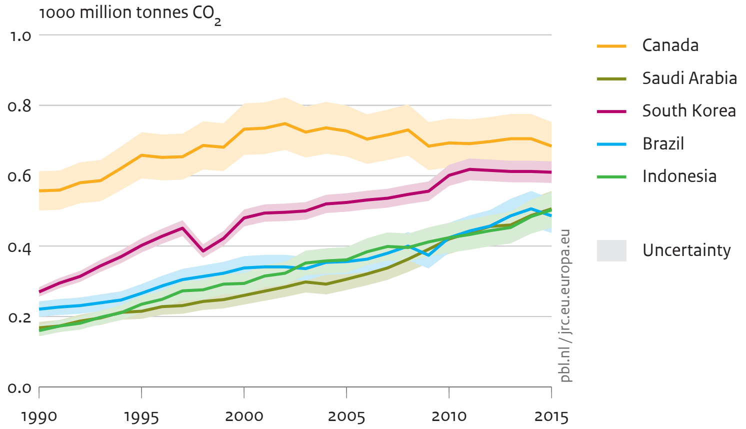
Coal-fired power plants cause one-third of global CO_2 emissions

Recent trends in the fossil fuel mix with shifts from coal to natural gas, and vice versa, in the United States, China and Europe, are very relevant for the overall trend in CO_2 emissions. IEA data for 2013 show that global coal combustion was responsible for 46% of CO_2 emissions from fossil fuel combustion, with 31 percentage points emitted from coal-fired power plants. Since coal emits more CO_2 per unit of energy than do oil and natural gas, many NGOs promote phasing out coal use in power generation, because of its large share in global CO_2 emissions and since coal-fired power plants have long technical lifetimes of several decades. Among the top 4 emitting countries and the European Union, coal-fired power plants also have high but variable shares in national CO_2 emissions: 48% for China, 31% for the United States, 28% for the European Union and 47% for India. However, the industry continues to build new coal-fired power plants, at a rapid pace, also in countries with an overcapacity. Utilisation rates decreased since 2005 in the top 4 emitting countries and the EU-28, to around 50% to 55%, and in India to around 65%. In China, the average coal-fired power plant ran at about 49% of its capacity in 2015. Over the course of 2015, coal-fired power plant construction activities were very different in China, compared to those in the rest of the world. In China there was an increase of 21.7 GW, whereas all other countries collectively decreased construction activities by 13.7 TW. A similar difference could be observed for the pre-construction coal plant pipeline. Since 2010, new coal-fired power plants have been built in 33 countries, totalling about 473.4 TW, of which in China and India 208 TW and 102 TW, respectively. These two countries now account for 85% of all new coal-fired power plants. Other countries, each with additions of more than 1 TW in 2015, were in decreasing order: Germany, Vietnam, Indonesia, the Netherlands, Turkey, Malaysia and the Russian Federation (Shearer et al., 2016).

Structural changes towards less carbon-intensive activities in China

The main reason for the curbing of global CO_2 emissions is the change in the world's fossil-fuel use due to the structural change in the economy and in the energy mix of China. For the first time since 2000, China's CO_2 emissions *decreased* by 0.7% in 2015 and its per capita CO_2 emissions by 1.2%, compared to 2014. Even though this relative change seems small, the difference corresponds to the total emissions in a country such as Greece.
Several recent papers suggest coal consumption and CO_2 emissions in China peaked in 2014 or 2015 (Qi et al., 2016; Korsbakken et al., 2016). The amount of Chinese CO_2 emissions in this report were calculated using the full revision of China's fuel statistics over the 2000–2014

Figure 2.3
CO_2 emissions from fossil-fuel use and cement production in the top 6 to 10 emitting countries



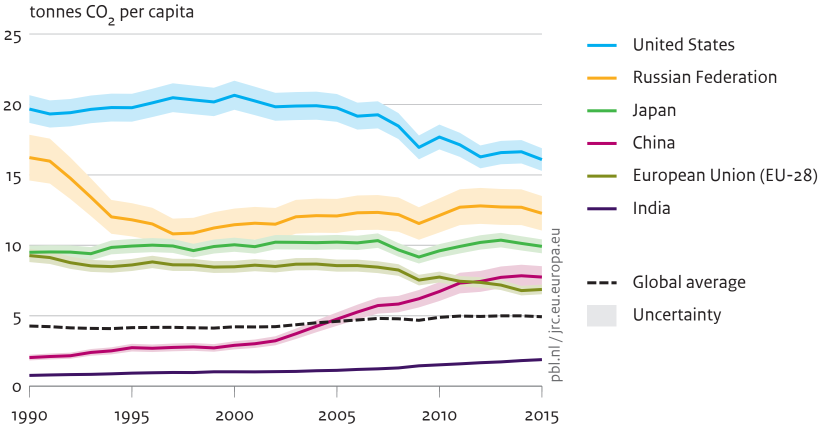
Source: EDGAR v4.3.2 FT2015 (JRC/PBL 2016: IEA 2014 (suppl. with IEA 2016 for China, BP 2016, NBS 2016, USGS 2016, WSA 2016, NOAA 2016)

period (amounts consumed and the energy content) announced last year and implemented in IEA (2016c). This data set shows small decreases in coal consumption of 0.8% in 2014 and 1.5% in 2015 (in energy units). China's CO_2 emissions still increased by 2.0% in 2014, in particular due to increasing consumption of oil products and natural gas, and then decreased again by 0.7% in 2015.
Although emissions in China, are double those of the United States, the Chinese per capita CO_2 emission level (7.7 tonnes CO_2/cap) remains below half that in the United States (16.1 tonnes CO_2/cap). Even though China's emissions increased extraordinarily rapidly, due to China's fast industrialisation path during the first decade of the 21st century (on average, 10% per year between 2002 and 2011), the average annual increase over the 2012–2015 period amounted to only 3%. This – and the even *decreasing* emissions in 2015 – was mainly due to a *decrease* in coal consumption of 1.5% (BP, 2016) and increase in the share of non-fossil fuel in primary energy consumption from 10.9% to 11.8%. The latter was achieved through substantial *increases* in nuclear energy (29%), hydropower (5%) and other renewable energy such as wind and solar energy (21%), in 2015, compared to 2014 levels.
Apart from the latter, China has an energy strategy aiming at reducing coal consumption and improving air quality. Among other things, it has put a cap on new coal mines and coal consumption, and has started country-wide carbon trading, initially with coal-fired power generation, encouraging hybrid and full electric cars as well as more energy-efficient cars and buildings (Adler, 2016). Moreover, China is also reducing excess capacity in industry (Xinhua, 2016).

Decreasing CO_2 emissions in the United States
CO_2 emissions in the United States decreased considerably with 2.6%, in 2015. This mainly resulted from a 13% drop in coal consumption (BP, 2016), which in percentage was the largest annual decrease in any fossil fuel in the United States, over the past five decades.
The 12% decrease in energy-related CO_2 emissions during the past decade mostly occurred in the *power sector*, due to a shift from coal to natural gas used for electricity generation, whereas the demand for electricity has remained rather constant since 2005 (EIA, 2016c).
The large number of recent closures of coal-fired power plants have mainly been due to the new air pollution standards, which came into effect in 2015. Some operators decided that retrofitting certain coal-fired plants would be too costly and, instead, opted to shut these plants down permanently. In addition, over the last decade, fuel consumption decreased in the transport sector and, to a lesser extent, also in the residential and industrial sectors, all contributing to the decrease in CO_2 emissions since 2005.
In addition, focusing on the last years, while electricity consumption increased in 2013 and 2014, the demand fell in 2012 and 2015 due to relatively warm winter temperatures. As the warmer winters also significantly decreased the consumption of natural gas for space heating, it also lowered natural gas prices. The drop in gas prices and very efficient gas-fired power plants increased the appeal of natural gas for base load power production. As a result, in 2015, for the first time ever, the total in kWhs produced by gas-fired power plants was almost equal to those produced using coal.

Figure 2.4

CO_2 emissions per capita from fossil-fuel use and cement production in the top 5 emitting countries and European Union



Source: EDGAR v4.3.2 FT2015 (JRC/PBL 2016: IEA 2014 (suppl. with IEA 2016 for China, BP 2016, NBS 2016); UNPD 2015 (WPP, Rev. 2015)

The European Union facing stagnation in emission reduction

After four years of *decreasing* emissions (by an average of 3.1% per year during 2011–2014), emissions in the European Union *increased* by 1.3% in 2015, compared to 2014 levels. Total EU emissions in 2015 reached 3.5 Gt CO_2, about 50 Mt CO_2 (the size of Sweden's inventory) more than in 2014. In particular, in the southern European countries, Spain and Italy, emissions increased considerably (by 7% and 5%, respectively), mainly because of a 24% increase in coal consumption in Spain and an 8% increase in oil and natural gas consumption in Italy. In other countries, such as United Kingdom, Finland and Denmark emissions decreased between 4% and 10% in 2015, compared to 2014 levels. Renewable energy resources in the European Union were further supported and increased by 15% (excluding hydropower), yielding a share of 8.3% in primary energy consumption in 2015. Although, in 2015, the amount of hydropower in the European Union declined by 10% - mainly in Italy, Spain, France, Portugal and Romania - due to less favourable weather, the share of total renewable electricity increased by 7 percentage points to 29% of total electricity production.

Trends over the last decades

Annual growth rates of global CO_2 emissions continued to decrease from 2012 until they plateaued in 2015. Globally, there are also signs of a partial decoupling between CO_2 emissions and GDP, which continued to increase in 2015 at 3%. Reports of previous years in this series on trends in Global CO_2 emissions (Olivier et al., 2013, 2014, 2015) suggest that the small increases in annual CO_2 emissions registered in 2012, 2013 and 2014, and currently estimated at 0.7%, 2.0% and 1.1%, could be signs of a permanent slowdown in the increase in global CO_2 emissions.
The 2015 stalling of global CO_2 emissions confirms this and is evidence of emission levels being no longer coupled to a global economic recession. Moreover, after four years of relatively low growth rates, China's growth in energy consumption and industrial production in the first three quarters of 2015 has been stalling under a continued increase in the share of renewable energy. Thus, it can be concluded that the slowdown of China's CO_2 emissions since 2012 has not been a temporary effect, but a more permanent trend, reflecting structural changes in the Chinese economy towards a less energy-intensive service and high value-added manufacturing industry, as well as a more low-carbon energy mix.
On a global scale, the slowdown since 2012 is also not a temporary, short-term effect, but has so far already lasted for four years. It may also reflect structural changes in the global economy, such as improvements in energy efficiency and the energy mix of the key global players. However, further mitigation of fossil-fuel use, and in particular of coal use, will be needed for large absolute decreases in global greenhouse gas emissions, which will be necessary to substantially mitigate anthropogenic climate change, as was concluded by both the IPCC (2014a,b) and the Paris Agreement (UNFCCC, 2015) (see Boxes 2.1 and 2.2). Technically, these reductions are still feasible (IPCC, 2014b; UNEP, 2014), but would need to be widely implemented very soon, if future global greenhouse gas emission levels need to remain compatible with pathways that could limit global warming to 2 °C, or even 1.5 °C, by the end of the 21st century,

Box 2.1 Linking economic trends with CO_2 emissions, GHG trends, atmospheric CO_2 concentrations and global warming

Gross Domestic product (GDP) can be considered the total value added achieved by all economic sectors, which greatly differ in terms of energy intensity, such as the power sector, energy-intensive basic materials industry, other industries, service sectors and agriculture. Moreover, household energy consumption for heating, electrical appliances and private transport is not directly coupled to GDP. Annual growth rates often greatly vary between sectors. Therefore, annual trends in GDP and **total energy consumption** are generally only very weakly related. Since the energy mix generally varies per sector and country, the link between global GDP and **global CO_2 emissions** is even weaker.

The relationship between the increase in **annual global CO_2 emissions** and the *annual* increase in **atmospheric CO_2 concentrations** (not included in this study) is also rather weak. This is because the net annual increase in CO_2 concentrations is affected by the large inter-annual changes in CO_2 emissions from forest fires and deforestation and in the amount of CO_2 absorbed by vegetation, in particular by growing forests, which vary substantially depending on temperature and the amount of sunshine and precipitation. Moreover, the large absorption of atmospheric CO_2 by the oceans also varies over time. These changes are larger in 'El Nino years', such as 2015.

The IPCC's Fifth Assessment Report (IPCC, 2014a,b) concluded that the **effects of anthropogenic greenhouse gas emissions** have been detected throughout the climate system and **are extremely likely to have been the dominant cause of the observed warming** since the mid-20th century. *Cumulative* emissions of carbon dioxide will largely determine global mean surface warming by the late 21st century and beyond. It would be possible, using a wide array of technological measures and changes in behaviour, to limit the increase in global mean temperature to 2 °C above pre-industrial levels. There are multiple mitigation efforts that in addition to those in place today required to reduce CO_2 emissions to near zero and so limit the increase in global mean temperature to 2 °C above pre-industrial levels.

compared to the pre-industrial global mean temperature (Rogelj et al., 2016; Van Vuuren et al., 2016).

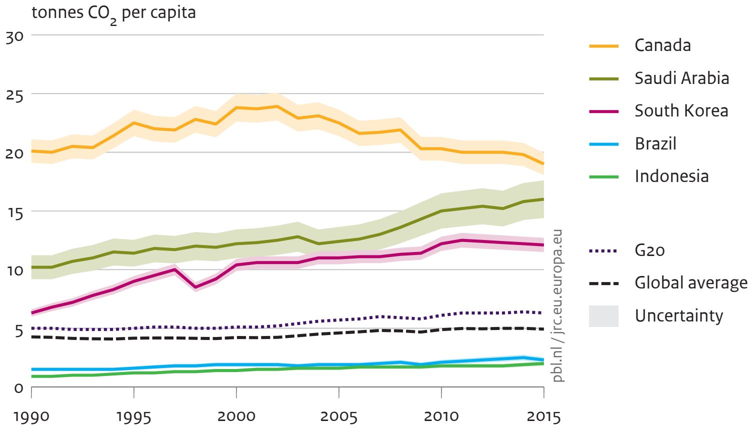
Uncertainties in emissions

It must be noted that all national emission inventories are subject to uncertainty. The level of uncertainty in national CO_2 emissions varies between countries. In this report, they range from 5% to 10% (95% confidence interval), with the largest uncertainties concerning the data on countries with rapidly changing or emerging economies, such as Russian Federation data on the early 1990s and data on China since the late 1990s, based on Marland et al. (1999), Tu (2011), Andres et al. (2012), Guan et al. (2012), Liu et al. (2015) and Korsbakken et al. (2016). Moreover, in general, the most recent statistics are also somewhat more uncertain for every country, since first published statistics are often subject to subsequent revisions when more detailed data become available (Olivier and Peters, 2002). For China, Wang and Chandler (2011) give a good description of the revision process for energy and GDP statistics, also in response to the two National Economic Censuses. Korsbakken et al. (2016) built on and extended the study by Wang and Chandler (2011) and compared the impact of various revisions of coal statistics by the NBS, following each of the three National Economic Censuses. For China, the Russian Federation and most other non-OECD countries, we assumed 10% uncertainty, whereas for the European Union, the United States, Japan India and other OECD countries, a 5% uncertainty was assumed. Our preliminary estimate of total global CO_2 emissions in 2015 is believed to have an uncertainty of about 5%, and our estimated emission decrease of 0.1% may be accurate to within ±0.5%. For more details, see Annex 3.

Importance of other sources of greenhouse gas emissions for mitigating climate change

This report assesses the trend in global CO_2 emissions from fossil-fuel use and industrial processes. For a comprehensive assessment of the trends in all greenhouse gas emissions up to 2010, including CO_2 from forest fires and other land-use changes, and the non-CO_2 greenhouse gases such as methane and nitrous oxide (which account for about one quarter of the global total in CO_2 eq. greenhouse gas emissions), we refer to the Fifth Assessment Report (AR5) of the IPCC Working Group III 'Mitigation of Climate Change' (IPCC, 2014a).
Although CO_2 emissions from fossil-fuel and carbonate use are key to greenhouse gas mitigation, other sources also contribute significantly, as shown in Figure 2.4. CO_2 emissions as discussed in this report cover about two-thirds of global total greenhouse gas emissions.

Figure 2.5
CO_2 emissions per capita from fossil-fuel use and cement production in the top 6 to 10 emitting countries and the G20



Source: EDGAR v4.3.2 FT2015 (JRC/PBL 2016: IEA 2014 (suppl. with IEA 2016 for China, BP 2016, NBS 2016); UNPD 2015 (WPP, Rev. 2015)

However, for individual countries their share can vary between more than 90% in most OECD countries, whereas it varies more widely in non-OECD countries (even lower than 10% in some African, Latin American and Asian countries). In many non-OECD countries deforestation emissions and emissions from rice production can be major emission sources. More information on recent trends in other sources can be found, for example, in national reports to the UNFCCC and in the EDGAR v4.3.2 dataset (EC-JRC/PBL, 2016), available at country and source level. In this report, CO_2 emissions are provided for fossil fuel + industrial processes ('FF+IP emissions'), including some small other CO_2 sources (in Figure 2.4 shown in blue). Other sources in these pie charts: CO_2 emissions from forest fires and deforestation ('Forests') (shown in red) (excluding CO_2 sinks/removals of mainly living carbon stock change), methane (CH_4), nitrous oxide (N_2O) and the F-gases HFCs, PFCs, and SF_6 as shares in total greenhouse gas emissions (using GWP-100 values from the Fourth IPCC Assessment Report). The source used for these other emission sources is EDGAR v4.2FT2010 (PBL/EC-JRC, 2012).

How do these CO_2 trends relate to the Paris Agreement on climate change mitigation?

Further analysis may show the extent to which the recent national CO_2 trends estimated in this report are in keeping with the total national greenhouse gas emission trends as expected from analyses of the Cancun pledges for 2020, *Intended Nationally Determined Contributions* (INDCs) and *Nationally Determined Contributions* (NDCs) under the Paris Agreement and other country pledges for 2025 or 2030. By 15 December 2015, 187 countries and the European Union had submitted their INDCs, summarising their climate-related actions after 2020 within the context of the Paris Agreement.

Den Elzen et al. (2016) assessed the mitigation policies described in the INDCs of 105 countries (covering approximately 91% of global greenhouse gas emissions in 2012), with a special focus on the G20 economies. Their analysis included *all* greenhouse gases and *all* anthropogenic emissions, including CO_2 emissions from forest fires and other land-use change and non-CO_2 greenhouse gases. They estimated the required reduction effort by comparing the greenhouse gas emission targets implied in the INDCs against the projected levels resulting from current mitigation policies. Despite these reductions, the global and G20 emission level is still projected to be higher by 2030 than it was in 2010. UNEP will also update their Emissions Gap Report (UNEP, 2016).

The assessment on the 105 countries is also summarised in the interactive PBL Climate Pledge INDC tool, in which, per country, the trend in total greenhouse gas emissions since 1990 is shown, and the impact of aggregated emission reductions compared to business-as-usual and current policies scenarios, assuming that INDCs will be fully achieved (PBL, 2015). In the same way, the trend in global CO_2 emissions as presented in this report is also summarised in another infographic (PBL, 2016).

In a recent article in Nature, Rogelj et al. (2016) assess the effect of current INDCs on reducing aggregate greenhouse gas emissions, their implications for achieving the temperature objective of the Paris Agreement (holding global warming to well below 2 °C and to 'pursue efforts' to limit it to 1.5 °C), and potential options for overachievement. From a different angle, Van Vuuren et al. (2016) provide insights into how different carbon budgets relate to typical values for the peak year of global emissions, the decarbonisation rate and the deployment

Box 2.2 Key elements on emissions under the Paris Agreement (UNFCCC, 2015; EC-CLIMA, 2016)
The Paris Agreement, which was adopted on 12 December 2015, is a global milestone for enhancing collective action and accelerating the global transformation to a low-carbon and climate-resilient society. The Paris Agreement entered into force in October 2016, after having been ratified by 55 countries, and accounts for at least 55% of global emissions.

The Paris Agreement includes both mitigation and adaptation actions and the countries agreed, among other things, on the following key elements:

On reducing global emissions:
- The target to keep the global average temperature **well below 2 °C** above pre-industrial levels;
- To pursue efforts to limit the temperature increase to **1.5 °C** above pre-industrial levels, since this would significantly reduce risks and the impacts of climate change;
- The need for **global emissions to peak as soon as possible**, recognising that this will take longer for developing countries;
- To undertake **rapid reductions thereafter,** in accordance with best available science.

On transparency, NDCs and global stock-take:
- Countries shall submit **national climate action plans** (Nationally Determined Contributions, NDCs) as contributions to the global response to climate change;
- Each successive NDC will represent a **progression** beyond the then current NDC and reflect its highest possible ambition;
- Countries shall **report** to each other and the public on how well they are doing on the implementation of their targets;
- Countries shall track their progress towards the long-term goal, using a robust **transparency and accountability system;**
- Countries shall, every 5 years, make a global stocktake to **set more ambitious targets** as required by science.

of low-carbon technology, using the recently compiled IPCC scenario database, and discuss how these vary as a function of non-CO_2 forcing, energy use and policy delay.

The INDCs do not always cover all sectors and all greenhouse gases. In order to assess their contribution to the total trend in greenhouse gas emissions, it is essential to comprehensively monitor total national emissions in order to assess the effectiveness of emission reduction measures. Such a monitoring system must have a measurable and verifiable structure, and be compatible with an international data assimilation system that uses atmospheric measurements of greenhouse gases.

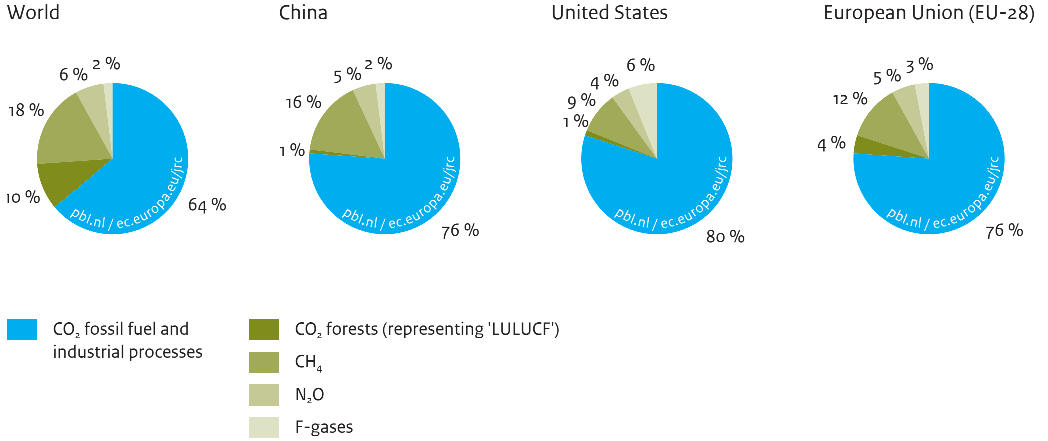
2.2 Different trends in the largest emitting countries and regions

2.2.1 China

China's CO_2 emissions, in 2015, *decreased* by about 0.7%, compared to 2014. This was mainly due to a 1.5% decline in coal consumption, partly compensated for by *increases* in oil consumption of 6.3% and natural gas of 4.7% (all percentages in energy units, e.g. in PJ) (BP, 2016). Coal is the dominant fossil fuel in the non-transport sectors: power generation, industry, residential and services (Table 2.1) (IEA, 2015b, 2016c).

China's CO_2 emissions from fossil fuel combustion, which account for about 85% of total national CO_2 emissions, originated in 2013 for 83% from coal, 14% from oil products and 3% from natural gas (Table 2.4). Although the shares of oil and natural gas are on the rise, the reliance of China on coal is one of the highest of all countries. To calculate the CO_2 emissions for China from all fossil-fuel-related activities, we used IEA's revised energy balance statistics on China (TJ with fuel consumed in each sector) for the 1990–2014 period (IEA, 2016c), which includes all detailed revisions published in May 2015 by the National Bureau of Statistics of China (NBS) for the 2000–2013 period on an aggregate level only (NBS, 2015c). For more information on how the IEA included the revised detailed energy balances of NBS, see IEA (IEA, 2016f). The very large share of coal combustion emissions in the national total was due to the large amount of coal used in the manufacturing industry (28% of the national total), whereas coal-fired power generation accounted for 48% of the national total (see Table 2.4).

Figure 2.6
Shares of greenhouse gas emissions, 2010



Source: CO_2 fossil fuel and industrial processes: EDGAR 4.3.2 (JRC/PB, 2016, notably IEA, 2014); others: EDGAR 4.2 FT2010 (JRC/PBL 2012)

Note: storage/removal of emissions (also known as 'sinks') are not shown here.
This figure differs from CO_2 emissions in this report: it includes CO_2 emissions from forest fires and deforestation ('Forests') (shown in red), but excludes CO_2 sinks/removals of mainly living carbon stock change. For the latter see GCP (2016). Moreover, 2010 was chosen as this is the most recent year for which EDGAR data on non-CO_2 sources are presently available.

Of the remaining 15% in CO_2 emissions, 9% stemmed from cement clinker production and other carbonate consumption, 4% from other non-combustion processes in the manufacturing industry, such as the production of crude steel and chemicals, and the remaining 2% from cokes production, gas flaring and such. (EDGAR v4.3.2, EC-JRC/PBL, 2016). CO_2 emissions from cement clinker production decreased by 4.5% in 2015, whereas total CO_2 emissions from, for example, the global production of steel and chemicals, remained constant in 2015.

Table 2.1 shows that the annual growth in coal production (in tonnes and in PJ), thermal power production (almost all from coal) and cement and steel production all slowed down since 2012, compared to the growth levels in the previous decade. This is in line with the lower annual increases in Gross Domestic Product (GDP) over the past four years. In fact, several of the physical indicators – for coal, thermal power, cement and steel – showed negative growth in 2015. Coal production, in tonnes, already showed a negative growth rate in 2014. Many of these changes appear to continue into 2016, as the 6 and 8 month statistics show.

With 10.7 billion tonnes in CO_2 emissions in 2015, China is by far the largest CO_2 emitting country, with a share in total global CO_2 emissions of almost 30%, followed by the United States, with 14% and the European Union with almost 10%. China's share in total global emissions was estimated at 15% in 2001, and the country surpassed the United States in 2005 as the largest emitting country (IEA, 2014; IEA, 2016c). This high ranking is mainly due to the size of its population and current economy (see Figures 2.3 and 2.4), but also because of the large share of coal in its energy mix, as it is has far greater coal reserves than those of oil and gas.

Moreover, after China became a member of the World Trade Organization (WTO) in 2001, its economy started to expand very rapidly. Although the share of value added (VA) of total industry in GDP decreased from 45% in 2001 to 41% in 2015, the share of its manufacturing industry in GDP remained at about 30% (World Bank, 2016), which together with South Korea's share of 29%, is the highest among the G20 countries. In contrast, most OECD countries of the G20 have manufacturing shares in the range of 10% to 15%, with the exception of Germany with 23% and South Korea with 29%. Also most non-OECD countries of the G20 have manufacturing industry shares of less than 20% (apart from Indonesia with 21%): India (16%), Russia (6%), Turkey (18%), Brazil (11%). The share of services in total GDP increased from 40% in 2000, first slowly but in the last four years rapidly, to 50% in 2015. India and Saudi Arabia have similar service sector shares, whereas most OECD countries of the G20 have shares ranging from 70% to 75%. Although the share in GDP of China's manufacturing industry did not change much, the amount of value added doubled from 2002 to 2010 and in 2015 it was even 2.5 times the value of 2002 (World Bank, 2016). In comparison, in 2002, the value added of China's manufacturing industry was only half that of the United States and about 40% that of the European Union.

Table 2.1

Annual growth rates in 2012 to 2015, according to selected energy trend indicators in China, compared to the previous decade and the first part of 2016 (%)

Indicator	Average annual growth rate 2002–2011 (±1SD*)	2012**	2013	2014	2015	2016 H1	2016 M1-8
CO_2 emissions	9.9%±4.1%	2.1	4.4	2.0	-0.7	-	-
GDP	10.4%±1.8%	7.6	7.6	7.2	6.8	6.7	-
VA Industry	11.7%±1.9%	8.2	7.9	7.3	6.0	-	-
VA Services	11.2%±2.2%	8.0	8.3	7.8	8.3	-	-
Coal production (tonnes)	9.9%±4.2%	4.8	0.7	-2.5	-3.2	-5.8	-10.2
Thermal power production	12.7%±5.1%	1.5	9.1	2.7	-2.7	-3.1	-0.5
Coal consumption (PJ)	10.0%±5.8%	1.4	2.0	0.1	-1.5	-	-
Oil product consumption (PJ)	7.1%±5.1%	5.1	4.3	2.2	6.3	-	-
Natural gas consumption (PJ)	17.1%±6.1%	8.4	14.5	9.9	4.7	-	-
Power consumption (PJ)	12.3%±3.3%	5.8	8.9	6.7	0.3	0.6	3.0
Cement production (tonnes)	12.3%±3.8%	5.3	9.3	2.3	-5.3	-5.3	2.5
Steel production (tonnes)	16.5%±7.4%	4.6	8.7	5.6	-2.3	-1.3	-0.1
Aluminium production (tonnes)	19.3%±11/2%	12.2	8.9	10.3	11.8	-1.7	-1.8

* *Standard deviation*
** *Leap year, so 0.3% higher than normal*
H1 *First half year of 2016; compared with H1 of 2015*
M1-8 *First eight months of 2016; compared with M1 to M8 of 2015*

Sources:
2002-2015: GDP (constant prices), VA (value added) (World Bank, 2016);
2002-2014: production of coal. thermal power, cement, steel and aluminium production (NBS, 2016b); electricity consumption (NBS, 016c); consumption of coal, oil, gas (NBS, 2016d);
2015: production of coal, thermal power, cement, steel and aluminium (NBS, 2016a);
2016 H1: NBS (2016e), except for steel (WSA, 2016) and aluminium (IAI (2016);
2016M1-8: NBS (2016f), except for steel (WSA, 2016) and for aluminium (IAI (2016).

In 2014, China's value added was on a par with that of the European Union, and 30% larger than that of the United States. Apart from the domestic demand for consumer goods, the products of China's industrialisation served the rapid development of buildings and other domestic infrastructure as well as the export of goods.

With 7.7 tonnes of CO_2 per person in 2015, the per capita emissions were somewhat (13%) higher than the EU-28 average and at about the same level of per capita emissions of Poland and South Africa (see Table 2.8). When comparing CO_2 emissions per USD of GDP (in PPP units), although decreasing over time, in 2015, China still had one of highest values among the G20 countries, about 13% higher than that of the Russian Federation and 7% higher than South Africa. However, the emissions per unit of GDP at PPP basis of China are decreasing faster than in other countries (see Section 2.3 and Figures 2.13 and 2.14).

After many years of annual increases in CO_2 emissions, on average, of 9.9% in the 2002–2011 period, the last four years showed a slowing down of annual emission increases, with consecutive growth rates of 2.1% in 2012, 4.4% in 2013, 2.0% in 2014 and a *decrease* of 0.7% in 2015 (IEA, 2016c; BP, 2016). The decrease in the annual trend of 2015 is unprecedented and is a sign of decoupling from economic growth. Annual GDP growth was also slowing down, but remained still positive (from 10% per year before 2012 to about 7% per year in 2013–2015). A key factor for this change in CO_2 emissions was the *decline* in coal consumption (in energy units) in 2015 of 1.5%, as estimated by BP (2016) based on data from NBS China. Although the Chinese energy statistics are more uncertain compared to those of most OECD countries, the slow-down and shift from manufacturing to a more service-oriented economy is corroborated by the recent trends in other indicators, such as electricity generation, thermal power generation, cement and steel production, and aluminium production (see Table 2.2). For a more detailed analysis of these phenomena, see Qi et al. (2016) and Green and Stern (2016).

This emission *decrease* of 0.7% in 2015 is consistent with the *decrease* of 2.7% in fossil-fuel fired power generation (predominantly coal-fired power plants) reported by the National Bureau of Statistics of China (NBS, 2016b).

Box 2.3 Uncertainty in China's statistics and in its CO_2 emissions

In the literature there is a lot of discussion on the accuracy of many statistics reported by the National Bureau of Statistics of China (NBS), on economic parameters such as GDP and Value Added, but also in physical statistics such as energy production and consumption in tonnes and volumes and in energy units and of various products of the manufacturing industry. Many analysts have noticed that NBS statistics may not be consistent with data reported by provinces and specific industry organisations, nor in absolute numbers neither in annual or monthly changes. Also NBS economic and energy statistics are revised regularly.

The uncertainty in CO_2 emissions from fossil-fuel combustion using international statistics is discussed in detail in Marland et al. (1999) and Andres et al. (2012), and general uncertainty characteristics in global and national emission inventories are discussed in Olivier and Peters (2002). Andres et al. (2012) compare several studies on the uncertainty of CO_2 emissions from fossil-fuel use and cement production and conclude that they range from between about 3% and 5% for the United States, to between 15% and 20% for China, based on a comparison of CO_2 estimates based on national coal statistics and on the sum of provincial coal statistics (Gregg et al., 2008), to estimates of 50% or more for countries with poorly maintained statistical infrastructure (Marland et al., 1999).

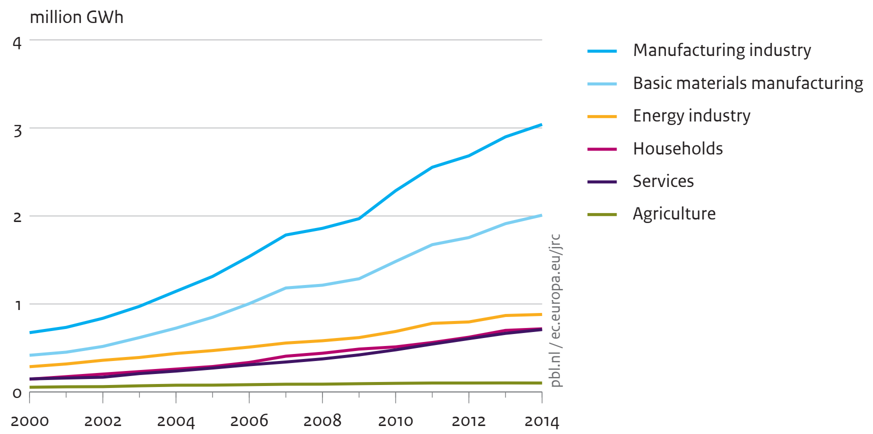
In recent years, the uncertainty in the CO_2 estimates for China was the subject of several studies. The uncertainty estimate by Gregg et al. (2008) was based on revisions of energy data for the transition period of the late 1990s, which may not be fully applicable since the revisions made by the National Bureau of Statistics of China in 2006, 2010 and 2016 (Tu, 2011). Guan et al. (2012), continuing the comparison made by Gregg et al. (2008), point out the large difference between total provincial coal consumption statistics and national total statistics, whereas Tu (2011) attributes the discrepancy for a large part to the unreported coal production by small private coal mines, as well as to staffing shortages at the National Bureau of Statistics of China (NBS). Also in 2011, Wang and Chandler (2011) gave a good description of the revision process of energy and GDP statistics by the NBS.

Since 2014, several studies on the accuracy of energy statistics of China and of its CO_2 emissions have shed new light on this issue (e.g. Ma et al., 2014; Liu et al., 2015; Ma and Zheng, 2016; Korsbakken et al., 2016). Korsbakken et al. (2016) built on and extended the study by Wang and Chandler (2011) and compared the impact of various revisions of coal statistics by the NBS, following each of the three National Economic Censuses and compared national and total provincial statistics and with correlated economic statistics, such as on fossil-fuel-fired power generation and cement and crude steel production over the 1995–2015 period.

For a more detailed discussion on the uncertainty in Chinese fuel consumption data as reported by different sources, we refer to Annex 3, where we conclude that the uncertainty is about 10% for China (which is twice the uncertainty for the OECD countries and similar to that for Russia).

The decrease in the power generated by coal-fired power plants, which produce about three-quarters of total electricity (NBS, 2015b) and which contribute to about half of the country's CO_2 emissions from fossil-fuel combustion (Table 2.4), was due to the still relatively 'slow' growth rate of total electricity consumption of 0.3% in 2015, compared to the previous decade which showed double-digit growth figures (the lowest since 2000). Moreover, for the 10th consecutive year, China added more newly installed hydropower capacity than the rest of the world combined. In 2015, China added 19,370 MW in new hydropower capacity, including 1,230 MW in pumped storage, resulting in a total installed capacity of 320 GW (IHA, 2016). Hydropower generation increased again in 2015 by 5% due an expansion of installed capacity. Hydropower accounted for 19.5% of total electricity generation, which is the largest share since 1990, while fossil-fuel power generation dropped by 2.7% in 2015 and accounted for 73% of total production. In addition, wind, solar and other renewable energy increased by more than 20% and together accounted for almost 5%.
The remaining 3% was generated by nuclear power, which saw an increase of 29% in 2015, compared to 2014.
The share of thermal (i.e. fossil-fuel-fired) electricity generation of 73% in 2015 was more than 2 percentage points lower than in 2014, and down from 80% in 2009.
In particular the increases in hydropower and of other renewable power generation, since 2009, by 3 percentage points each, have reduced the reliance on coal-fired power generation, not only in percentages but, for the first time, also in absolute amounts. Also, the absence of growth in electricity demand helped to reduce coal-fired power generation. Expansion of nuclear power has a longer lead

Figure 2.7
Electricity consumption per sector in China



Source: NBS 2016

time which can be seen in the growth in the share by 1 percentage point, from 2% in 2009 to 3% in 2015. Unlike in developed countries, China's manufacturing industry is the sector with the largest consumption of electricity and fuel. Therefore, the demand for energy, in general, is largely driven by trends in basic materials production (Table 2.2 and Figure 2.7). As Table 2.2 indicates, there has been a substantial slowdown in the growth rate of the demand for materials, halving the physical growth in this sector since 2012. First reports on 2016 show a further slowdown or even decrease in most indicators.

2.2.2 United States

In the United States, CO_2 emissions decreased in 2015 by 2.6%, to 5.15 billion tonnes, following previous increases of 1.8% and 1.1% in 2013 and 2014, respectively. The 2015 emission level was similar to the lowest levels reported for 2012 and 1993, over the 1993–2015 period. GDP in 2015 continued to increase by 2.4%, a similar rate as that in 2014 and even 2012. However, in both 2012 and 2015, winter weather temperatures were very mild, as indicated by the relatively low number of Heating Degree Days (HDD) in these years, which are indicators for the demand for space heating (EIA, 2016c). CO_2 emissions from fossil-fuel combustion, with 96% in total US CO_2 emissions the dominant source, decreased by 2.7% in 2015 to about 5.0 billion tonnes, compared to 2014. Generally, the annual changes in fossil-fuel-related CO_2 emissions mainly depended on the annual changes in the *economy* (market tendencies and *fuel prices*), on the *weather* and also on fossil-fuel-related *policies* (e.g. emission standards). When comparing long-term trends, we note that, while the United States saw a relatively high annual population increase of 27% since 1990, US CO_2 emissions increased by only 3.4% in this period (for more details, see Section 2.3).

Although total CO_2 emissions were 3.4% higher in 2015, than in 1990, energy-related CO_2 emissions were 12% below 2005 levels (between 2000 and 2005, US CO_2 emissions plateaued at their highest level since 1990). The US Energy Information Administration (EIA) has analysed these changes over the last 10 years (EIA, 9 May 2016) and concluded that the emission decrease was mostly in the *electric power sector*, due to a shift from coal to natural gas used in electricity generation, whereas the demand for electricity remained rather constant since 2005 (EIA, 2016g). The decrease in electricity consumption was almost equally distributed over the residential, commercial and industrial sectors.
In addition, over the last decade, fuel consumption in the transport sector decreased and, to a lesser extent, also in the residential and industrial sectors, all contributing to the decline in CO_2 emissions since 2005. In 2013, coal combustion was responsible for one-third of fossil-fuel-combustion-related CO_2 emissions, which were almost all emitted from power plants (Table 2.4).

The decrease in CO_2 emissions in 2015 was mainly caused by a drop of 13% in 2015 in total *coal consumption* (BP, 2016), which is the largest annual decrease, in percentages, of any fossil fuel in the United States over the past five decades. Similarly, declines of 12% in coal consumption occurred in 2009 and 2012 (EIA, 2016n). These decreases were mainly in the coal-fired power sector, where 95% of coal was used (most of the remainder having been used in the iron and steel industry). The large number of recent closures of coal-fired power plants was mainly due to the Mercury and

Table 2.2
Shares of sectors in total electricity consumption in China, in 2000, 2010 and 2014 (%)

Sector	2000	2010	2014
Agriculture	4.0%	2.3%	1.8%
Manufacturing industries	52.1%	56.3%	55.8%
of which: Smelting of ferrous metals	8%	11%	10%
of which: Basic chemical materials	9%	7%	8%
of which: Smelting of non-ferrous metals	5%	7%	8%
of which: Non-metallic mineral products	6%	6%	6%
of which: Textile	3%	3%	3%
of which: Metal products	1%	2%	2%
of which: Total basic materials manufacture	29.2%	34.1%	34.5%
Energy industries (including transport losses)	21.0%	16.0%	18.0%
Service sector	10.9%	11.4%	12.5%
of which: Offices	4.6%	5.8%	6.4%
of which: Wholesale, retail, hotels, restaurants	3.1%	3.%1	3.5%
of which: Transport, storage and post	3.2%	2.4%	2.6
Residential sector	10.8%	12.2%	12.7

Source: NBS, 2016b

Air Toxics Standards (MATS), which became effective in 2015. These new standards require large coal-fired and oil-fired power plants to adhere to stricter emission limits by implementing emission control technologies. Some operators have decided that retrofitting some coal-fired plant would be too costly and, instead, chose to retire the plants (EIA, 2015d).

In addition, focusing on the past years, electricity consumption increased in 2013 and 2014, but demand fell in 2012 and 2015, due to relatively warm winter temperatures. As the warmer winters also significantly decreased the consumption of natural gas for space heating, it also lowered natural gas prices (EIA, 2016b). The mix of power plants used is determined by the available capacity and the relative costs to operate the various technologies. Recent additions were mostly gas-fired and renewable energy technology, whereas plant retirements were mainly coal plants. The drop in natural gas prices and very efficient gas-fired technology made natural gas also attractive for baseload power production. At the same time, coal-fired power generation decreased because of the cost per kWh compared to natural gas as well as the cost to comply with the increased regulation to reduce emissions of air pollutants. However, the relative increase in natural gas consumption in gas-fired power generation was not as large as the decrease in coal consumption, not only because of the higher conversion efficiency of natural gas plants, but also because power from renewable energy sources increases over time. As a result, in 2015, for the first time, total kWhs produced by gas-fired plants was almost equal to those produced by coal-fired power plants (EIA, 2016g). In April 2015, gas-fired power generation surpassed coal-fired power generation, on a monthly basis (EIA, 2016o).

The total increase in the use of *natural gas* in 2015 was 3.0% (BP, 2016). About one third of gas consumption occurred in the residential and commercial sectors (predominantly for space heating), one third for power generation and another third in the manufacturing industry and the energy sector's own use (EIA, 2015b). As mentioned above, due to the relatively mild winter of 2015, natural gas and electricity consumption for space heating was below normal and below 2014 levels. In 2015, population-weighted HDDs, which are a measure of the demand for space heating in buildings (houses and offices) were 9% lower than in 2014 (see Annex 4). Similarly, the warmer summer months increased the electricity demand for air conditioning, for which so-called Cooling Degree Days (CDD) are used as a proxy for this demand, which is generally met by gas-fired power generation (EIA, 2016o). However, since the United States has about three times as many HDDs as they have CDDs, the annual variation in CO_2 emissions due to the weather will generally follow the annual variation in HDDs (EIA, f2016). Thus, the 3% increase in gas consumption was primarily due to higher levels of power consumption and partly compensated for by lower power consumption in buildings.

CO_2 emissions from the combustion of *oil products* increased by 1.6% in 2015 (BP, 2016). CO_2 emissions from road transport accounted 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 (see Table 2.4 and *EIA*, 2016u).

Total petrol consumption, mainly used by passenger cars, increased by 2.7% in 2015, the largest increase since 2002, whereas diesel consumption decreased slightly by 0.5%, after five years of annual changes between -5% and +5%. Diesel consumption was about 30% of petrol consumption (by volume) and mainly used in freight transport. Jet fuel consumption, used by airlines, jumped by 4.7% in 2015. This is the same level as in 2008, which is about 10% below the highest annual use which was in 2000 (EIA, 2016r).

As a result of these trends, fossil-fuel-related CO_2 emissions from coal and natural gas consumption, with coal decreasing and gas increasing, in 2015 were about equal. CO_2 from natural gas combustion is expected to surpass those from coal combustion in 2016. However, the largest share in fossil-fuel CO_2 emissions will still originate from the combustion of oil products, being much larger than the equal levels of coal and gas combustion in 2015 (1.5 higher) (EIA, 2016q).

Biofuel use for transport (fuel ethanol and biodiesel) increased by 4.3% in 2015, increasing its share in total transport fuels to nearly 5%. Blends of oil-based petrol with 10% ethanol (often called 'E10') accounted for more than 95% of the fuel consumed in petrol-fuelled vehicles. The total volume of ethanol blended into motor fuels used in the United States has continued to increase since 2010, to about 9.9%(v) in 2015 (EIA, 2016)d. Biodiesel (and renewable diesel) fuels are produced by refining vegetable oils or animal fats. Biodiesel is blended with fossil-fuel diesel by up to 5% or 20% by volume (called 'B5' and 'B20'). Renewable diesel is a diesel-like fuel that meets specifications for use in diesel engines. The use of fuel ethanol, which makes up 85% of total transport biofuels, increased by 3.7% in 2015, whereas total biodiesel consumption (including renewable diesel) increased by 7.7% EIA (EIA, 2016s).

The amount of total renewable energy used in power generation has continued to increase over time, but in smaller amounts since 2011. In 2015, the increase was 1.8% (or 6.5% excluding hydropower that decreased by 8%), reaching a share of 13.4% in power generation (or 7.2% excluding hydropower). In 2011, the increase was still 19% (or 15% excluding hydropower). In particular, the annual increase in wind power of 26% in 2011 was at a maximum; in subsequent years, the increases were 15%, 19%, 8% and 5%, respectively. Also solar electricity (PV), which doubled annually from 2012 to 2014, increased in 2015 'only' by 40%. In contrast, hydropower decreased by 3% in 2014 and 2015, and, as a result, the share of the 'new' renewable power sources 9.8% (biomass, wind power, solar power, and geothermal sources) surpassed the share of hydropower (7.9%) in 2015 by 2 percentage points (EIA, 2016s; BP, 2016).

In August 2015, the US EPA announced and finalised *the Clean Power Plan* (CPP) rule to reduce CO_2 pollution by existing power plants, under Section 111(d) of the Clean Air Activity (US EPA, 2015). The EIA estimates that, in a case that excludes the proposed rule, CO_2 emissions from the power sector will be 25% higher, by 2030 and beyond, than in the case that the CPP is implemented (EIA, 2016h). The EIA expects that the shift away from coal power plants to a combination of more gas-fired power plants and electricity from renewable energy and a higher energy efficiency will be accelerated by the implementation of US EPA's Clean Power Plan. However, also without the CPP implemented, considerable growth in renewable electricity is expected throughout the United States, due to the recent extension by the US Congress of favourable tax treatment for renewable energy sources. The CPP would enhance the projected average annual growth of renewable power and gas-fired power from 2015 to 2030 by 0.8 percentage point and 1.0 percentage point to 4.7% and 1.6% per year, respectively (EIA, 2016l).

Interestingly, many new natural gas-fired power plants under construction are near major areas where shale gas is produced. About 18.7 GW of new gas-fired generation capacity will come in operation between 2016 and 2018. Many of these plants are concentrated around the Marcellus and Utica shale regions, which are mostly located in Pennsylvania (1.8 GW), West Virginia (2.3 GW), Ohio (1.9 GW) and Massachusetts (0.7 GW). Over the past years, shale gas production has been developed as well as natural gas infrastructure to transport the gas to populated areas along the Atlantic Coast. Also in Texas, which produces the most natural gas of all states, 3.2 GW of gas-fired generating capacity is under construction (EIA, 2016i). In addition, in Florida, three gas-fired power plants with 3.8 GW capacity are under construction, as the regional gas pipeline network is being expanded to transport more shale gas to the state.

In road transport fuel standards proposed jointly by the US EPA and the Department of Transportation's National Highway Traffic Safety Administration would increase fuel economy and reduce diesel consumption in medium- and heavy-duty vehicles (pickups, vans and trucks). The first phase of medium- and heavy-duty vehicle standards was recently implemented, starting with car model year 2014. Phase two vehicle and engine performance standards would cover model years from 2021 for most types (US EPA, 2016). The EIA estimates that, by 2040, the implementation of these standards will improve the average fuel economy of this group of vehicles by 33% (EIA, 2016m). Also, for passenger cars, the addition of several fuel-efficient technologies to standard petrol vehicles can substantially improve their fuel economy, such as for medium-sized passenger cars by 50% (EIA, 2014). Apart from the 96% in CO_2 emissions from fossil-fuel combustion in the United States, half of the remaining 4% originates from industrial non-combustion processes, mainly from the production of chemicals such as ammonia and ethylene (95 million tonnes CO_2) and cement clinker production (about 39 million tonnes CO_2). These sources saw virtually no change in 2015 compared to 2014 (USGS, 2016).

Gas flaring

Flaring of so-called associated gas that is produced in oil production, which cannot be marketed, is not a very large source of CO_2 emissions in the United States, but the amount almost quadrupled since 2007. The increase in oil production by hydraulic fracturing that took off around 2007 increased flaring emissions, from about 5 million tonnes in the beginning to 20 million tonnes of CO_2 presently (EDGAR 4.3.2; EC-JRC/PBL, 2016). In 2014, flaring emissions in the United States increased by about 30% compared to 2013, as derived from satellite observations (Elvidge et al., 2016), but, in 2015, gas flaring in North Dakota (that produced and flared or vented almost half the US total) declined sharply from around 30% in total natural gas produced in January 2014 to around 10% in January 2015 (EIA, 2016k). This is ahead of targets set by North Dakota's Industrial Commission aimed at decreasing the amount of flared gas over the next years (EIA, 2015c). For a discussion of general trends in oil and gas production, in particular in the United States, and gas flaring including the role of hydraulic fracturing, see Section 2.4.

2.2.3 European Union

The European Union (EU-28), in 2015, emitted 3.47 billion tonnes of CO_2, which is 1.3% more than in 2014 (3.42 billion tonnes of CO_2). The share of the European Union in global total CO_2 emissions remained at 9.6%, of which Germany contributed 2.1% (0.1% less), the United Kingdom 1.1% (also 0.1% less), Italy 1.0% (0.1% more), while France, Poland and Spain kept their shares at 0.9%, 0.8% and 0.7%, respectively.

In 2015, the EU-28 no longer continued the decreasing trend of 2012–2014, instead showing an *increase* of 1.3%, which resulted from contrasting trends in the various EU Member States. Relatively large *increases* in CO_2 from 2014 to 2015 occurred in the southern EU Member States of Portugal (7.4%), Spain (6.7%), Bulgaria (5.2%) and Italy (5.1%), whereas CO_2 emissions in the northern European countries further *decreased* in 2015: Finland (9.7%), Denmark (8.3%), United Kingdom (4.0%) and Sweden (2.7%). These trends were decoupled from GDP, which ranged between 0% and 4.3% for all EU Member States, with the exception of Malta and Greece.

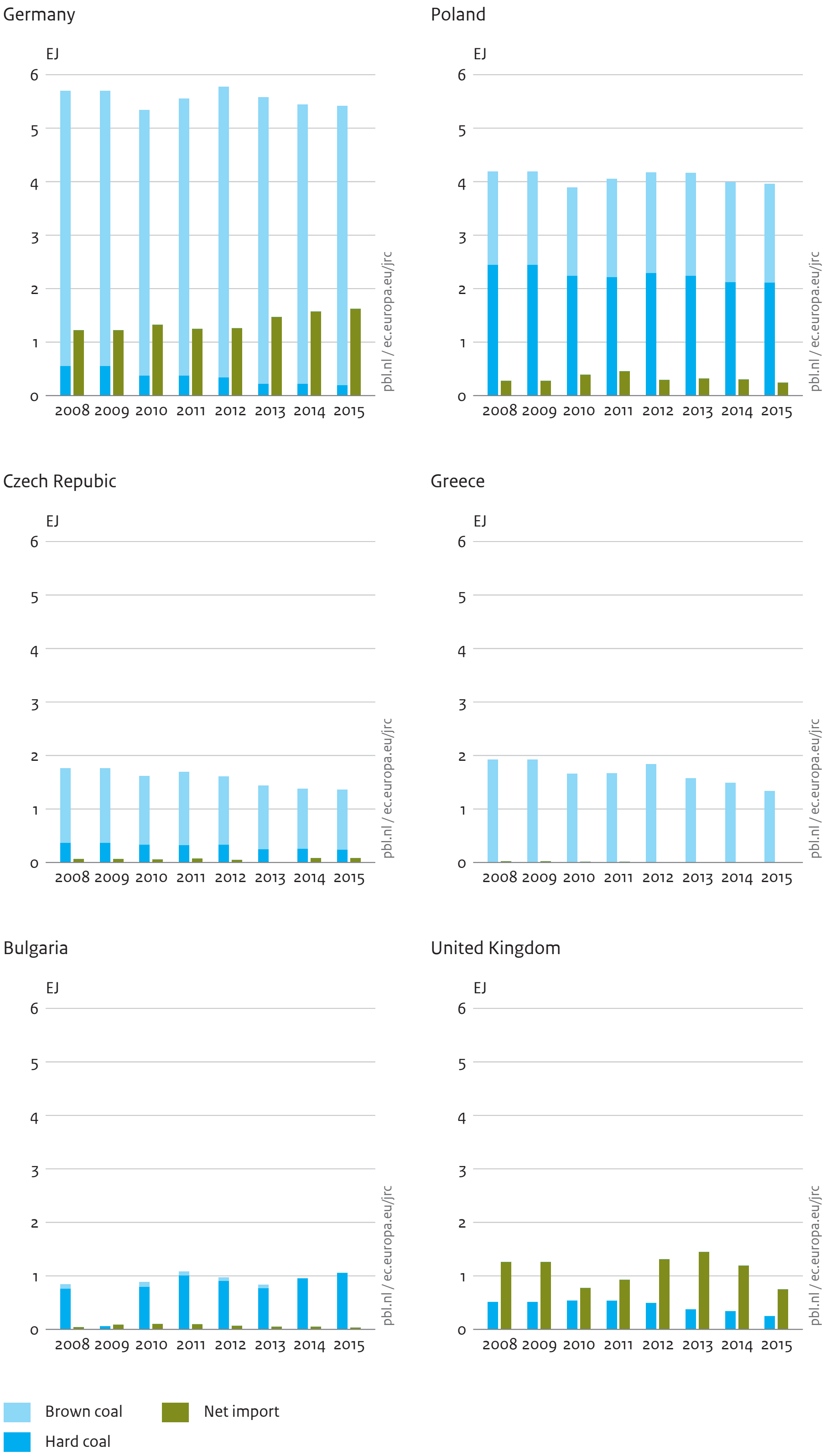
This increase was mainly due to the increase in fossil-fuel combustion, for which an increase of 1.4% is estimated, as a result of an increase in natural gas consumption of 4.6%, an increase in oil consumption of 1.5% and a decrease in coal consumption of 1.8% in 2015, compared to 2014 (BP, 2016). This total increase in fossil-fuel consumption of 1.4% is higher than the estimated 0.7% released by Eurostat, the statistical office of the European Union (Eurostat, 2016b). The large increases reported by Eurostat for Portugal (8.6%) and Hungary (6.7%) were similar to our estimates, but Eurostat reported also a large increase for Slovakia (9.5%), for which BP (2016) only reported a 2.5% increase. For Denmark and Finland, our estimated emission reductions are similar to those by Eurostat. In 2013, coal combustion was responsible for one third of total fossil-fuel-related CO_2 emissions in the European Union, which were mostly emitted by power plants but also by the manufacturing industry (Table 2.4). The year 2015 was the third year on a row that saw a decrease in coal consumption.

The increase of 4.6% in the EU's natural gas consumption in 2015, compared to 2014, as estimated by BP (2016), is in line with Eurostat (2016d) that reported a 4.3% increase. The differences in CO_2 emissions are mainly related to differences between the estimated coal consumption decreases and oil consumption increases. BP (2016) reported a 1.8% decrease in coal consumption in 2015, compared to 2014, whereas Eurostat (2016c) estimated a 5.6% decrease. For oil consumption in 2015, BP (2016) reported a 1.5% increase, whereas Eurostat (2016e) estimated a 6.1% increase. It should be noted that coal and oil data in Eurostat are based on accumulated monthly statistics. Eurostat reported that the difference between the accumulated monthly data and the annual data is negligible for natural gas (less than 1.9% and with a 5-year average of only 0.7%), whereas for coal and oil, the difference is significant (up to 8.7% with 5-year average of 3.5%). For this reason, and for a consistent approach across countries, we used BP data for our trend estimates for 2015, assuming BP fuel data are based on annual consumption data.

With the fuel-specific energy consumption trends, we evaluated the trends for the major energy consumers in the EU-28; first the major sectors under the Emissions Trading System with power generation and other industry (contributing 26% to the total), then the major sectors under the Effort Sharing Decision: transport (33%) and households (25%) (Eurostat, 2016e).

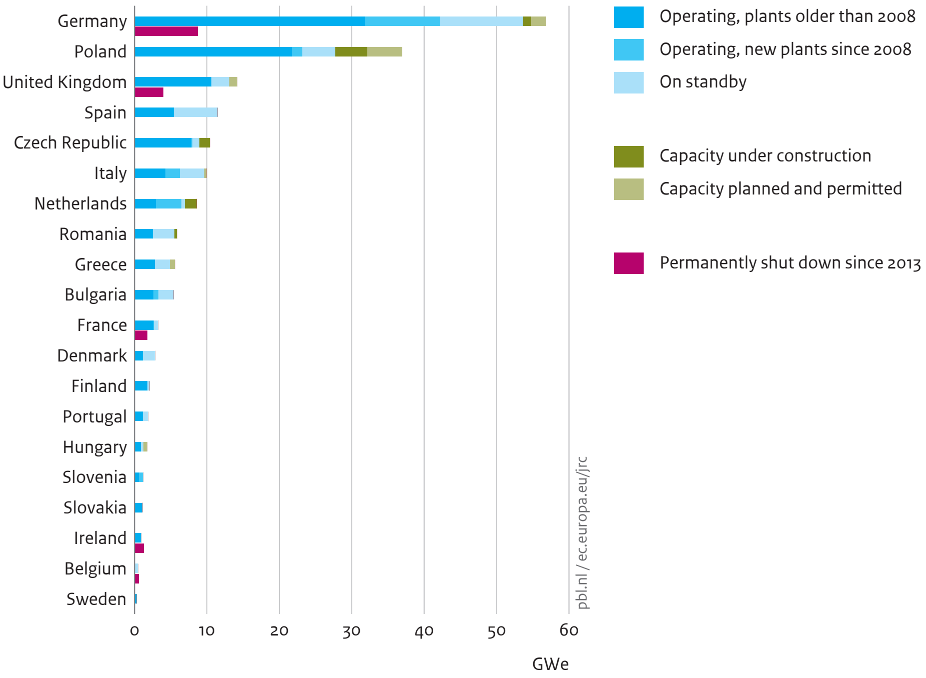
Figure 2.8

Production of hard and brown coal and coal import for the top 6 coal consuming countries in European Union



Source: Euracoal 2016

Figure 2.9
Coal-fired power generation in European Union, 2016



Source: Global Coal Plant Tracker 2016

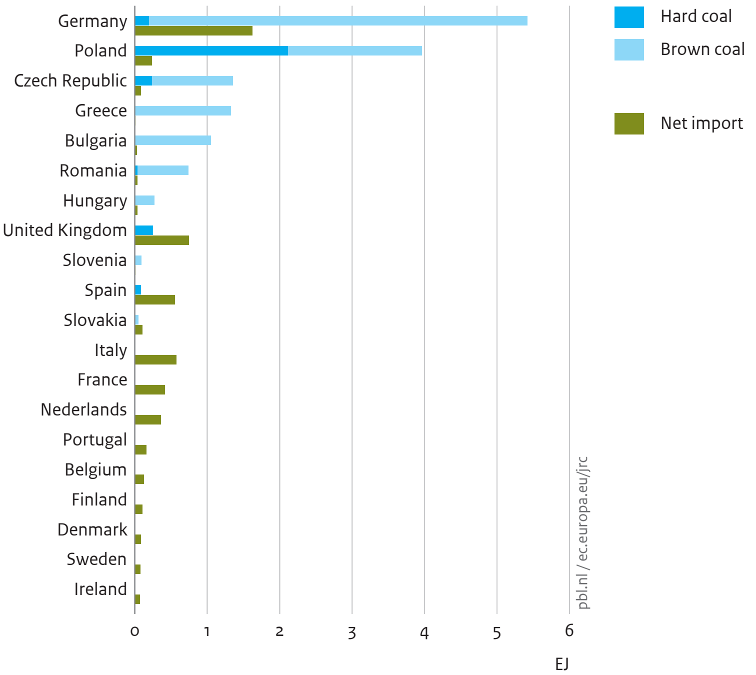
EU's Emissions Trading System

In the EU-28, 45% of total greenhouse gases are emitted by the large industrial facilities and power plants that are part of the EU Emissions Trading System (EU ETS), and they have been steadily reducing their emissions. A 0.7% reduction in CO_2 emissions by these facilities and power plants was reported for 2015, compared to 2014, by the EU ETS data viewer (EEA, 3 June 2016). This is a much smaller reduction in CO_2 emissions than in 2014, for which a 4.9% reduction was reported, as electricity demand increased, amongst other things, because of a 3% higher demand for space heating in 2015 than in 2014. However, the decrease of 1.8% in the consumption of coal, which is mainly used in power plants, contributed to the net EU ETS decrease of 0.7%. A continued emission reduction effort is undertaken in all sectors of the EU ETS, with (shares in brackets) fuel combustion in industries and power plants (66%), industrial process emissions (31%) and aviation (3%). Under the EU reporting regulation, the Member States projected a further 8% reduction in CO_2 emissions from stationary installations under the EU ETS, in the 2015–2020 period (EEA, 2015).

The power generation

CO_2 emissions from the power generation sector decreased by 0.6% (Sandbag, 2016), while total power generation increased by 1.3% in 2015, compared to 2014, after four years of decreases, at an average rate of 1.4% per year (BP, 2016). The decrease in emissions was due to a larger overall share of renewable electricity in 2015 (hydropower, wind, solar and biomass power) and to a decline of 1.8% in coal consumption in the European Union, where it was mainly used in the power sector.
This was the third year in a row that coal consumption in the European Union declined. Coal consumption declined in almost half of the EU countries, predominantly in the UK, and further significant decreases were also seen in Greece, Denmark, Finland, Italy and Germany. This was partly offset by increased coal consumption in one-third of the EU countries, predominantly in Spain and the Netherlands, and also significant increases in coal consumption were in Portugal, Romania and Poland in 2015 (BP, 2016).
Since 2014, total renewable sources have contributed with the largest share (29%) to total power generation, followed by nuclear energy (27%), coal (25%), natural gas (15%), oil (2%) and waste (1%) (Eurostat, 2016f). Although the amount of hydropower in the European Union declined by 10% due to less favourable weather conditions, the share of total renewable electricity increased by 7 percentage points in 2015 to 29% in total EU wide power generation in 2015.
Even though the share of fossil fuel, and in particular coal, has decreased on average by 8% per year over the 2012–

Figure 2.10
Production of hard and brown coal and coal import in European Union, 2015



Source: Euracoal 2016

2014 period, the total amount of produced and imported coal in EU-28 only decreased by 3.1% and even increased slightly in certain EU Member States (e.g. Germany, see Figure 2.8). Similarly, the coal power capacity in EU-28 has been reduced by 10.3% with several coal power plant retirements in both 2015 and the first half of 2016, but Germany compensated for the retirement of old plants with new plants and increased its capacity by 3.3% (Shearer et al., 2016). A new plant was also built in Poland, and so were three more in the Netherlands, resulting in the contributions shown in light blue in Figure 2.9. The fuel for these plants still predominantly consists of domestic coal, but imported coal is used in many EU Member States except Greece, Bulgaria, Romania and Hungary (see Figure 2.10).

However, Figure 2.9 does not show planned retirements, such as the retirement of old coal plants in the Netherlands which are planned for 2017. Also, for certain countries, the data set for last year may not be completely up to date; for example, for the Netherlands, where no other plants have been under construction since April 2015. In fact, two thirds of coal plants currently in the EU have been in operation for 30 years or more (Global coal plant tracker, 2016). Several other EU Member States, such as Austria, Finland and the United Kingdom, have announced to phase out coal-fired power production.

On the other hand, Poland, which generates about three quarters of its power in coal-fired power plants, has plans for a substantial increase in its coal power capacity (Shearer et al., 2016). Overall, since 2003, the European Union has seen a net decrease in coal power capacity of 15.2 GWe (18.4 GWe added and 33.6 GWe retired).

Other industry

In addition to the combustion-related CO_2, the steel industry also produces significant amounts of CO_2 emissions from non-combustion processes (notably in blast furnaces). These emissions decreased by 1.9% in 2015, compared to 2014 (EEA, 2016), while total crude steel production decreased by 3% in 2015 (Table A2.4). The EU's top 7 steel producing countries have mainly been reducing their CO_2 emissions (except for Spain), from largest to smallest contributor: Germany (-0.6%), France (-7.2%), Spain (+4.2%), Italy (-7.2%), United Kingdom (-10.0%), Belgium (-1.0%) and Slovakia (-3.1%). Steel demand in the European Union fell after the economic crisis of 2008, but for 2016 is expected to grow by 1.4%.

Furthermore, CO_2 is also emitted during the production process of non-metallic minerals (e.g. cement, lime, plaster, glass and ceramics), which in 2015 increased in the European Union by 2.5%, compared to 2014. This is the result of widely varying trends in EU Member States with increases for the top 7 emitters (except for the decrease in Germany), from largest to smallest contributor: Germany (-0.2%), France (+2%), Spain and Italy (+3.9%), Poland (+5.5%), United Kingdom (+3.1%) and Romania (+3.3%). Cembureau (2016) reported for the European Union a similar increase of 3.7% for cement production in 2015 compared to 2014, but with decreases for Italy (down by 3.4%) and France (down by 3.1%), which seemed to have recovered more slowly from the decrease over the past two years, than most other Member States.

The transport sector

In 2015, CO_2 emissions from road transport increased mainly because of a 4.1% increase in diesel consumption (with a share of 45% of total oil products consumed in the European Union), compared to 2014. Petrol consumption (with a 14.4% share) remained almost constant with only a 0.3% increase in 2015, compared to 2014.

Domestic passenger transport in the European Union mainly occurs by passenger car (82%), only 12% by bus and 6% by railway (Eurostat, 2016a). As such, passenger cars are responsible for around 12% of total CO_2 emissions. In 2009, EU Regulation 443 set mandatory emission reduction targets for new passenger cars from 2015 onwards (EC/EU, 2009). The regulation requires that, from 2015 onwards, new cars registered in the EU do not emit more than an average of 130 grams of CO_2 per kilometre (g CO_2/km). This represents a fuel consumption of around 5.6 litres of petrol per 100 km (l/100 km) or 4.9 litres of diesel per 100 km. The average emission level for a new passenger car sold since 2014 has been well below the 2015 target.

The household and service sectors

CO_2 emissions in the EU's residential and service sectors increased by 1.5% in 2015, compared to 2014. It should be noted that 2014 had a very mild winter, and that in 2015 although the weather was also mild in certain regions, it was not in others, which resulted on average in a 3% greater demand for space heating within the European Union, for which in particular natural gas and electricity were used (see Annex 4, Table A4.1). Bulgaria and Hungary showed increases of 5.8% and 5.1%, respectively, whereas the northern EU Member States, Denmark, Finland and Sweden and the United Kingdom showed decreases of between 9% and 3%.

2.2.4 India

India continued to increase its CO_2 emissions to 2.47 billion tonnes in 2015, which was 5.1% more than in 2014. This growth rate is similar to the one observed for 2013 and 2007, and a little below the average growth rate of 6.8% for the 2006–2015 period (Figure 2.2). If India continues with this average growth rate, it will surpass the total emissions in the European Union by 2020, assuming also that the European Union will decrease its emissions at the 2006–2015 average rate of 1.9% per year. India's emissions already surpassed those of the Russian Federation in 2009 and India meanwhile is a major emitting country (see Figure 2.2), effectively cancelling out the emission reductions in 2015 by China and the United States. However, India's per capita emissions of 1.9 tonnes CO_2/cap are more than three times lower than the average per capita emissions in the EU and even lower than the average per capita emissions in developing countries.

India's emission increase seems to be coupled with its GDP growth. In 2015, GDP continued to increase, with a growth rate of 7.6%, compared to 2014. This economic growth confirms a further acceleration of India's economy over the past three years, and adds to the average growth over the past decade (2006–2015) of 7.4% (World Bank, 2016). Since 75% of India's national economy consists of domestic demand (Damodaran, 2011), its GDP trend remains relatively unaffected by global financial recessions.

Table 2.4 shows the shares of fuel types and sectors in India's fossil-fuel combustion CO_2 emissions. In 2013, coal combustion was responsible for 72% of its total fossil-fuel combustion CO_2 emissions, predominantly from power plants (47% of fossil-fuel combustion emissions, but also a substantial fraction from the manufacturing industry (22%).

The increase in CO_2 emissions in 2015 was mainly caused by the 5.1% increase in Total Primary Energy Supply (TPES), i.e. energy consumption, in particular the 8.1% increase in oil consumption (with a TPES share of 27.9%), and the 4.8% increase in coal consumption (with a TPES share of 58.1%), according to BP (2016). The coal consumption increase is of concern, because in 2014 India's emissions surpassed those of the United States and became the second largest coal consumer, after China (Shearer et al., 2016). In the 1990–2010 period, India doubled its coal power capacity from 50 GW to 100GW, and then added another 102 GW in coal power, in the 2010–2015 period. In 2015 alone, 20.2 GW in new power plants were taken into operation, and another 12.7 GW were added in the first half of 2016. Currently, 64.7 GW is under construction and 178.2 GW is further permitted, according to the Global Coal Plant Tracker (2016). The planned projects still need to overcome certain barriers, such as financially strapped electricity distribution companies, the insufficient rail transport capacity for domestic coal use and the high cost of coal imports, according to Shearer (2016). These are also the reasons for the diminished utilisation rate of 64.5% for the operational coal plants CEA (2015). India's coal production increased by 7%, however these do not meet all of India's needs, and further challenges for mining expansion include the evacuation of populated areas and the declining energy content and high ash content of the domestic coal (Shearer et al., 2016).

In addition to increasing domestic coal mining, the Indian Ministry for Energy has set a target for increasing renewable energy by 175 GW, by 2021 (consisting of 100 GW in solar power and 60 GW in wind power), and a target for reducing grid transmission losses to 15% by 2019 (which is 6 percentage points under than what is currently perceived). Renewable energy, in 2015, increased by 13.7% in 2015, compared to 2014, yielding an electricity generation share of 2.2%. Also, nuclear energy increased by 9.6%, but still provides only an electricity generation share of 1.4%. India's INDC contribution includes 40% non-fossil energy sources for power generation by 2030.

Aside of the power generation, India also increased its process emissions from cement production by 4.9%, in 2015, compared to 2014, which is in line with the cement production rate of 6% reported by ICRA (2016). A further increase in cement production is envisaged, in particular by increasing the utilisation rate from 72% to 77%. Steel sector process emissions in 2015 only increased by 2.4%, which is slightly more than the 1.7% increase in crude steel production, reported by WSA (2016), compared with 2014.

2.2.5 Russian Federation

In 2015, the Russian Federation's CO_2 emissions continued to decrease by 3.4% to about 1.76 billion tonnes, which is the third and largest decrease in a row since 2013, on average by 1.3% per year. Its 61 million tonnes of CO_2 saved is of the same order of magnitude as the decrease China's 69 million tonnes. This decrease seems (contrary to in China) related to the decrease in GDP of 3.7% in 2015, compared to 2014 (World Bank, 2016). Russia's share in global CO_2 emissions dropped in 2015 to 4.9%, as a result of its continuously shrinking share of 5.2% in 2011. Over these past 4 years, Russia's share in total emissions from non-EU economies in transition (EIT) has stayed at 65% (65.4% in 2015), illustrating that all economies in transition are showing a decreasing emission trend (on average by 2.1% per year).

Table 2.5 shows the shares of fuel types and sectors in fossil-fuel combustion CO_2 emissions in the Russian Federation. In 2013, coal combustion was responsible for one quarter of total fossil-fuel combustion CO_2 emissions in Russia, only half of which emitted by power plants. Combustion of natural gas accounts for about half of total fossil-fuel-related emissions. In Russia, 70% of fuel combustion emissions are emitted by coal, oil and gas production sector. The table also shows that half of the total combustion-related emissions are from coal combustion in fuel production, while one fifth is from gas consumption for power generation.

The decrease in CO_2 emissions in 2015 was mainly due to a decrease in the consumption of oil by 5.2%, and natural gas by 5.0% (BP, 2016). In particular, the production of heavy residual fuel oil and diesel was reduced considerably, by 21.2% and 5.2%, respectively. Natural gas remains Russia's leading fuel with a share in primary energy consumption of 53%. Coal consumption, in contrast, slightly increased, by 1.3%. Half of the coal is used by so-called autoproducers of electricity and heat (i.e. produced by industries and companies for building management) (IEA, 2014). Renewable energy (excluding hydropower) still represents an insignificant fraction of the fuel for primary energy consumption (less than 0.02%). Nuclear power production increased in 2015 by 8%, compared to 2014, but this positive effect on CO_2 emissions was partially cancelled by a decrease in hydropower of -3% (BP, 2016). The decrease in natural gas consumption was also related to the relatively mild winter in 2015 (see Annex 4), whereas the decrease in hydropower may have been caused by droughts in Russia (as in the rest of the world).

The fleet of coal plants in Russia is the fifth largest in the world and is expanding for export to China. Russia is constructing a 1,350 MW power plant, at the Erkovetskaya site near the Chinese border, and more plants for a further 8,000 MW have been announced and permitted (Shearer et al., 2016). These plants should not only become the world largest, but would also be targeted at supplying the Beijing grid (which requires the construction of 2000 km of transmission lines).

Oil production in Russia grew by another 1.2% (doubling the growth rate of 2014), but mainly for exports. In 2015, about 47% of the produced oil was exported: 29% to Europe and 8% to China. In addition, 52% of the oil products (3.5 percentage points more than in 2014) were also exported as the government introduced technical regulations modernising oil refineries, which means they have to switch to modern fuel types by 2016 and to cut fuel oil production by a factor of 3 by 2025 (Deloitte, 2014; Lukoil, 2013). Oil production remains a priority for Russia, even though the export saw the opposite trend and declined over the year 2015 (Tradingeconomics, 2016). At the northern coast of Russia, in December 2013, Gazprom began to produce oil, and in 2015 was ready for year-round exports at a production rate of 130,000 barrels/day. In 2016, a new terminal was added and the so-called Arctic Gate started to export crude oil at double the output rate of 260,000 barrels/day. According to Lee (2016), oil export by tanker ships is expected to double in the next five years.

In contrast to the oil production, the natural gas production further declined in 2015 by 1.5% (but halving the negative growth rate of 2014) (BP, 2016). Despite this decline in gas production, Russia increased its natural gas exports to the West by up to 159 billion cubic metres in 2015, which was a 2.3% increase, compared to 2014. Gazprom Export (2016) reported, for 2015, to have supplied 27 billion cubic metres of natural gas to Turkey and 132 billion cubic metres to EU Member States, of which 34% was consumed in Germany, 19% in Italy, 8% in the United Kingdom and less than 7.4% in the remaining countries. Deloitte (2016) reported that, in 2015, the total production drilling market (mainly horizontal drilling for increasing the metreage, i.e. the number of metres drilled) grew by 12%, whereas exploratory drilling decreased by 10%. Western Siberia remains a leader in drilling volumes; however, it is losing its share over other regions, because of problems in well maintenance costs.

2.2.6 Japan

In 2015, Japan further decreased its CO_2 emissions by 2.2%, at almost the same rate as observed in 2014 (down by 2.4%), yielding a share in global CO_2 emissions of 3.5%. The total in CO_2 nevertheless amounted to 1.2 billion tonnes, which is double the total amount of CO_2 emissions in South Korea, the 8th largest emitter. Japan's per capita emissions of 9.9 tonnes CO_2/cap per year are of the same order of magnitude as those of Germany (9.4) and the Netherlands (9.8) (Table 2.8). Japan also has a GDP level that is similar to Germany's (only about 30% higher), which also increased, but only at 0.5% in 2015, compared to 2014. This increase is small but positive, in contrast to that of the year before. It was the first time since 2006 that a positive GDP growth was combined with negative emission growth, giving signs of potential structural changes in the economy, decoupling economic growth from emissions growth.

Table 2.5 shows the shares of fuel types and sectors in fossil-fuel combustion CO_2 emissions in Japan. In 2013, coal combustion by Japan's power plants was responsible for a quarter of the country's total fossil-fuel combustion CO_2 emissions, but also a substantial share was emitted by coal combustion in the manufacturing industry (10%).

BP (2016) reports an increase in the non-fossil fuel-related part of the total primary energy consumption of 1.4 percentage points, which in 2015 yielded a total share of 8.3%. This resulted from the restarting of nuclear energy (after the complete shutdown for full safety revision of all reactors in the aftermath of the Fukushima accident), the 9% increase in hydropower and 25% increase in other renewable energy types. Moreover, oil and natural gas consumption both decreased in 2015 by 3.9%h compared to 2014. Only the consumption of coal increased slightly, with 0.6% in 2015 (BP, 2016).

Since the Fukushima accident of March 2011, 4 of Japan's reactors are up and running again, after they were found to comply with the more stringent safety regulations to address issues dealing with tsunamis and seismic events (IEA, 2016e). In 2015, the Sendai 1 and 2 nuclear power plants were restarted, and, in the first half of 2016, Takahama 3 and Ikata 3 nuclear power plants also came online again. Several more reactors will resume their commercial operations in the coming years, following Japan's strategy to decarbonise and diversify its energy mix in a cost-effective way. In addition, Japan continued to boost solar energy and installed 10 GW of photovoltaic energy in 2015.

Fuel consumption was reduced in the residential sector (by 2.2%). The heavy industry also reduced its process emissions; by 5.0% in the iron and steel industry and by 3.8% in the cement sector. Over the past four years, Japan succeeded in reducing its electricity demand by 10% by increasing energy efficiency, but it did not succeed in reducing its coal consumption (BP, 2016).

Since 2010, only 1 new coal power plant came online in 2013 (1,850 MW), bringing Japan's total in operational coal plants capacity to 44 GW. Even though no new plants came online in 2015, new coal plants with a capacity of 3,060 MW are currently under construction and another 19,050 MW has already been announced and permitted (Global Coal Plant Tracker, 2016). Shearer et al. (2016) reported an increase in coal imports for Japan of 4.8% to an import record of 114 million tonnes of coal in 2015. Pressure against increased coal use resulted in challenging two coal-fired power plant proposals in Japan and in limiting the country's support for overseas coal plants.

In 2015, Japan decreased its imports of crude oil and oil products by 0.8%, and its gas imports by 4.0%, compared to 2014. Nevertheless, Japan remained the world's largest natural gas importer in 2015, with a share of 11.3% from the total in gas traded globally, equalling 118 billion cubic metres in Liquefied Natural Gas (LNG), followed by Germany that imported gas by pipeline, with a share of 10.0% in the total amount of natural gas traded globally (BP, 2016). The total amount of imported oil represents 7.2% of the total in oil traded globally and equals the amount that India imported in 2015 (BP, 2016).

2.2.7 South Korea

After a significant increase of 8.1% in 2010, CO_2 emissions in South Korea decreased by 0.5% in both 2012 and 2013, remained unchanged in 2014, and increased again by

0.9% in 2015, which was below the average increase over the last ten years (1.7%) (see Figure 2.3). The share of national CO_2 emissions in the global total increased from 1.1% in 1990 to 1.8% in 2005, and decreased slightly again in 2015 (1.7%). This trend is partially explained by the fact that since 1990, national coal consumption increased 3.5 times, increasing the share in the global total from 1.1% to 2.2% in 2015. In the first part of the last decade, the average annual increase in coal consumption was 7.4% and slowed down to 0.3% over the 2012–2015 period (BP, 2016). South Korea has 10.2 GW coal power capacity under construction and cancelled 3.7 GW in 2015, which will be replaced by nuclear energy (Shearer et al., 2016). Table 2.5 shows the shares of fuel types and sectors in fossil-fuel combustion emissions in South Korea. In 2013, coal combustion was responsible for half of total fossil-fuel combustion CO_2 emissions, of which coal combustion by power plants was responsible for the lion's share (40% of total fossil-fuel combustion emissions) .

The economy of South Korea, which is ranked as a high-income OECD country by the World Bank, is supported mainly by service and industrial sectors, which contributed 60% and 38%, respectively, to the nation's GDP in 2014 (World Bank, 2016).

2.2.8 Canada

Table 2.5 shows the shares of fuel types and sectors in fossil-fuel combustion CO_2 emissions in Canada. In 2013, the combustion of oil products was responsible for about half of total fossil-fuel-related CO_2 emissions in Canada, half of which from road transport. Only one fifth of Canada's CO_2 emissions stem from power generation, due the large share of hydropower in Canada's electricity generation (60% in 2015 as shown in Table 3.1).

Canada's share in global CO_2 emissions decreased slowly from 2.1% in 1990, to 1.9% in 2005, and further down to 1.5% in 2015. After decreases during the economic recession of 1.2% in 2008 and 5.6% in 2009, followed by an increase of 1.4% on average over the 2010–2014 period, its CO_2 emissions decreased again by 2.9% in 2015. This is linked with coal consumption, which overall increased by an average 1% between 1990 and 2005 and decreased by 4.1% over the past decade, thus changing the share in total global coal consumption from 1.2% in 1990 to 0.5% in 2015 (BP, 2016). New regulation in Canada requires new coal-fired power plants to include carbon capture and storage (CCS) (Shearer et al., 2016). Canada has a highly service-oriented economy and, according to the World Bank (2016), it is the 10th largest economy in the world.

2.2.9 Brazil

Brazil and Indonesia are the 9th and 10th largest CO_2 emitting countries in our ranking for 2015, because we did not consider the emissions from deforestation and forest fires. Table 2.6 shows the shares of fuel types and sectors in fossil-fuel combustion CO_2 emissions in Brazil. In 2013, the combustion of oil products was responsible for 70% of total fossil-fuel-related CO_2 emissions, of which road transport has a share of 40% in total emissions. Only 17% of Brazil's CO_2 emissions in 2013 stemmed from power generation, due to the large share of hydropower in Brazil's electricity generation (more than 60% in 2015 as shown in Table 3.1).

The CO_2 emissions in Brazil increased, on average, by 3.3% over the last 10 years, with variations from a 6.6% decrease in 2009, to a 13.5% increase in 2010 and to a decrease of 3.8% in 2015. The share in the global total also increased from 1% in 1990 to 1.3% in 2015. Brazil has almost doubled its coal consumption since 1990. Over the last decade, the average increase in coal consumption was 3.6%, with large annual variations such as a decrease of 19.3% in 2009 followed by an increase of 30.2% in 2010. In 2015, coal consumption decreased by 0.8% (BP, 2016). Since 2010, Brazil has added 1.8 GW in new coal power capacity (Shearer et al., 2016). Despite a negative economic growth rate of 3.8% in 2015, Brazil is the ninth largest economy in the world. It developed a services sector, which contributes around 68% to its national GDP, followed by the manufacturing and agricultural sectors with 26% and 6%, respectively (BP, 2016). In 2015, Brazil also added significant, new renewable capacity (REN21, 2016) and had a share of 9.1% in total global hydropower consumption (BP, 2016).

2.2.10 Indonesia

Table 2.6 shows the shares of fuel types and sectors in fossil-fuel combustion CO_2 emissions in Indonesia. In 2013, the combustion of oil products was responsible for half of total fossil-fuel combustion CO_2 emissions, whereas coal combustion accounted for one third.

Indonesia increased its share in total global CO_2 emissions from 0.6% in 1990 to 1.2% in 2005 and 1.4% in 2015. Since 1990, the only decline in CO_2 emissions has been recorded for 2008 (0.6%); in 2015, the increase was 4%, which was above the average over the last 10 years (3.4%). Coal consumption in Indonesia increased continuously, at an average rate of 15.5% per year, between 1990 and 2007, then decreased by 13% in 2008 and increased again by 14.4%, on average, between 2009 and 2015. The share of national coal consumption in total global coal consumption was 0.2% in 1990 and by 2015 had reached a share of 2.2% (BP, 2016). Although, in Indonesia, there is considerable resistance to new coal development, since 2010 the country has added 11.8 GW in new coal power capacity and has cancelled 5.5 GW of old plans for additional coal power capacity (Shearer et al., 2016).

2.2.11 Saudi Arabia

Table 2.6 shows the shares of fuel types and sectors in fossil-fuel combustion CO_2 emissions in Saudi Arabia. In 2013, the combustion of oil products was responsible for about 70% of total fossil-fuel combustion CO_2 emissions, and the remaining 30% was from the combustion of natural gas. Because of the abundance of oil and natural gas reserves, Saudi Arabia does not use coal as a fuel. In 2013, 45% of its national total CO_2 emissions were from power generation and one quarter of total CO_2 emissions stems from oil-fired power production.

Over the last decade, CO_2 emissions in Saudi Arabia increased by 5.2%, on average. In 2015, the increase was 3.9%; the largest increases were reached in 2008, 2009 and 2010 (7.5% each year) and the smallest increase was in 2013 (0.8%). The share of its national CO_2 emissions in the global total increased, steadily, from 0.7% in 1990, to 1% in 2005 and to 1.4% in 2015. Regarding its economy, the Public Investment Fund provided support to important sectors such as the petroleum refineries, the petrochemical industry and the energy sector, and future perspectives shows a move towards a more diverse and sustainable economy (Investopedia, 2016; Saudi Vision 2030, 2016).

2.2.12 G20 countries

The G20 consists of Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, South Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, United Kingdom, United States and the European Union. As a whole, the G20 was responsible for 81.5% of global CO_2 emissions in 2015.

Table 2.3 shows the shares of fuel types and sectors in fossil-fuel-related CO_2 emissions in the group of G20 countries. In 2013, coal combustion was responsible for more than half of the total fossil-fuel-related CO_2 emissions. Over one third of the G20 group's total in CO_2 emissions were from power generation.

The share of the G20 in the global total decreased by 0.4% in 2015, compared to 2014. Over the last 10 years, CO_2 emissions in the G20 increased by 20%, with an annual average of 1.9%. In 2015, the 10 largest CO_2 emitters among the G20 are China, the United States, the European Union, India, the Russian Federation, Japan, South Korea, Canada, Brazil, Indonesia and Saudi Arabia, Together these 10 accounted for 93.6% of the total in CO_2 emissions from the G20.

2.2.13 Other remaining countries

The remaining 194 non-G20 countries, collectively, contributed 14.6% to global CO_2 emissions in 2015. Table 2.3 shows the shares of fuel types and sectors in fossil-fuel combustion CO_2 emissions in this large group of mostly non-OECD countries. Compared to the G20, this group had a very low share (30%) of coal-combustion-related CO_2 emissions in the group's total CO_2 emissions from fossil-fuel combustion in 2013. In that year, power generation accounted for 30% of the group's total fossil-fuel combustion CO_2 emissions.

The eight largest emitting countries in this group, contributing 6.2 percentage points to the group's total, are (share in global total in brackets): Iran (1.7%), Taiwan (0.8%), Thailand (0.8%), Kazakhstan (0.7%), Malaysia (0.7%), Ukraine (0.6%), Egypt (0.6%) and Nigeria (0.2%). Over the last decade, the CO_2 emissions in these eight countries increased by 10.3%, with an annual average of 1.4%. For the rest of the countries in this group of 'other countries', the increase was 33%, over the last 10 years, with an annual average increase of 3.2%.

2.3 Comparison of emissions in the various countries

Although emissions in China, India and other countries with emerging economies increased very rapidly in recent years (Table 2.7 and Figure 2.2), in both relative and absolute figures, the picture is different for CO_2 emissions per capita (see Table 2.8 and Figure 2.4) and per unit of GDP (Figure 2.13). Where, since 1990, in the European Union CO_2 emissions decreased from 9.2 to 6.9 tonnes per capita, and in the United States from 19.8 to 16.1 tonnes per capita, they increased in China from 2.0 to 7.7. As such, Chinese citizens, together representing 19% of the world population in 2015, on average emitted about 0.8 tonne of CO_2 per capita more in 2015 as the average European citizen. In contrast, India's emissions of 1.9 tonnes per capita are 5 tonnes per capita lower than the EU average.

The trends in CO_2 *emissions per capita* in the top 5 emitting countries and the EU-28 are shown in Figure 2.14 (left). These trends reflect a number of factors, including the large economic developments in China, structural changes in national and global economies, the impacts of major economic downturns for example such as those in the Russian Federation in the early 1990s, in the United States in 2008, 2009 and 2011, and in Europe in 2009 (for the whole of the EU-28) and 2011 and 2012 (mainly in some EU-15 countries).

In the lowest levels of CO_2 per capita of OECD-1990 countries in 2015 are those of France (5.1 tonnes CO_2/cap because of the amount of nuclear energy used in that country) and the highest levels were seen in Australia (18.6 tonnes CO_2/cap because of its very high share of coal

Table 2.3

CO_2 emissions from fossil fuel combustion in 2013, by sector and fuel, globally, in the G20 and in other countries (source: IEA, 2015c)

World	Total	Coal	Oil	Gas	Other	Total	Coal	Oil	Gas	Other
Total sectors (Mt CO_2)	**32,190**	**14,796**	**10,825**	**6,381**	**175**	**100%**	**46%**	**34%**	**20%**	**1%**
Power and heat generation *	**13,656**	9,887	887	2,753	128	42%	31%	3%	9%	0%
Other energy industry own use	**1,674**	423	548	702	1	5%	1%	2%	2%	0%
Manufacturing industry **	**6,115**	3,867	983	1,223	42	19%	12%	3%	4%	0%
Road transport	**5,547**		5,464	83		17%		17%	0%	
Other transport ***	**1,838**		1,683	143		6%		5%	0%	
Residential sector	**1,869**	294	576	998	0	6%	1%	2%	3%	0%
Other buildings ****	**1,492**	326	683	478	5	5%	1%	2%	1%	0%

G20	Total	Coal	Oil	Gas	Other	Total	Coal	Oil	Gas	Other
Total sectors (Mt CO_2)	**26,315**	**13,811**	**7,577**	**4,747**	**167**	**100%**	**52%**	**29%**	**18%**	**1%**
Power and heat generation *	**11,883**	9,273	488	2,001	121	45%	35%	2%	8%	0%
Other energy industry own use	**1,315**	406	455	453	1	5%	2%	2%	2%	0%
Manufacturing industry **	**5,212**	3,556	724	892	40	20%	14%	3%	3%	0%
Road transport	**4,450**		4,400	50		17%		17%	0%	
Other transport ***	**678**		541	125		3%		2%	0%	
Residential sector	**1,522**	277	446	799	0	6%	1%	2%	3%	0%
Other buildings ****	**1,253**	298	524	426	4	5%	1%	2%	2%	0%

Other countries (non-G20)	Total	Coal	Oil	Gas	Other	Total	Coal	Oil	Gas	Other
Total sectors (Mt CO_2)	**5,875**	**986**	**3,247**	**1,634**	**9**	**100%**	**17%**	**55%**	**28%**	**0%**
Power and heat generation *	**1,772**	614	399	752	7	30%	10%	7%	13%	0%
Other energy industry own use	**359**	16	93	249		6%	0%	2%	4%	
Manufacturing industry **	**902**	311	259	331	1	15%	5%	4%	6%	0%
Road transport	**1,097**		1,064	33		19%		18%	1%	
Other transport ***	**1,160**		1,142	17		20%		19%	0%	
Residential sector	**346**	17	131	199		6%	0%	2%	3%	
Other buildings ****	**239**	28	159	52	0	4%	0%	3%	1%	0%

* Includes public power and heat production

** Excludes emissions from non-energy use and feedstock use of fuels

*** Excludes international marine and aviation bunkers, except for the world, where these are included in transport

**** Service sector; includes agriculture and forestry

in power generation). The per-capita CO_2 emissions in the United States decreased from 16.6 in 2014 to 16.1 tonnes CO_2/cap in 2015, and decreased in Japan to 9.9 tonnes CO_2/cap.

When comparing CO_2 trends between countries over a decade or more, trends in population numbers also should be taken into account, as population growth differs considerably, also between developed countries, with the highest growth rate since 1990 seen in Australia (40% between 1990 and 2015), in Canada (30%) and in the United States (27%). The populations of the European Union and Japan, however, increased much less (by 6.8% and 3.5%, respectively), and the Russian Federation even saw a decline of 2.8%. In comparison, the population of China increased by 19.2%, India 50.6% and Brazil 38.2% since 1990 (see Table 2.8).

The CO_2 emissions from G20 countries[1] (see Section 2.2.12) increased in the period from 1990 to 2015 by 60%. From 2014 to 2015 CO_2 emissions decreased with 0.5%. Of the total world population, 82% is living in countries which are member of the G20. The per-capita CO_2 emissions of G20 countries increased from 5.0 (1990) to 6.3 (2015) tonnes CO_2/cap, almost identical to the United Kingdom (6.2 tonnes CO_2/cap in 2015). The group of G20 countries account for 80% of the global GDP. Per unit of GDP emissions decreased with 28% in the 1990–2015 period.

The remaining 194 countries account for 14.6 % to global CO_2 emissions in 2015 (excluding international bunkers).

Table 2.4

CO_2 emissions from fossil fuel combustion in 2013, by sector and fuel, in China, the United States, the European Union and India (source: IEA, 2015c)

China	Total	Coal	Oil	Gas	Other	Total	Coal	Oil	Gas	Other
Total sectors (Mt CO_2)	**8,909**	**7,433**	**1,145**	**299**	**32**	**100%**	**83%**	**13%**	**3%**	**0%**
Power and heat generation *	4,353	4,251	15	56	32	49%	48%	0%	1%	0%
Other energy industry own use	389	279	61	48		4%	3%	1%	1%	
Manufacturing industry **	2,743	2,484	175	85		31%	28%	2%	1%	
Road transport	610		581	29		7%		7%	0%	
Other transport ***	143	12	131	0		2%	0%	1%	0%	
Residential sector	330	191	75	63		4%	2%	1%	1%	
Other buildings ****	340	215	107	17		4%	2%	1%	0%	

United States	Total	Coal	Oil	Gas	Other	Total	Coal	Oil	Gas	Other
Total sectors (Mt CO_2)	**5,120**	**1,702**	**1,990**	**1,399**	**26**	**100%**	**33%**	**39%**	**27%**	**1%**
Power and heat generation *	2,128	1,596	29	486	18	42%	31%	1%	9%	0%
Other energy industry own use	282	10	109	164		6%	0%	2%	3%	
Manufacturing industry **	422	96	66	252	8	8%	2%	1%	5%	0%
Road transport	1,445		1,443	2		28%		28%	0%	
Other transport ***	256		209	47		5%		4%	1%	
Residential sector	323		54	269		6%		1%	5%	
Other buildings ****	263		80	179		5%		2%	3%	

European Union (EU-28)	Total	Coal	Oil	Gas	Other	Total	Coal	Oil	Gas	Other
Total sectors (Mt CO_2)	**3,340**	**1,128**	**1,290**	**867**	**54**	**100%**	**34%**	**39%**	**26%**	**2%**
Power and heat generation *	1,254	927	50	239	38	38%	28%	1%	7%	1%
Other energy industry own use	156	32	87	36	0	5%	1%	3%	1%	0%
Manufacturing industry **	414	118	85	195	15	12%	4%	3%	6%	0%
Road transport	819		815	3		25%		24%	0%	
Other transport ***	42		38	4		1%		1%	0%	
Residential sector	416	41	115	259	0	12%	1%	3%	8%	0%
Other buildings ****	239	10	99	130	1	7%	0%	3%	4%	0%

India	Total	Coal	Oil	Gas	Other	Total	Coal	Oil	Gas	Other
Total sectors (Mt CO_2)	**1,869**	**1,348**	**447**	**72**	**1**	**100%**	**72%**	**24%**	**4%**	**0%**
Power and heat generation *	945	886	25	32	1	51%	47%	1%	2%	0%
Other energy industry own use	43	3	31	10		2%	0%	2%	1%	
Manufacturing industry **	493	410	66	17		26%	22%	4%	1%	
Road transport	206		203	4		11%		11%	0%	
Other transport ***	16		16			1%		1%		
Residential sector	87	14	66	8		5%	1%	4%	0%	
Other buildings ****	78	36	40	2		4%	2%	2%	0%	

* Includes public power and heat production

** Excludes emissions from non-energy use and feedstock use of fuels

*** Excludes international marine and aviation bunkers

**** Service sector; includes agriculture and forestry

Table 2.5

CO_2 emissions from fossil fuel combustion in 2013, by sector and fuel, in the Russian Federation, Japan, South Korea and Canada (source: IEA, 2015c)

Russian Federation	Total	Coal	Oil	Gas	Other	Total	Coal	Oil	Gas	Other
Total sectors (Mt CO_2)	**1,659**	**425**	**350**	**865**	**19**	**100%**	**26%**	**21%**	**52%**	**1%**
Power and heat generation *	**595**	211	24	360		**36%**	13%	1%	22%	0%
Other energy industry own use	1,164	854	64	229	17	70%	51%	4%	14%	1%
Manufacturing industry **	**293**	109	54	129	1	**18%**	7%	3%	8%	0%
Road transport	**139**		139			8%		8%		
Other transport ***	**96**		33	63		6%		2%	4%	
Residential sector	**98**	6	17	75		**6%**	0%	1%	5%	
Other buildings ****	**81**	54	19	7	1	**5%**	3%	1%	0%	

Japan	Total	Coal	Oil	Gas	Other	Total	Coal	Oil	Gas	Other
Total sectors (Mt CO_2)	**1,235**	**461**	**501**	**260**	**10**	**100%**	**37%**	**41%**	**21%**	**1%**
Power and heat generation *	**594**	316	96	177	5	**48%**	26%	8%	14%	0%
Other energy industry own use	42	20	19	4		**3%**	2%	2%	0%	
Manufacturing industry **	**223**	126	74	18	5	**18%**	10%	6%	1%	0%
Road transport	**192**		192	0		16%		16%	0%	
Other transport ***	**22**		22	-		2%		2%		
Residential sector	**56**		35	21		5%		3%	2%	
Other buildings ****	**106**		64	40		9%		5%	3%	

South Korea	Total	Coal	Oil	Gas	Other	Total	Coal	Oil	Gas	Other
Total sectors (Mt CO_2)	**572.2**	**289.8**	**156.1**	**110.7**	**13.7**	**100%**	**51%**	**27%**	**19%**	**2%**
Power and heat generation *	**304.4**	229.6	17.1	53.5	4.2	**53%**	40%	3%	9%	1%
Other energy industry own use	**41.4**	25.0	15.9	0.5		**7%**	4%	3%	0%	
Manufacturing industry **	74.8	31.6	10.7	23.0	9.4	**13%**	6%	2%	4%	2%
Road transport	**87.7**		84.9	2.8		15%		15%	0%	
Other transport ***	**3.1**		3.1	-		1%		1%		
Residential sector	**33.2**	3.5	8.6	21.1		**6%**	1%	2%	4%	
Other buildings ****	**27.5**	-	15.7	9.8		5%		3%	2%	

Canada	Total	Coal	Oil	Gas	Other	Total	Coal	Oil	Gas	Other
Total sectors (Mt CO_2)	**536.32**	**81.03**	**256.43**	**197.9**	**0.96**	**100%**	**15%**	**48%**	**37%**	**0%**
Power and heat generation *	**104.9**	67.3	6.5	30.9	0.2	**20%**	13%	1%	6%	0%
Other energy industry own use	**91.3**		26.7	64.6		17%		5%	12%	
Manufacturing industry **	**72.6**	13.7	23.8	34.3	0.8	**14%**	3%	4%	6%	0%
Road transport	139.9		139.8	0.1		26%		26%	0%	
Other transport ***	**33.9**		27.5	6.4		6%		5%	1%	
Residential sector	**41.3**	0.1	6.6	34.6		**8%**	0%	1%	6%	
Other buildings ****	52.5		25.5	27.0		10%		5%	5%	

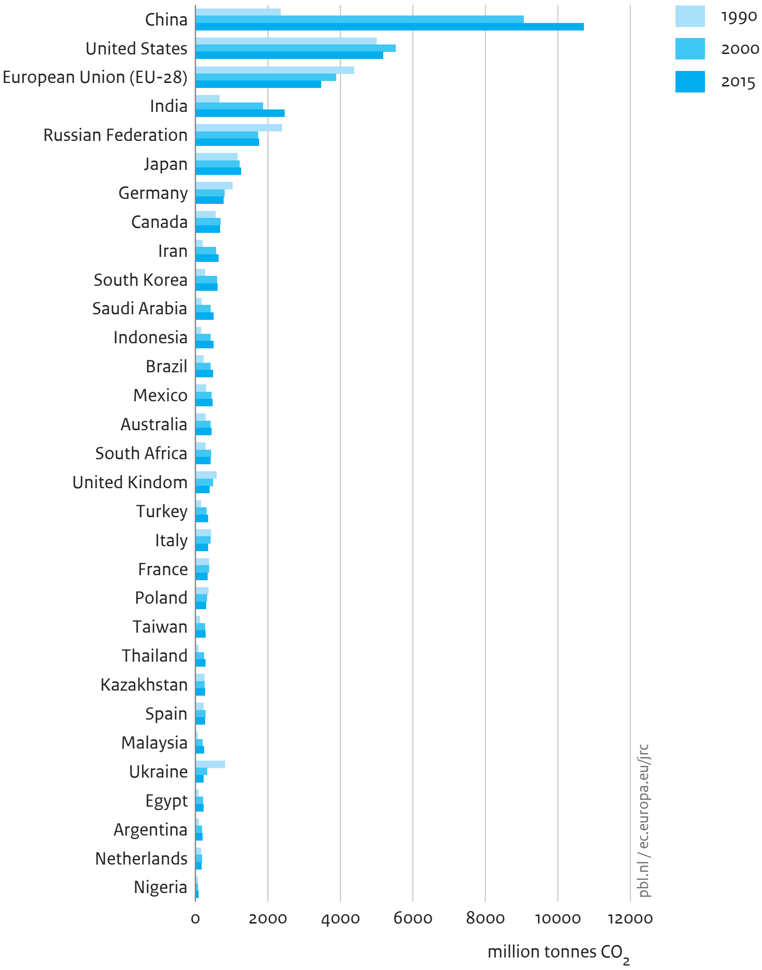
* Includes public power and heat production

** Excludes emissions from non-energy use and feedstock use of fuels

*** Excludes international marine and aviation bunkers

**** Service sector; includes agriculture and forestry

Figure 2.11
CO_2 emissions per country from fossil-fuel use and cement production



Source: EDGAR v4.3.2 FT2015 (JRC/PBL 2016: IEA 2014 (suppl. with IEA 2016 for China, BP 2016, NBS 2016, USGS 2016, WSA 2016, NOAA 2016)

Of the large countries in category per-capita CO_2 emissions in decreased in Kazakhstan (15.8 in 2014 and 15.2 in 2015) and Taiwan (12.0 in 2014 and 11.9 in 2015). On average the other big countries (Egypt, Iran, Kazakhstan, Malaysia, Nigeria, Taiwan, Thailand and the Ukraine per-capita CO_2 emissions decreased from 4.3 in 2014 to 4.2 in 2015. The remaining 186 countries remained constant for 2014 to 2015 at 1.5 tonne per person.Another indicator of the CO_2 intensity of a country is the ratio of CO_2 *emissions over GDP* as shown in Figures 2.14 and 2.15 (right). However, this indicator is much more uncertain than population, as is explained in Box 2.3. For the CO_2 intensity related to GDP of a country (CO_2 per USD of GDP) it is recommended to compare levels between countries and longer term trends only. Main reason is that a substantial contribution to a country's economic activities, and thus to its GDP, is made by the service sector, which is not an energy-intensive activity (see for example Table 2.2). In contrast, in many countries energy-intensive activities such as power generation and fossil fuel production are only contributing a small fraction to total GDP. Therefore, the correlation between annual changes in CO_2 and GDP for a specific year is rather weak, so this indicator should be used best to analyse longer term trends and country-specific CO_2 intensity levels.

Figure 2.14 (right) shows that over the past decade, most top 5 emitting countries and the European Union experienced a declining trend in CO_2 in terms of GDP, but the ranking order of countries more or less remains the same: with a lower emission level in the European Union; medium levels in the United States and India; and higher levels in the Russian Federation and China, the last two emitting relatively high amounts of CO_2 per USD of GDP.

Box 2.3 Uncertainty in Gross Domestic Product (GDP) in USD, in general and in constant Purchasing Power Parity (PPP)

Gross Domestic Product (GDP) is generally more uncertain than population numbers due to different reasons:

- It is more difficult to have complete and accurate statistics because it tries to capture various inhomogeneous economic activities: from large to small, from product manufacture to services, for temporary and permanent businesses. Sometimes revisions of definitions and estimation methods occur, that may lead to changes of several per cent.
- To produce consistent time series with constant prices instead of current prices in the years, all annual data needs to be corrected for inflation. The definition and estimation method of annual inflation is not unambiguous and therefore also adds to uncertainty in the annual GDP at constant prices.
- To compare between countries, GDP in national currency needs to be converted into one common currency unit, for example the USD. Here the annual average exchange rates to the common currency are a cause of uncertainty, even more so when GDP are compared using Purchasing Power Parity (PPP) conversion factor, to correct for differences in purchase power of currencies between countries (sometimes called 'the hamburger' unit).
- Only officially recorded activities may be accounted for in the GDP, or illegal or unrecorded economic activities may have been estimated and accounted for in the GDP, too. The latter can range from a few per cent to much more than 10%.

Although the GDP definition used in this report is the same as in last year's report (GDP at PPP prices in constant USD_{2011}), there may be changes in present historical GDP data over the 1990–2014 period, due to revisions by national statistical bureaus. For example, changes in many OECD countries are below 1%, but for certain countries they are greater. For example, for Spain and the United Kingdom, GDP values for 2013 and 2014 decreased by about 1.5% compared to last year's data set. Of the other G20 countries, China's GDP values went up by about 2%, and Brazil's GDP increased by 3% to 7%, over the whole 1990–2014 time series. Other G20 countries with larger changes are the Russian Federation (up by about 7%) and Indonesia (up by 5%), also over the whole historical time series. Of the other non-G20 countries, Taiwan (with increases of 15% in 2014 and up to 30% in 1990) and Thailand (with an increase of 7% over the whole time series) stand out because of their relatively large increases.

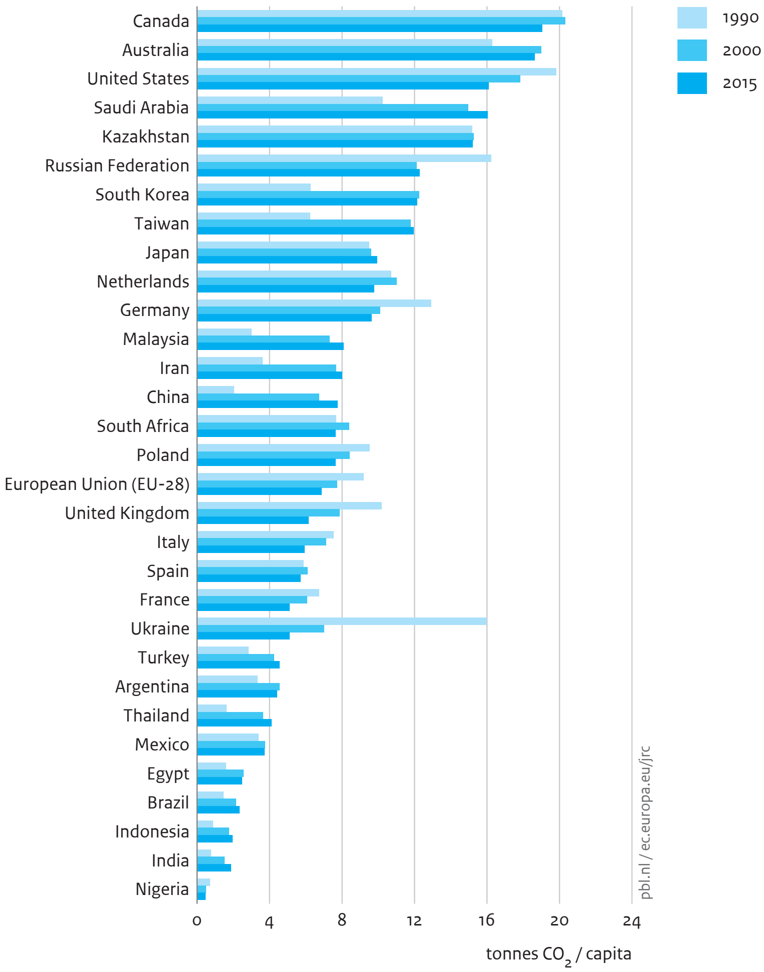
Note that for most OECD countries, World Bank and International Monetary Fund (IMF) GDP statistics do now include the recent revision of the definition of the Gross Domestic Product (GDP) as adopted the updated international guidelines for national economic account in the 2008 UN System of National Accounts ('SNA 2008') (UN, 2009). These revisions include, amongst others, estimates of illegal or otherwise underreported economic activities.

The trends for the Russian Federation and China were less smooth; partially due to very large and fast changes in their economies. Japan is an exception, with more or less the same level of CO_2 per USD in GDP, even over the last two decades. In 2015, the emission intensity of the European Union was about 60% of the United States and about one third of China. The higher levels for the Russian Federation and China indicated a larger share of more energy-intensive economic activities, the use of less energy-efficient technologies, a larger share of coal in the energy mix, or a combination of these factors. This is also the case for the Ukraine, which is depicted in Figure 2.13 as the country with the largest emissions related to GDP. The 3.4% global economic growth in 2014 and 3.0% in 2015 was about two-thirds of the average growth level since 2004 (4.3% per year), excluding the recession years 2008 and 2009.

Note that GDP is much more uncertain than population as a measure for comparing CO_2 intensities over time or between countries, due differences in definition, methodology, interpretation and estimates which are involved in calculating total GDP of a country as well as correcting GDP for annual inflation. And more uncertainty is added when converting GDP to a common currency for comparisons between countries. Whether it is market exchange rate or Purchasing-Power-Parity (PPP), all have their limitations. For example, the recent changes in the definition of GDP according to UN agreements resulted into changes up to 5% for some countries.
These elements add further uncertainty to the comparisons of CO_2 intensities relative to GDP between countries (see Box 2.3).

Figure 2.12 and Table 2.8 shows the change in per capita CO_2 emissions for 1990–2015 and of population for a numbers of countries. The emissions are excluding

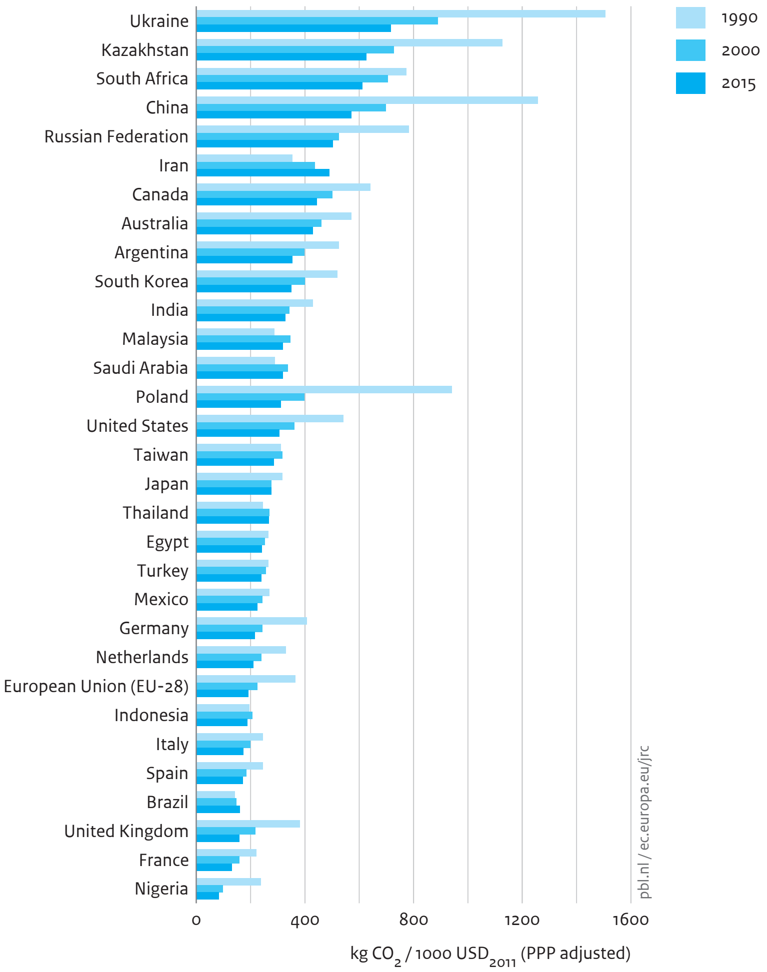
Figure 2.12
CO_2 emissions per capita from fossil-fuel use and cement production



Source: EDGAR v4.3.2 FT2015 (JRC/PBL 2016: IEA 2014 (suppl. with IEA 2016 for China, BP 2016, NBS 2016); UNPD 2015 (WPP, Rev. 2015)

LULUCF emissions ('IPCC sector 5'). These tables and the numbers used in Figure 2.1 to 2.15 can also be found as a spreadsheet on the PBL website: http://www.clo.nl/nl0533 and on the EDGAR website at JRC: http://edgar.jrc.ec.europa.eu

Figure 2.13
CO_2 emissions per unit of GDP from fossil-fuel use and cement production



Source: EDGAR v4.3.2 FT2015 (JRC/PBL 2016: IEA 2014 (suppl. with IEA 2016 for China, BP 2016, NBS 2016); World Bank 2016; IMF 2016

Table 2.7

Trends in CO_2 emissions per country/group, 1990-2015 (unit: billion tonnes of CO_2) also available on http://edgar.jrc.ec.europa.eu/overview.php?v=CO2ts1990-2015

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
China[1]	**2.4**	**2.5**	**2.6**	**2.9**	**3.1**	**3.4**	**3.4**	**3.4**	**3.5**	**3.4**	**3.7**	**3.9**
United States[1]	**5.0**	**5.0**	**5.0**	**5.2**	**5.2**	**5.3**	**5.5**	**5.6**	**5.7**	**5.7**	**5.9**	**5.8**
European Union (EU-28)[1]	**4.4**	**4.3**	**4.2**	**4.1**	**4.1**	**4.1**	**4.2**	**4.1**	**4.1**	**4.1**	**4.1**	**4.2**
France[1]	0.38	0.41	0.40	0.38	0.37	0.38	0.39	0.39	0.41	0.41	0.40	0.41
Germany[1]	1.02	0.99	0.94	0.93	0.92	0.91	0.94	0.91	0.90	0.87	0.86	0.88
Italy[1]	0.43	0.43	0.43	0.42	0.41	0.44	0.43	0.44	0.45	0.45	0.46	0.46
Netherlands	0.16	0.17	0.17	0.17	0.17	0.17	0.18	0.17	0.18	0.17	0.17	0.18
Poland	0.36	0.36	0.35	0.34	0.33	0.36	0.37	0.36	0.34	0.33	0.31	0.31
Spain	0.23	0.24	0.25	0.23	0.24	0.25	0.24	0.26	0.27	0.30	0.31	0.31
United Kingdom[1]	0.58	0.59	0.58	0.56	0.56	0.55	0.57	0.55	0.55	0.54	0.55	0.56
India[1]	**0.7**	**0.7**	**0.7**	**0.8**	**0.8**	**0.9**	**0.9**	**1.0**	**1.0**	**1.1**	**1.1**	**1.1**
Russian Federation[1]	**2.4**	**2.4**	**2.2**	**2.0**	**1.8**	**1.8**	**1.7**	**1.6**	**1.6**	**1.7**	**1.7**	**1.7**
Japan[1]	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.3**	**1.2**	**1.2**	**1.2**	**1.3**	**1.2**
Other OECD countries G20[2]	**1.7**	**1.8**	**1.8**	**1.9**	**2.0**	**2.1**	**2.1**	**2.2**	**2.2**	**2.3**	**2.4**	**2.4**
Australia[1]	0.28	0.28	0.28	0.29	0.29	0.30	0.31	0.32	0.34	0.35	0.36	0.37
Canada[1]	0.56	0.56	0.58	0.59	0.62	0.66	0.65	0.65	0.69	0.68	0.73	0.74
Mexcio[1]	0.29	0.32	0.32	0.31	0.33	0.32	0.33	0.35	0.37	0.36	0.38	0.38
South Korea[1]	0.27	0.30	0.31	0.34	0.37	0.40	0.43	0.45	0.39	0.42	0.48	0.49
Turkey[1]	0.15	0.16	0.16	0.17	0.17	0.18	0.19	0.21	0.21	0.21	0.23	0.21
Other G20 countries	**0.9**	**1.0**	**1.0**	**1.0**	**1.1**	**1.1**	**1.2**	**1.3**	**1.3**	**1.3**	**1.4**	**1.4**
Argentina[1]	0.11	0.11	0.12	0.12	0.12	0.12	0.14	0.14	0.14	0.15	0.15	0.14
Brazil[1]	0.22	0.23	0.23	0.24	0.25	0.27	0.29	0.31	0.31	0.32	0.34	0.34
Indonesia[1]	0.16	0.17	0.18	0.20	0.21	0.24	0.25	0.27	0.28	0.29	0.29	0.32
Saudi Arabia[1]	0.17	0.17	0.19	0.20	0.21	0.22	0.23	0.23	0.24	0.25	0.26	0.27
South Africa[1]	0.28	0.28	0.29	0.28	0.29	0.30	0.31	0.33	0.33	0.31	0.32	0.31
Total Group of Twenty (G20)[3]	**18.5**	**18.6**	**18.6**	**18.8**	**19.1**	**19.7**	**20.1**	**20.3**	**20.4**	**20.5**	**21.2**	**21.4**
Other large countries	**1.7**	**1.7**	**1.7**	**1.6**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**1.6**	**1.6**	**1.7**
Egypt	0.09	0.09	0.09	0.10	0.09	0.10	0.11	0.11	0.12	0.12	0.12	0.13
Iran	0.20	0.22	0.24	0.24	0.27	0.28	0.29	0.30	0.30	0.33	0.35	0.37
Kazakhstan	0.25	0.26	0.27	0.23	0.21	0.18	0.16	0.14	0.14	0.13	0.14	0.13
Malaysia	0.06	0.07	0.07	0.08	0.08	0.09	0.10	0.11	0.10	0.11	0.12	0.13
Nigeria	0.07	0.08	0.08	0.08	0.07	0.08	0.09	0.09	0.08	0.08	0.09	0.10
Taiwan	0.13	0.14	0.14	0.15	0.16	0.17	0.18	0.20	0.21	0.21	0.23	0.24
Thailand	0.09	0.10	0.11	0.13	0.14	0.16	0.18	0.18	0.16	0.17	0.17	0.18
Ukraine	0.82	0.77	0.68	0.60	0.49	0.50	0.42	0.40	0.39	0.39	0.39	0.38
Remaining countries (186)[4]	**1.7**	**1.7**	**1.6**	**1.6**	**1.6**	**1.7**	**1.7**	**1.8**	**1.8**	**1.8**	**1.9**	**1.9**
International transport	**0.63**	**0.64**	**0.67**	**0.67**	**0.69**	**0.72**	**0.74**	**0.76**	**0.79**	**0.82**	**0.85**	**0.82**
Total	**22.7**	**22.8**	**22.7**	**22.9**	**23.1**	**23.8**	**24.3**	**24.6**	**24.8**	**24.9**	**25.8**	**26.1**

1 Member of the Group of Twenty (G20). The European Union (EU-28) is also a member.

2 'Other OECD countries G20 (5)' exclude six not listed OECD countries which total emissions comprise about 10% of this group: Chili, Iceland, Israel, New Zealand, Norway and Switzerland.

3 Total emissions of the Group of Twenty (G20) comprises the sum of the five countries and the EU in bold + five listed under 'Other OECD countries' and five listed non-OECD countries. In other words, it is the sum of all countries/EU labelled [1], excluding the four EU-28 countries that are also member of the G20 to avoid double counting.

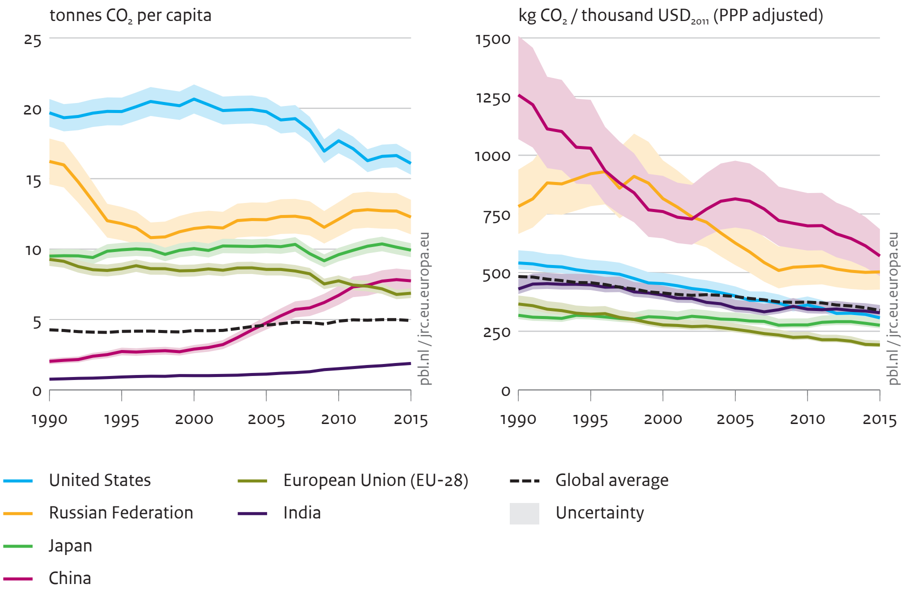
4 Total emissions of 'Remaining countries (186)' comprises the sum of all countries minus G20 and minus the six 'Other big countries', and includes six not listed small OECD countries.

2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
4.2	4.8	5.6	6.2	6.9	7.6	7.8	8.3	9.1	9.9	10.1	10.6	10.8	10.7
5.8	5.8	5.9	5.9	5.8	5.9	5.7	5.2	5.5	5.4	5.2	5.3	5.3	5.2
4.1	4.2	4.3	4.2	4.2	4.2	4.1	3.8	3.9	3.7	3.7	3.6	3.4	3.5
0.40	0.41	0.41	0.41	0.40	0.40	0.39	0.37	0.38	0.35	0.35	0.36	0.33	0.33
0.86	0.86	0.86	0.83	0.84	0.82	0.83	0.77	0.81	0.79	0.80	0.82	0.77	0.78
0.47	0.48	0.49	0.49	0.49	0.48	0.47	0.41	0.42	0.41	0.40	0.36	0.34	0.35
0.18	0.18	0.18	0.18	0.17	0.18	0.18	0.17	0.18	0.17	0.17	0.17	0.16	0.17
0.30	0.31	0.31	0.31	0.32	0.32	0.32	0.30	0.33	0.32	0.31	0.30	0.29	0.30
0.33	0.34	0.35	0.37	0.36	0.37	0.34	0.30	0.29	0.29	0.28	0.25	0.25	0.26
0.54	0.56	0.56	0.56	0.56	0.55	0.53	0.48	0.49	0.46	0.47	0.46	0.42	0.40
1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.8	1.9	2.0	2.1	2.2	2.3	2.5
1.7	1.7	1.7	1.7	1.8	1.8	1.7	1.7	1.7	1.8	1.8	1.8	1.8	1.8
1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.3
2.5	2.5	2.6	2.6	2.6	2.7	2.7	2.7	2.7	2.8	2.8	2.8	2.9	2.8
0.38	0.39	0.41	0.41	0.41	0.43	0.43	0.44	0.42	0.43	0.43	0.43	0.44	0.45
0.75	0.72	0.74	0.73	0.70	0.72	0.73	0.68	0.69	0.69	0.70	0.71	0.71	0.68
0.38	0.39	0.40	0.42	0.43	0.44	0.44	0.43	0.45	0.46	0.48	0.49	0.48	0.47
0.50	0.50	0.52	0.52	0.53	0.54	0.55	0.56	0.60	0.62	0.62	0.61	0.61	0.62
0.22	0.23	0.24	0.25	0.28	0.30	0.30	0.30	0.31	0.33	0.34	0.33	0.35	0.36
1.4	1.5	1.5	1.6	1.6	1.7	1.8	1.8	1.9	1.9	2.0	2.0	2.1	2.1
0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.18	0.19	0.19	0.19	0.19	0.19	0.19
0.34	0.34	0.35	0.36	0.36	0.38	0.40	0.37	0.42	0.44	0.46	0.49	0.51	0.49
0.32	0.35	0.36	0.36	0.38	0.40	0.40	0.41	0.42	0.43	0.44	0.45	0.48	0.50
0.28	0.30	0.29	0.31	0.32	0.34	0.36	0.39	0.42	0.44	0.46	0.46	0.49	0.51
0.32	0.35	0.38	0.40	0.41	0.43	0.45	0.43	0.43	0.42	0.41	0.42	0.43	0.42
21.8	22.8	23.8	24.6	25.4	26.3	26.3	26.1	27.6	28.6	28.8	29.4	29.7	29.5
1.7	1.8	1.9	2.0	2.0	2.1	2.2	2.1	2.2	2.2	2.2	2.3	2.3	2.2
0.14	0.14	0.15	0.17	0.18	0.19	0.20	0.20	0.21	0.22	0.23	0.22	0.22	0.23
0.38	0.40	0.43	0.47	0.50	0.53	0.54	0.57	0.57	0.58	0.59	0.60	0.63	0.63
0.15	0.16	0.18	0.19	0.22	0.23	0.26	0.23	0.25	0.27	0.26	0.27	0.27	0.27
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
0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.07	0.08	0.09	0.08	0.08	0.08	0.09
0.25	0.26	0.26	0.27	0.28	0.28	0.27	0.26	0.27	0.27	0.27	0.28	0.28	0.28
0.19	0.20	0.22	0.23	0.23	0.23	0.24	0.23	0.24	0.25	0.26	0.27	0.28	0.28
0.38	0.39	0.38	0.37	0.37	0.38	0.36	0.30	0.32	0.34	0.33	0.32	0.28	0.23
2.0	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.7	2.8	2.8	2.9	3.1
0.86	0.86	0.95	1.00	1.05	1.09	1.10	1.05	1.12	1.15	1.09	1.11	1.12	1.15
26.6	27.7	29.0	30.0	31.0	32.2	32.4	32.0	33.9	34.9	35.2	35.9	36.3	36.2

Figure 2.14

CO_2 emissions from fossil-fuel use and cement production in the top 5 emitting countries and European Union

Per capita | Per unit of GDP

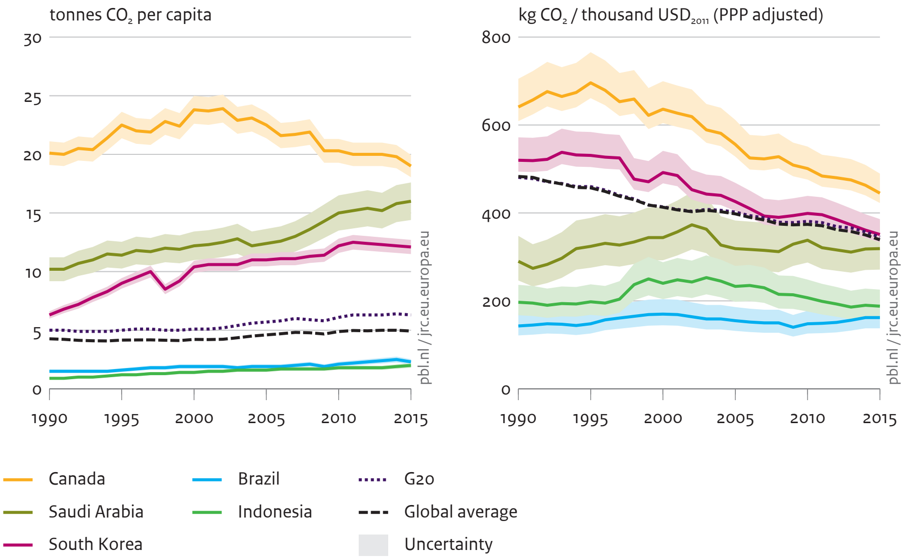


Source: EDGAR v4.3.2 FT2015 (JRC/PBL 2016: notably IEA 2014 (suppl. with BP 2016, NBS 2016); UNPD 2015 (WPP, Rev. 2015)

Figure 2.15

CO_2 emissions from fossil-fuel use and cement production in the top 6 to 10 emitting countries and the G20

Per capita | Per unit of GDP



Source: EDGAR v4.3.2 FT2015 (JRC/PBL 2016: notably IEA 2014 (suppl. with BP 2016, NBS 2016); World Bank 2016; IMF 2016

Table 2.8

CO_2 emissions in 2015 (million tonnes CO_2) and CO_2/cap emissions, 1990–2015 (tonnes CO_2 per person)

Country	Emissions 2015	CO_2/cap in 1990	CO_2/cap in 2000	CO_2/cap in 2010	CO_2/cap in 2013	CO_2/cap in 2014	CO_2/cap in 2015	Change '90-'15	Change '90-'15 in %	Change in CO_2 1990-2015 in %	Change in population 1990-2015 in %
China[1]	10,720	2.0	2.9	6.7	7.7	7.8	7.7	5.7	281%	355%	19%
United States[1]	5,180	19.8	20.8	17.8	16.6	16.6	16.1	-3.7	-19%	3%	27%
European Union[1]	3,470	9.2	8.4	7.7	7.2	6.8	6.9	-2.3	-25%	-21%	6%
Germany[1]	780	12.9	10.5	10.1	10.1	9.6	9.6	-3.3	-25%	-24%	2%
United Kingdom[1]	400	10.2	9.3	7.9	7.1	6.5	6.2	-4.0	-39%	-31%	13%
Italy[1]	350	7.5	8.0	7.1	6.1	5.6	5.9	-1.6	-21%	-17%	5%
France[1]	330	6.7	6.7	6.1	5.6	5.1	5.1	-1.6	-24%	-14%	13%
Poland	300	9.5	8.2	8.4	7.9	7.5	7.6	-1.9	-20%	-19%	1%
Spain	260	5.9	7.6	6.1	5.4	5.3	5.7	-0.2	-3%	14%	18%
Netherlands	170	10.7	10.8	11.0	10.1	9.5	9.8	-0.9	-9%	3%	13%
India[1]	2,470	0.8	1.0	1.5	1.7	1.8	1.9	1.1	147%	272%	51%
Russian Federation[1]	1,760	16.2	11.5	12.1	12.7	12.7	12.3	-4.0	-24%	-26%	-3%
Japan[1]	1,260	9.5	10.0	9.6	10.4	10.1	9.9	0.4	4%	8%	4%
Canada[1]	680	20.1	23.8	20.3	20.0	19.8	19.0	-1.1	-5%	23%	30%
Iran	630	3.6	5.3	7.7	7.8	8.0	8.0	4.4	123%	214%	41%
South Korea[1]	620	6.3	10.4	12.2	12.3	12.2	12.1	5.9	93%	129%	17%
Saudi Arabia[1]	510	10.2	12.2	15.0	15.2	15.8	16.0	5.8	56%	201%	93%
Indonesia[1]	500	0.9	1.4	1.8	1.8	1.9	2.0	1.1	122%	214%	42%
Brazil[1]	490	1.5	1.9	2.1	2.4	2.5	2.3	0.9	60%	120%	38%
Mexico[1]	470	3.4	3.7	3.8	3.9	3.8	3.7	0.3	10%	63%	48%
Australia[1]	450	16.3	18.8	19.0	18.4	18.6	18.6	2.3	14%	60%	40%
South Africa[1]	420	7.7	7.1	8.4	7.9	8.0	7.7	0.0	0%	47%	48%
Turkey[1]	360	2.8	3.6	4.3	4.3	4.5	4.5	1.7	60%	132%	46%
Taiwan	280	6.2	10.6	11.8	11.9	12.0	11.9	5.7	92%	121%	16%
Thailand	280	1.6	2.7	3.7	4.0	4.1	4.1	2.5	151%	200%	20%
Kazakhstan	270	15.2	9.2	15.3	15.6	15.8	15.2	0.0	0%	7%	7%
Malaysia	250	3.0	5.3	7.3	7.9	7.9	8.1	5.1	168%	345%	67%
Ukraine	230	16.0	8.0	7.0	7.0	6.1	5.1	-10.9	-68%	-72%	-13%
Egypt	230	1.6	1.8	2.6	2.5	2.5	2.5	0.9	55%	152%	62%
Argentina[1]	190	3.3	3.9	4.5	4.4	4.4	4.4	1.1	32%	75%	33%
Nigeria	90	0.7	0.7	0.5	0.5	0.5	0.5	-0.2	-34%	26%	91%
Global total	36,250	4.3	4.2	4.9	5.0	5.0	4.9	0.7	15%	60%	38%
G20	29,530	5.0	5.1	6.1	6.3	6.4	6.3	1.3	25%	60%	28%
Non-G20	6,720	2.2	1.9	2.1	2.1	2.1	2.1	-0.1	-4%	59%	62%

[1] Member of the Group of Twenty (G20). The European Union (EU-28) is also a member.

Note

1 Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russian Federation, Saudi Arabia, South Africa, South Korea, Turkey, United Kingdom, United States and the European Union.

THREE

How to mitigate CO_2 emissions from energy supply and consumption

3.1 Introduction

CO_2 emissions originate almost for 90% from fossil-fuel combustion and are determined by the elements: energy demand, energy efficiency and fuel mix.

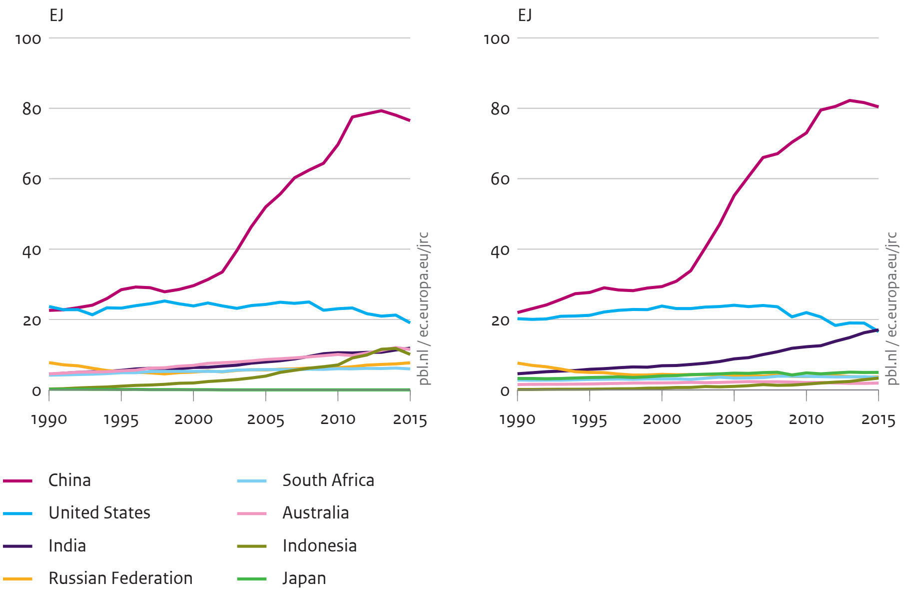
- Historic time series of energy demand indicate a continuous growth, in particular of the level of energy-intensive activities, such as related to power generation, basic materials manufacturing industry and road transport. However, also in other sectors, such as households and the service sector, energy saving is an important factor determining energy demand.
- Increasing energy efficiency has not only been the target of industry, but also of policies and its further strengthening remains important.
- The fuel mix is determining the CO_2 emissions and a change towards less carbon-intensive fuels (e.g. low-carbon gas instead of carbon-intensive coal) and including nuclear or renewable energy resources would be very effective. The renewable energy industry has been emerging over the past two decades, partially with significant policy support.

In addition, energy consumption is affected by certain ambient conditions: warm or cold winters affect the demand for space heating and in some countries hot summers affect the demand for air conditioning. Moreover, the topography, orography, climate and level of technological development of a country affect activities such as distances travelled and the potential for renewable energy such as hydropower and wind, solar and tidal energy or even nuclear energy.

Analysis for a group of IEA countries showed that improved energy efficiency has been the main reason for decoupling total energy consumption from economic growth (IEA, 2008, 2016d). The IEA has published many studies showing and analysing historical improvements in various economic sectors (e.g. IEA, 2008, 2015c,d, 2016d). It was concluded that changes caused by the oil price shocks in the 1970s and the resulting energy policies had a larger impact on the increase in energy demand and reduction in CO_2 emissions than the energy efficiency and climate policies implemented in the 1990s. The IEA estimates that, in 2015, global investment in energy efficiency increased by 6% to USD 221 billion. The global energy intensity, which is the amount of energy used per unit of gross domestic product (GDP), improved by 1.8%. This is more than the 1.5% improvement seen in 2014, and triple the average annual rate (0.6%) seen in the previous decade. The high improvement rate is remarkable, since energy prices were low. The IEA concludes that there is still much scope for further improvements, and underlines the pivotal role of policy in driving energy efficiency (IEA, 2016d). For more detailed information on trends in energy efficiency improvement and on carbon capture and storage (CCS) we refer to the 2013 report (Olivier et al., 2013).

The global energy mix is significantly influenced by the fossil fuel price, as mentioned above, and in particular the relative price differences between coal, oil products and natural gas. The historic increase of the share of natural gas consumption in the total primary energy mix showed stagnation since 2002, not because of the absolute decrease in gas consumption but because of the much higher growth rate of coal consumption, mainly in China. Recent trends in the fossil-fuel mix with shifts from coal to gas[1], or vice versa, in the United States, China and Europe, are very relevant for the overall trend in CO_2 emissions. IEA data for 2013 shows that coal combustion *globally* was responsible for 46% of CO_2 emissions from fossil-fuel combustion, with 31% points emitted from coal-fired power plants, the remaining 15% points emitted mainly from other industrial coal combustion (in cement, iron and steel, chemical industries in particular) but also from some smaller scale combustion in the residential and service sectors. Industry, in particular iron and steel manufacturing, was globally the second largest source of CO_2 responsible for 19%, followed by road transport (17%) (Table 2.3).

Figure 3.1
Main coal producing and consuming countries



Source: BP 2016

Recently, in climate change mitigation policies more emphasis is being placed on the use coal and a phase-out of coal, in particular for power generation, because of its large share in global CO_2 emissions and since coal-fired power plants have large technical lifetimes of several decades. Over the past five years, the G20 – and in particular, the United States, the United Kingdom and Canada – have shown a clearly declining trend in coal power, in terms of cancelled plans, policies and closures announcements (Mandel, 2016). The IEA warns for possible lock-in effects: when coal-fired power plants are built they tend to have long lifetimes (IEA, 2015c). New plants may prevent opportunities for large CO_2 reductions in the near future and provide limited room for other, less carbon-intensive, sources of power generation. Apart from closure of coal-fired plants, CO_2 reduction options are co-firing of biomass, capture and storage (CCS) and improvement of the generation efficiency.

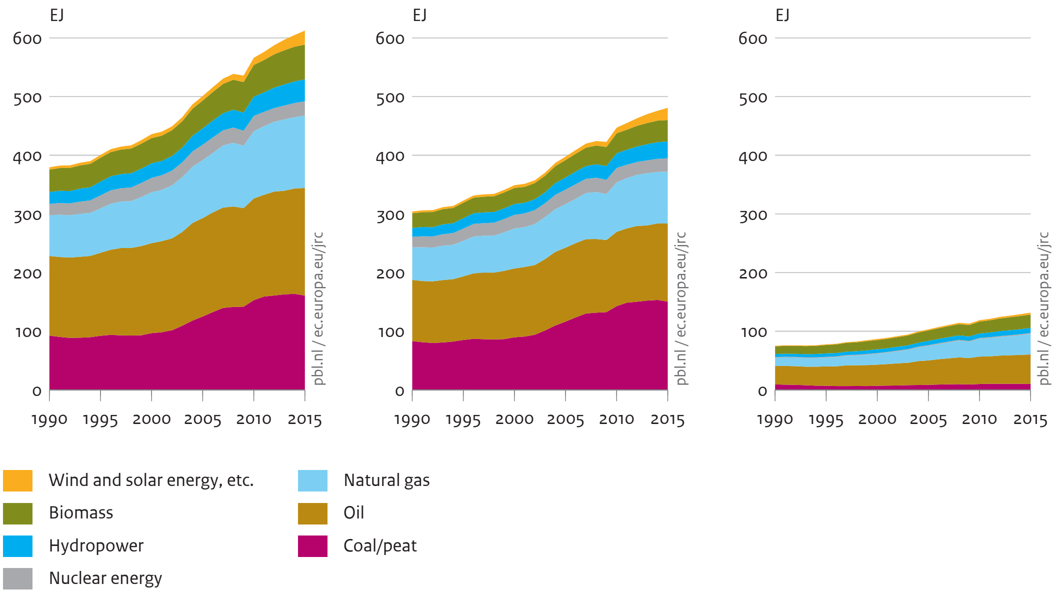
Coal is produced in various countries around the globe, but 95% of global production is concentrated in 25 countries, whereas 90% of global consumption is concentrated in 16 countries (BP, 2016). It is not accidental that the four of the top 6 CO_2 emitting countries are also in the top-6 coal producing and coal consuming countries (see Figure 3.1). The share of coal in the energy mix of the top 5 countries varies from 33% in the United States to 43% in India, 47% in China and 49% in Poland. This leads to shares of coal in CO_2 emissions from fossil fuel combustion varying from 26% (Russian Federation), via 33-34% (United States and European Union), 72% (India) to 83% (China) in 2013 (Table 2.1.b). For more detailed information on the fuel mix and the available large amount of coal in comparison to shale gas and oil resources, we refer to last year's report (Olivier et al., 2015).

Section 3.2 presents general trends in the fossil fuel mix, Section 3.3 shows more detailed trends in renewable energy, and Section 3.4 looks more specifically at changes in nuclear energy.

3.2 Trends in global fossil-fuel consumption and fuel mix

The historical trend in the global primary energy mix as presented in Figure 3.2 shows a steady increase in the share of natural gas consumption in the total primary energy mix between 1970 and the early 2000s.
The stagnation of the natural gas share since 2002 was not due to an absolute decrease in gas consumption, but trend breaks in the relative growth rate of natural gas and oil shares are due to the much higher growth rate of coal consumption since 2002. This strong increase in coal consumption was mainly caused by the rapidly developing economy of China, which shows a quite different primary energy supply mix than that of the

Figure 3.2
Total primary energy supply, per type



Source: IEA 2016; BP 2016

Note: Figures 3.2 to 3.6 were calculated using a substitution method for nuclear, hydro and other non-biomass renewables as in BP 2016 (i.e. assuming 38% conversion efficiency)

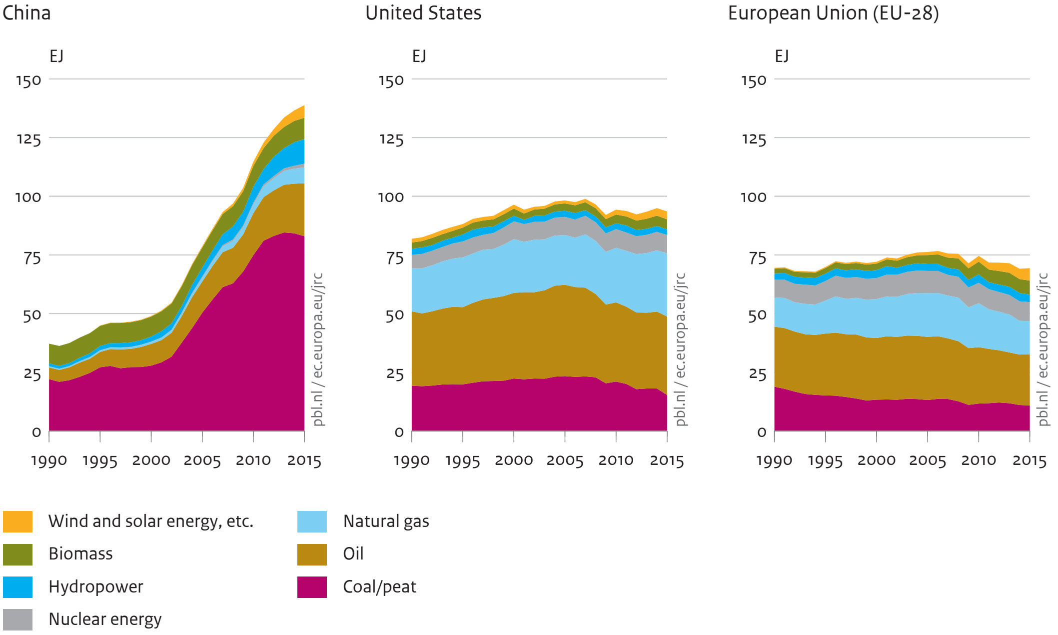
United States and the European Union, as shown in Figure 3.3. In Figures 3.4 to 3.7 the structure and trends in total primary energy supply of other large energy consuming countries is shown, which are part of the G20.

The related CO_2 emissions in 2012 reported by the IEA are given in Tables 2.3 to 2.6. Fossil fuel combustion accounts for about 90.5% of total global CO_2 emissions, excluding those from forest fires and the use of wood fuel (EDGAR 4.3.2; EC-JRC/PBL, 2016). Despite the fact that the global economy continued to grow (3.1%) in 2015 compared to 2014 (IMF, 2016), the CO_2 emissions from global fuel combustion decreased by 0.1%, which is in contrast with the annual CO_2 growth over the past six years (BP, 2016). The diverging pattern of the CO_2 emission trends in OECD and non-OECD countries tends to moderate, with a decrease of 1.5% in OECD countries, which is higher than the average over the last ten years (0.8%), versus a 0.9% increase in non-OECD countries that is far below that of the average of the past decade (3.6%).

Coal consumption

Coal consumption decreased globally by 1.8% in 2015, compared to 2014 (in energy units), which is the greatest decrease on the record according to BP (2016). China, with a share of 50% of global coal consumption, continued to decline 0.8% in 2014 and 1.5% in 2015 for the first time in the last 10 years, confirming the slowdown in the increase in coal consumption in 2012 (1.3%) following the large increases in coal consumption in 2010 and 2011 (3.8% and 8.9%, respectively) and marking a turning point with decreases for two consecutive years. The policies to accelerate the development of service industries (e.g. in 2015 the share of GDP was 50.5% from services, 40.5% from industry and 9% from agriculture) (World Bank, 2016), the new energy and environmental policies (e.g. phasing-out the highly polluting coal-fired boilers), and industry restructuring targeting coal-intensive industries have moderated and reduced the coal consumption in China. If the ongoing action plans are successfully implemented further reductions in coal consumption are expected in the next years e.g. the share of coal in primary energy consumption will be less than 62% by 2020 (IMF, 2016). The accuracy of China's coal consumption data is commonly estimated at about 5% to 15%, with higher uncertainties expected for the data of the past 15 years, as is also shown in recent statistical revisions, which suggest higher historical coal consumption in China (EIA, 2015e). Annex 3 provides more details on uncertainty. Coal consumption in India, which is the second-largest coal consuming country with a share of 10.6% in the global coal consumption and the world's third-largest coal producer, keeps increasing at a high pace, by 9.8% in 2012, 7.8%% in 2013, 9.3% in 2014 and 4.8% in 2015; since coal

Figure 3.3
Total primary energy supply in China, United States and European Union, per type



Source: IEA 2016; BP 2016

consumption in India is outpacing domestic production, India increased coal imports, has set an ambitious coal production target for 2020 and is expanding the transport infrastructure to facilitate additional coal production (BP, 2016; IMF, 2016). Coal consumption in OECD countries decreased collectively by 6.1%, with large decreases in the United States (12.7%), Canada (7.3%), and in Europe, i.e. in Germany (0.6%), the United Kingdom (21.6%), Italy (0.3%) and Turkey (4.7%). This includes brown coal (lignite).

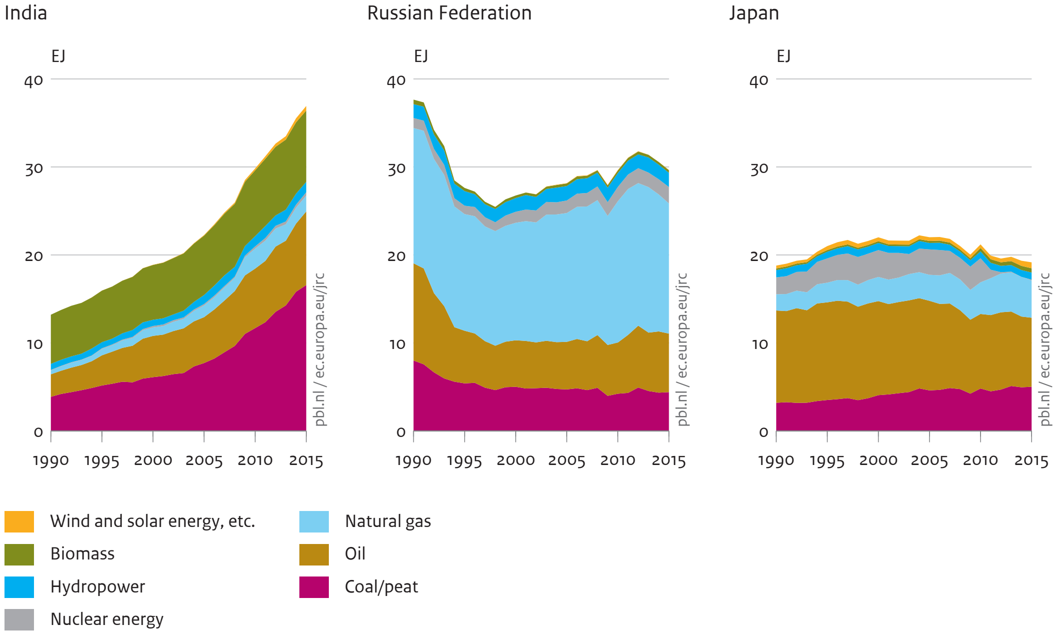
Natural gas production

Consumption of natural gas in 2015 increased globally by 1.7%, compared with 2014 (in energy units) (BP, 2016). The United States had the highest share of 22.8% in natural gas consumption in 2015 followed by the European Union (11.5%), Russian Federation (11.2%), China (5.7%) and Iran (5.5%). Of the countries with more than a 2% share in the world's natural gas consumption, the largest increases took place in Iran (6.2%), Germany (5%), China (4.7%), the United Arab Emirates (4.3%), Saudi Arabia (4%), the United States (3%), and the United Kingdom (2.4%). The European Union saw a large decline (9.8%) in 2011 due to warm weather, a weak economy, high gas prices and increases in renewable electricity production. Since then, EU gas consumption has continued to decrease, by 2.4% in 2012, by 1.7% in 2013, and by the highest decline on record of 11.1% in 2014. In 2015 the EU gas consumption increased by 4.6% mainly caused by increases in Belgium (9.6%), Italy (9.1%), France (7.8%), Hungary (6.6%), Germany (5%), Spain (4.9%), Poland (3%) and the United Kingdom (2.4%) (BP, 2016). According to Eurogas (2015) this increase in gas consumption in EU is among others due to lower gas price in the UK, higher use for summer air-conditioning in Italy and Greece and economic recovery in France, Slovakia and Czech Republic. Comparing to other fuels, gas had a share of 23.8% in the world's total primary energy supply in 2015.

Oil consumption

Global fossil oil consumption increased by about 1.9% in 2015 compared to 2014 (in energy units) (BP, 2016). The United States had the largest share (20%) of global oil consumption, followed by the European Union (14%) and China (13%). The United States oil consumption increased by 1.6% in 2015, from 0.7% in 2014, China's oil consumption increased by 6.3%, which is higher than the 10-year average growth (5.5%) and the European Union's oil consumption for the first time after nine years of decline with 2.5% on average, increased in 2015 by 1.5%. According to BP (2016), in 2015, Europe had the greatest share of global total oil imports (22%) followed by the United States (15%) and China (13%). The top net importers (imports minus exports) are: the European Union, China, the United States, Japan and India. On the global scale, fossil oil has always made up the lion's share of the world's total primary energy supply, but it is recently losing ground. Whereas in 2000 accounted for 38%, it currently accounts for 33%, while the share of coal has increased from 25% to 29%.

Figure 3.4
Total primary energy supply in India, Russian Federation and Japan, per type



Source: IEA 2016; BP 2016

3.3 Trends in renewable energy sources

Together, renewable energy sources meet almost one-fifth of global final energy consumption, including traditional biofuels such as fuel wood; this will continue to grow considering the high-profile agreements announced in 2015 i.e. the commitments of G7 and G20 to accelerate the access to renewable energy, and the Sustainable Development Goal on Sustainable Energy for All of the United Nations (REN21, 2016). However, without clear commitments the low oil and coal prices could affect this trend. Almost 147 GW of the renewable power capacity, which is the largest annual increase on record, was added globally in 2015. At the end of 2015, the total in global power capacity generated from renewable energy had exceeded 1849 GW, up 8.7% from 2014, supplying an estimated 23.7% of global electricity (16.4% in hydropower, 3.5% in wind power, 2% in biomass power and 1.1% solar PV (see Table 3.2) (BP, 2016; REN21, 2016; IEA, 2016b).

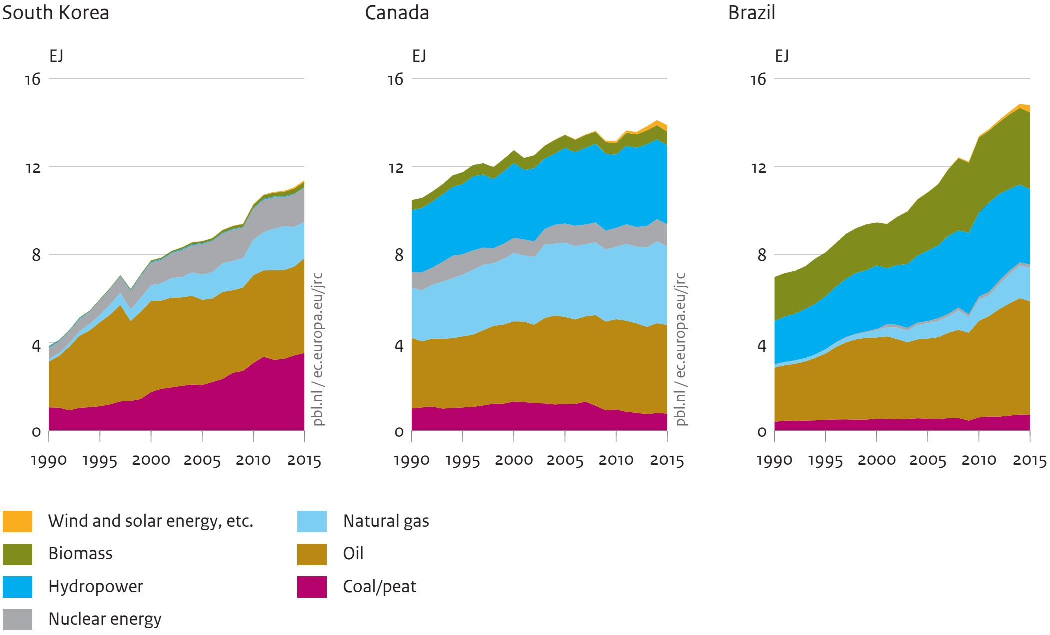
Today, about 146 countries have renewable energy support policies in place and at least 173 countries (an increase of 5% compared to 2014), two thirds of which are countries without yearly national emissions inventory reporting, have renewable energy targets in place. The rise of developing world support contrasts with slackening of policy support in some European countries and the United States. In 2015 high levels of penetration of different forms of renewable energy, for example within the European Union, the share of wind power in national electricity demand reached 17.7% in Spain, 13.6% in Germany and 12%% in the United Kingdom, and of PV 8.9% in Italy, 5.9% in Germany and 5% in Spain (BP, 2016).

Renewable energy sources provide a strong contribution to greenhouse gas emission reduction. For example, in 2012, the equivalent of 720 Mt CO_2 was avoided in the European Union due to the final renewable energy consumption in electricity, heating/cooling and transport sectors, which represents nearly 40% in total greenhouse gas emission savings (Banja et al., 2015).

In 2015, the investment in global new renewable power capacity was more than twice that of investment in net fossil fuel power capacity, which continue for six consecutive years the trend of renewable energy outpacing fossil fuel in the last years, and for the first time the total investments in renewable power in developing countries were higher than in developed countries. The investment in renewable energy was up 17% from the previous year, in China accounting for 36% of global total investment.

By the end of 2015, China achieved almost 100% electrification partly because of off-grid PV progressively installed since 2012. In developed countries, investment in

Figure 3.5
Total primary energy supply in South Korea, Canada and Brazil, per type



Source: IEA 2016; BP 2016

renewable energy decreased by 8% in 2015. The increased use of renewable energy in China together with the efforts in the OECD to promote energy efficiency and renewable energy proved to be essential for a large degree of decoupling of economic growth and CO_2 emissions growth, which is confirmed by the IEA (2016a).

Since 2004, when wind and solar power had a share of 0.5% in global power generation, the share has doubled every four years, up to almost 4.6% in 2015. Although in the same period hydropower increased globally by almost 40%, its share remained the same, at about 16.4%. Biomass and other forms of renewable energy, such as geothermal, increased their share slowly to more than 2.2% in 2015, up from 1% in 1990. The share of nuclear power decreased over this period by 5%, from about 16% to 10.7% (BP, 2016).

Hydropower

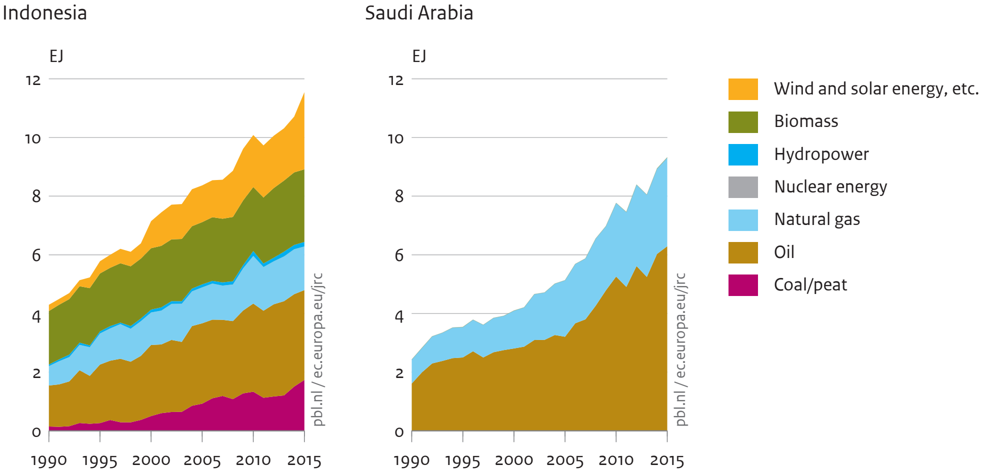
Hydropower output was 3,943 TWh in 2015, showing an increase by 1% compared to 2014 (down from 2 % in 2014) (BP, 2016). The top 5 hydropower countries when considering the capacity in 2015 were China (27.8% share), Brazil (8.6%), the United States (7.5%), Canada (7.4%), and the Russian Federation (4.5%) (REN21, 2016). The top 20 countries in terms of wind power production at the end of 2015 are listed in Table 3.1. Of the 49% increase in the hydropower output since 2002, China accounted for more than 64%, Brazil for 5.7% and Canada for 2.6% (BP, 2016).

In terms of newly installed capacity in 2015 (28 GW), China led with 16.1 GW, followed by Brazil (2.5 GW), Turkey (2.2 GW), India (1.9 GW), Vietnam (1 GW) and Malaysia (0.7 GW), increasing the total global capacity to about 1064 GW (REN21, 2016). In 2015, hydropower production declined in many countries due to droughts, but significant increases can be seen in Turkey (65%), Sweden (17%), Japan (9%) and China (5%) (see Table 3.1) (BP, 2016).

Wind power

Total global wind power capacity was 433 GW in 2015 and increased 17% compared to 2014 (REN21, 2016), which led to an increase in wind power to almost half of the global electricity growth (GWEC, 2016). Wind power output was 841.2 TWh in 2015, an increase of 17.4% compared to 2014 (BP, 2016). The top 10 countries in terms of wind power production at the end of 2015 are listed in Table 3.2.
In 2015, most new wind power capacity was installed in Asia (53.3%), Europe (21.8%) and North America (17%). Asia with 40.6% of the total in 2015 is the largest total wind power capacity in the world, followed by Europe (34.1%) and North America (20.5%). China, the world's largest wind power market since 2009, added 30,750 MW in new wind capacity in 2015, resulting in a total of 145.4 GW installed by the end of 2015. Wind power represented 3.3% of the total electricity generated in China last year up from 2% in 2012. During 2015, 13,800 MW of additional wind power was installed in the European Union,

Figure 3.6
Total primary energy supply in Indonesia and Saudi Arabia, per type



Source: IEA 2016; BP 2016

Note: Figures 3.2 to 3.6: Figures were calculated using a substitution method for nuclear energy, hydropower and other non-biomass renewable energy, as in BP 2016 (i.e. assuming 38% conversion efficiency)

resulting in a total capacity of 147.7 GW. Germany installed 6013 MW of additional capacity, Poland 1266 MW, followed by France (1073 MW), the United Kingdom (975 MW), and Turkey (956 MW) (GWEC, 2016). The total wind power capacity installed in the European Union by the end of 2015 was enough to cover 9.6% of the EU's electricity generation and on average, produced 310.1 TWh of electricity BP (2016); wind met 8% in 2013, up from 7% in 2012, 6.3% in 2011 and 4.8% in 2009. After its strongest year ever in 2012 (28% increase), the United States added 8598 MW wind capacity in 2015, a 13% increase, up from 7.9% in 2014, bringing its total wind capacity to 74.5 GW; by the end of 2015 wind provided 4.5% of total US installed generation capacity and could reach 10% in 2020 (BP, 2016; GWEC, 2014, 2016).

Solar energy

Total global *solar photovoltaic* (PV) capacity increased rapidly from 2004 (2.6 GW) to 2015 (227 GW). The increase in 2015 was 28.2% down from 37.5% in 2013 (REN21, 2016; IEA, 2016b). According to BP (2016), PV power output was 253 TWh in 2015, an increase of 32.6% compared to 2014. The top 10 countries in terms of solar PV power production at the end of 2015 are listed in Table 3.3.
The global total PV installed in 2015 was 50 GW, up from 40.2 GW in 2015 and was dominated by growth in China (30.4% share in global total PV added) with 15.2 GW and Japan (22%) with 11 GW. By comparison, the United States (14.6%), United Kingdom (7.4%) and Germany (3%) installed 7.3, 3.7 and 1.5 GW, respectively (REN21, 2016). Regarding cumulative installed capacity, Europe with 96.9 GW represents 42% of the world's cumulative PV capacity in 2015, North America 12.3% and the rest of the world including countries in the Asia Pacific region 45.7%. In Europe, PV covers 3.4% of the electricity demand and 7% of the peak electricity demand (BP, 2016; SolarPowerEurope, 2016; IEA, 2016b).

Total global *solar heat* (SH) capacity of water collectors increased in 2015 by 6% to about 435 GWth (357 TWh). China was again the leading country with approximately 30.45 GWth newly installed capacity bringing the country total to about 319.9 GWth. The solar water heating collectors global capacity shares of the top 5 countries in 2015 were: China 71.3%, the United States 3.9%, Turkey 3.2, Germany 3% and Brazil 1.9% (see Table 3.2). According to REN21(2016), by the end of 2015, the cumulative installed capacity, per type, was 100% glazed water collectors in China, Turkey and Germany.
By comparison, in Brazil more than half (56.5%) were glazed water collectors, and the United States had 83.1% in unglazed water collectors and 16.9% in glazed water collectors. Unglazed water collectors share in global cumulative installed capacity was 3.5%. Data about solar air collectors, which absorb solar radiation and use it to heat building ventilation air or to provide drying air for industrial applications, are uncertain; according to REN21 (2016) they play a minor role on the market and the new capacity added in 2015 was 1.6 GWth.
Concentrated Solar Power (CSP) is a large-scale promising technology, albeit with high initial capital costs.
The modest growth over the years has been driven by government support schemes. After its record in 2012, when the total global CSP capacity increased by more

Table 3.1

Recent trend in hydropower production in top 20 countries and the European Union (TWh)

Country	2010	2011	2012	2013	2014	2015	Change 2015–2014 (TWh)	Change 2015–2014 (%)	2015 share in total (%)	2015 share in national electricity generation (%)
China	722	699	872	920	1,073	1,126	53.5	5.0%	28.5%	19.4%
Canada	351	376	380	392	383	383	0.5	0.1%	9.7%	60.5%
Brazil	403	428	415	391	373	361	-12.5	-3.3%	9.1%	62.3%
European Union	378	314	337	370	373	338	-35.8	-9.6%	8.6%	22.6%
United States	263	323	279	271	262	254	-8.3	-3.2%	6.4%	5.9%
Russian Federation	168	165	165	183	175	170	-5.3	-3.0%	4.3%	16.0%
Norway	117	120	142	128	135	137	2.0	1.5%	3.5%	95.0%
India	111	132	116	132	131	124	-6.4	-4.9%	3.2%	9.5%
Japan	91	85	81	84	89	97	8.0	9.1%	2.4%	9.3%
Venezuela	77	83	82	83	74	76	2.4	3.3%	1.9%	59.8%
Sweden	67	67	79	61	64	75	10.7	16.7%	1.9%	43.8%
Turkey	52	52	58	59	41	67	26.3	64.6%	1.7%	25.8%
Vietnam	28	41	53	57	60	64	3.8	6.4%	1.6%	38.8%
France	63	46	59	70	62	54	-8.1	-13.0%	1.4%	9.5%
Colombia	41	48	48	44	45	45	-0.1	-0.1%	1.1%	58.0%
Italy	51	46	42	53	58	44	-14.0	-24.2%	1.1%	15.6%
Argentina	41	40	37	41	41	42	1.0	2.3%	1.1%	28.6%
Switzerland	36	32	38	38	37	38	0.2	0.6%	1.0%	53.0%
Austria	38	34	44	42	41	37	-4.3	-10.4%	0.9%	56.8%
Pakistan	30	30	30	32	33	35	1.7	5.2%	0.9%	31.4%
Mexico	37	36	31	27	38	30	-8.1	-21.2%	0.8%	9.8%
Other countries	679	633	643	713	693	688	-5.0	-0.7%	17.4%	10.7%
Global total	**3,466**	**3,516**	**3,693**	**3,822**	**3,908**	**3,946**	**38.2**	**1.0%**	**100%**	**16.4%**

Source: BP (2016)

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

than 60% to about 2.5 GW, the growth continued in the next period to about 4.8 GW total global capacity at the end of 2015, an increase of 10% comparing to 2014 (REN21, 2016), most of which being concentrated in Spain and the United States (Jager Waldau, 2013). Despite the fact that Spain added no new capacity in 2015 it remains the global leader reaching 2.3 GW of CSP. The United Stated added 110 MW to end the year increasing CSP to just over 1.7 GW. Newly installed capacity in Morocco (160 MW) and South Africa (150 MW) surpassed those in the leading countries marking a turning point in the CSP market expansion. Other countries with existing CSP are India (225), United Arab Emirates (100 MW), Algeria (25 MW), Egypt (20 MW), Australia (12 MW) and Thailand (5 MW).

Competitiveness of wind power and solar power

The competitiveness of renewable for power generation continued improving considering the price evolution and the fact that these technologies are becoming more efficient. In 2014 the cost-competitiveness of biomass, hydropower, geothermal and onshore wind for power generation technologies has reached historical levels providing electricity competitively compared to fossil fuel-fired power generation. For both wind and solar, 2015 was a record year mainly because the decline of the technology costs; since 2010 the onshore turbine prices declined up to 45% and for solar photovoltaic modules the prices decreased up to 80%. The wind projects are delivering electricity at USD 0.07/kWh average generation cost for onshore wind and at USD 0.18/kWh for offshore wind, whereas the levelised cost of electricity of solar PV was USD 0.13/kWh (IRENA, 2015, 2016). China and India have some of the most competitive renewable power generation projects with the total installed costs lower than in the rest of the world. In 2016, the costs of tenders for solar PV in Mexico and for offshore wind energy in Denmark and the Netherlands have further decreased, substantially. In 2015, China played a dominant role in the investments in renewables accounting for 36% in total global but there are also plans for hundreds more coal power plants (IRENA, 2016; REN21, 2016; RTCC, 2016).

Table 3.2
Recent trend in wind power production in top 10 countries and the European Union (TWh)

Country	2010	2011	2012	2013	2014	2015	Change 2015–2014 (TWh)	Change 2015–2014 (%)	2015 share in total (%)	2015 share in national electricity generation (%)
European Union	148.8	178.9	205.5	234.3	251.1	310.1	59.0	23.5%	36.9%	9.6%
United States	95.6	121.4	142.2	169.5	183.5	192.9	9.4	5.1%	22.9%	4.5%
China	44.6	70.3	96.0	141.2	159.8	185.1	25.3	15.8%	22.0%	3.2%
Germany	37.8	48.9	50.7	51.7	57.4	88.0	30.6	53.4%	10.5%	13.6%
Spain	44.2	42.4	49.5	53.9	52.3	49.3	-3.0	-5.7%	5.9%	17.7%
India	19.7	24.5	30.1	33.6	37.1	41.4	4.3	11.6%	4.9%	3.2%
United Kingdom	10.3	15.7	19.8	28.4	32.0	40.4	8.4	26.3%	4.8%	12.0%
Canada	8.6	10.9	13.5	16.5	20.6	24.6	4.0	19.3%	2.9%	3.9%
Brazil	2.2	2.7	5.1	6.6	12.2	21.7	9.5	78.0%	2.6%	3.7%
France	9.4	11.6	14.3	15.2	16.2	20.2	4.0	24.7%	2.4%	3.5%
Sweden	3.5	6.1	7.2	9.9	11.5	16.6	5.1	44.8%	2.0%	9.8%
Other countries	65.7	81.4	98.1	117.1	134.0	161.1	27.1	20.2%	19.1%	1.8%
Global total	**341.5**	**435.9**	**526.5**	**643.7**	**716.5**	**841.2**	**124.8**	**17.4%**	**100%**	**3.5%**

Source: BP (2016)

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

Biofuels for transport

Global biofuel production has been growing steadily reaching 130.7 billion litres in 2015 with a share of 75.2% ethanol, 23% biodiesel and 3.7% hydrotreated vegetable oil (HVO), which represents an increase of 3.6% compared to the previous year (REN21, 2015). Consumption of biofuel in road transport has increased by 4.8% globally in 2015. The two leading countries are the United States with a share of 45.7% and Brazil with a share of 22.5% in global biofuel consumption. In 2015, the European Union as a whole had a share of 17.5% in global total with Germany and France the largest contributors. In the United States, the biofuel consumption in road transport has been growing rapidly until 2013 (8.3% in 2013), yet this growth slowed down in 2014 and in 2015 the increase was only 2.1%; almost all gasoline is E10 as a result of about a decade of biofuel mandate requiring to blend the petroleum-based gasoline by 10% ethanol. Continuing further this growth requires moving towards higher ethanol blends (Snow, 2013). According to EIA because of the diversity of economic, environmental and distribution system issues a higher ethanol blends remain very limited. However, EPA has issued partial waiver for a higher volume of ethanol in gasoline in newer vehicles (American Interest, 2016). In the European Union, after an increase of 5.2% in 2012 and a decrease of 9.9% in 2013 the biofuel consumption increased again in 2014 by 8.2% and decreased in 2015 by 3.1, driven by large decreases in 2015 in Germany (6.3%), the United Kingdom (17.1%) and Austria (26.3%). Significant increases have been seen in Sweden (22.6%), Finland (12.7%), and Portugal (28.3%) (see Table A1.1 in Annex A1.2).

Current fuel ethanol and biodiesel use represents about 3% of global road transport fuels and could be expected to have reduced CO_2 emissions with a similar percentage if all biofuel had been produced sustainably. In practice, however, net reduction in total emissions in the biofuel production and consumption chain is between 35% and 80% (Eickhout et al., 2008; Edwards et al., 2008). These estimates also exclude indirect emissions, such as those from additional deforestation (Ros et al., 2010). An example of the latter is biodiesel produced from palm oil from plantations on deforested and partly drained peat soils. Thus, the effective reduction will be between 1% and 2%, excluding possible indirect effects. Large uncertainty in terms of greenhouse gas emission reductions compared to the fossil fuels is driven by both the complexity of the biofuel pathways and the diversity of the feedstock, nevertheless, in the near future the advanced biofuels (lignocellulosic, algae) are expected to deliver more environmental benefits (Carlsson and Vellei, 2013). In the EU-28, where the absolute level of greenhouse gas emission saving due to renewable energy use in transport sector increased by 2.1% per year between 2009-2012, it is essential to fulfil the sustainability criteria for biofuels and ensure the commercial availability of second-generation biofuels. Yet, some countries have difficulties in fulfilling sustainability criteria and the percentage of renewable content to be reached by 2020 of 10% has been lowered to 5%-7.5% range (Banja et al., 2015; EC, 2009; Biofuels digest, 2016).

Recently, emission reductions in the transport sector through tax incentives and blending mandates act as a

Table 3.3

Recent trend in power production of solar PV in top 10 countries and the European Union (TWh)

Country	2010	2011	2012	2013	2014	2015	Change 2015–2014 (TWh)	Change 2015–2014 (%)	2015 share in total (%)	2015 share in national electricity generation (%)
European Union	23.2	46.4	71.3	85.3	97.3	109.5	12.2	12.6%	43.3%	3.4%
China	0.7	2.6	6.4	15.5	23.1	39.2	16.1	69.7%	15.5%	0.7%
US	3.0	4.7	9.0	16.0	27.5	39.0	11.5	41.8%	15.4%	0.9%
Germany	11.7	19.6	26.4	31.0	36.1	38.4	2.4	6.6%	15.2%	5.9%
Japan	3.3	4.5	6.1	10.7	19.5	30.9	11.4	58.6%	12.2%	3.0%
Italy	1.9	10.8	18.9	21.6	22.3	25.2	2.9	13.0%	10.0%	8.9%
Spain	7.1	8.7	12.0	12.7	13.7	13.9	0.2	1.6%	5.5%	5.0%
United Kingdom	0.04	0.2	1.4	2.0	4.1	7.6	3.5	86.6%	3.0%	2.2%
France	0.6	2.1	4.0	4.7	5.9	7.3	1.5	25.1%	2.9%	1.3%
India	0.3	0.5	1.4	2.8	4.4	6.6	2.2	50.9%	2.6%	0.5%
Australia	1.0	2.0	2.4	3.8	5.0	6.1	1.1	22.6%	2.4%	2.4%
Other countries	3.7	8.0	14.1	21.7	29.4	38.8	9.4	32.0%	15.4%	0.4%
Global total	**33.3**	**63.8**	**101.9**	**142.6**	**190.8**	**253.0**	**62.3**	**32.6%**	**100%**	**1.1%**

Source: BP (2016)

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

driver for biofuel development. If successfully implemented, global demand will be driven by blending mandates in the European Union, the United States, China and Brazil. In 2015, biofuels mandates were in place in the European Union, 13 countries in North and South America, 12 in Asia and the Pacific, 11 in Africa and Indian Ocean and 2 from non-EU countries in Europe (Biofuels digest, 2016; GFRA, 2016). The traditional biofuel with 2% growth per year are on track to meet the Energy Technology Perspectives 2oC Scenario (2DS) targets for 2025, while for advanced biofuels a faster market penetration is needed to achieve the requirement of 56.8 billion litres in 2025 for decarbonisation of transport sector; however, biofuel policies oriented to avoid negative impacts on environment, social and economic sustainability are needed (IEA, 2015a).

3.4 Trends in nuclear energy

End December 2015, 441 nuclear power reactors generated 10.7% of the world's total electricity (BP, 2016). The International Atomic Energy Agency (IAEA) reports in September 2016 an additional 11 reactors, mounting the total of operational reactors to a new world record of 449 on line (IAEA-PRIS, 2016). This increase took off after three years of almost constant number of reactors 439-441 (see Figure 3.7) but 449 is only one reactor more than the number of reactors before the Fukushima accident (March 2011). In the wake of the disaster, 13 reactors were permanently shut down.

Globally, power generation by nuclear reactors increased by 1.3% in 2015 compared to 2014 (BP, 2016; IAEA, 2016), but regionally there are large differences (see Table 3.5). Some large Asian countries increased their nuclear electricity generation in 2015 compared to 2014 considerably: China with 23% from 8 new reactors, South Korea with 5% from one new reactor and Russia with 8% from one new reactor. In contrast, some EU countries decreased their nuclear electricity generation: Belgium with 29%, Sweden with 14% and Germany with 6%.

More specifically, the changes per country can be summarised as follows.

- **China** more than doubled its nuclear electricity generation over the past 5 years from 74 TWh in 2010 to 171 TWh in 2015 and is further constructing 7 new reactors, of which 1 is planned to connect in 2016 to the grid (BP, 2016; IAEA, 2016). Further 33 more reactors are planned. As such China starts to climb up amongst the top 5 nuclear countries with USA, France, Russia and Japan (see Table 3.5 and Figure 3.8).
- **South Korea** produced in 2015 almost the same amount nuclear electricity as China (165 TWh) (BP, 2016; IAEA, 2016). Also South-Korea is expanding its park of nuclear reactors, with an extra two, of which one is expected to come on line in 2016.
- **Russian Federation** remains third largest nuclear electricity generator with 195 TWh in 2015, after USA and France. Russia connected one new reactor to the grid in December 2015 of fast breeder type, which serves not only power generation but also plutonium production. Another reactor of this type is also planned

Table 3.4
Recent trend in power production from biomass, geothermal and other renewables in top-10 countries and the European Union (TWh)

Country	2010	2011	2012	2013	2014	2015	Change 2015–2014 (TWh)	Change 2015–2014 (%)	2015 share in total (%)	2015 share in national electricity generation (%)
European Union	129.3	138.7	154.8	163.8	174.3	181.2	6.9	4.0%	35.0%	5.6%
United States	75.1	75.8	77.0	80.7	84.1	85.2	1.1	1.4%	16.4%	2.0%
China	24.9	31.6	33.8	38.4	46.5	52.9	6.4	13.8%	10.2%	0.9%
Germany	34.3	37.6	44.7	46.7	49.5	50.2	0.6	1.3%	9.7%	7.8%
Brazil	31.5	32.2	35.3	40.5	46.2	50.1	3.9	8.4%	9.7%	8.6%
United Kingdom	11.9	13.0	14.7	18.2	22.7	29.0	6.3	27.8%	5.6%	8.6%
Japan	24.5	24.2	25.3	26.4	26.8	27.7	0.9	3.4%	5.3%	2.7%
Italy	14.8	16.5	18.1	22.7	24.6	25.1	0.4	1.6%	4.8%	8.9%
India	11.8	14.0	16.1	18.1	18.8	20.5	1.7	9.2%	4.0%	1.6%
Finland	10.9	11.1	11.1	11.9	11.7	11.3	-0.4	-3.2%	2.2%	16.5%
Philippines	10.0	10.1	10.4	9.8	10.5	11.1	0.6	6.1%	2.2%	13.5%
Other countries	126.4	134.1	139.0	142.8	150.6	155.1	4.5	3.0%	29.9%	1.7%
Global total	**376.1**	**400.1**	**425.4**	**456.2**	**492.0**	**518.2**	**26.2**	**5.3%**	**100%**	**2.2%**

Source: BP (2016)

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

Excluding hydropower, wind and solar electricity.

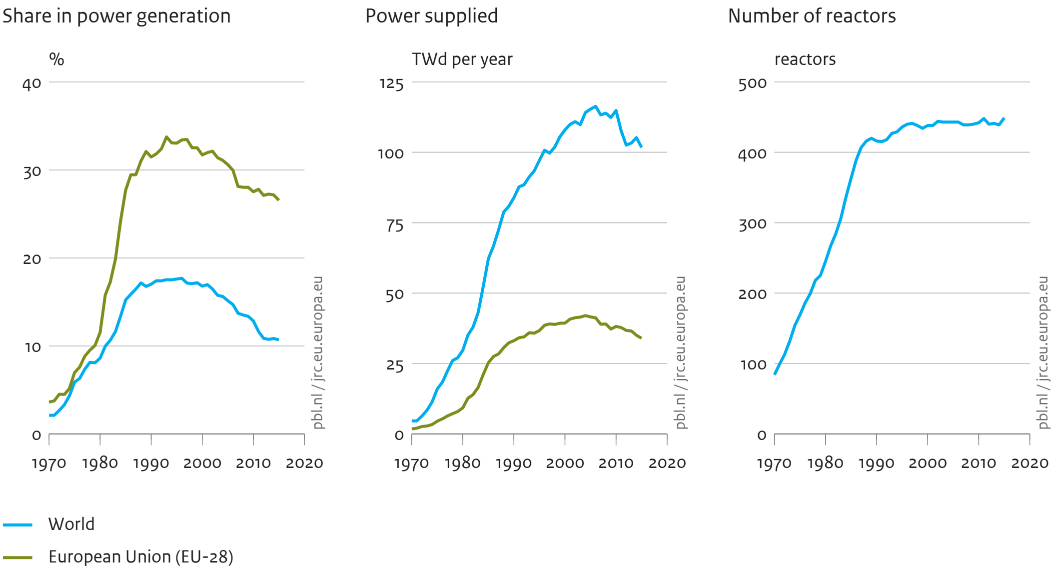
together with 20 other power generation reactors of light water type.

- **United States** is the number one nuclear electricity producer in absolute terms, keeping its level in 2015 as in 2014 at 839 TWh. Moreover, the 20% nuclear share is further supported, because the US-EPA Clean Power Plan (US EPA, 2014) aims to reduce carbon emissions from US power plants 25% below 2005 levels by 2020 by increasing the thermal efficiency, greater use of nuclear power and renewables, and greater use of gas. As such, USA is constructing 4 reactors to become operational by 2020 and has another 23 large ones planned, together with 19 small ones by end 2020 (WNA-USA, 2016).
- **Japan** is slowly recovering from a total shutdown of all its reactors after the Fukushima disaster in 2011. From its original 54 reactors, 42 reactors are again operable and potentially able to restart, and 24 of these are in the process of restart approvals (WNA-Japan, 2016). The first two restarted in August and October 2015, delivering the first 4.5 TWh. Japan has 1 reactor permanently shut down and is constructing two new reactors and plans 7 more (IAEA, 2016).

And in the countries of the European Union:

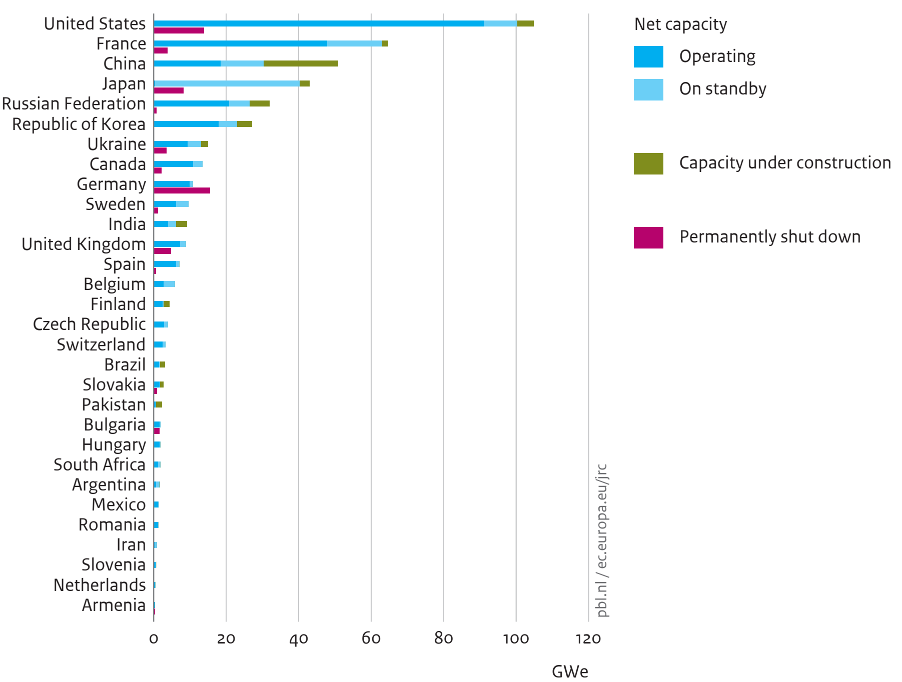
- **France** is still the second largest nuclear electricity producer of the world (after USA) and kept producing in 2015 with its 58 reactors the same amount leading to a constant 76.5% nuclear share. End 2016 a new reactor is expected to connect to the grid, after a long construction period of 9 years. France has become the world's largest net electricity exporter, mainly to Italy but also to UK. Nevertheless, the large nuclear electricity share, which is due to the energy security policy of the 1970s, might be reduced to 50% by 2025. In July 2015, the new Energy Transition for Green Growth bill was approved, which introduces a nuclear cap at present level and so forces with new reactors the shutdown of old ones (WNA-France, 2016).
- **Germany** is slightly decreasing further its nuclear share to 14% in 2015, coming from one quarter till March 2011. Even though the government cancelled the original phasing out of nuclear energy in 2009, they reintroduced it after the Fukushima disaster with the immediate shutdown of eight reactors (WNA-Germany, 2016).
- **Belgium** has 7 reactors, of which two are evaluated for a phase-out project, and three other reactors faced since 2014 safety incidents: one reactor was affected by sabotage on the secondary loop and two other reactors had to undergo a full safety evaluation after the discovery of reactor vessel micro cracks. In 2016 all three are again connected to the grid, even though Germany reacted angry to the restart of the latter two (FANC, 2016). In summary: in 2014 only 34 TWh were produced and in 2015 only 26 TWh, which is considerably lower than the mean annual electricity production of 47 TWh in the period 2000-2010 (BP, 2016; IAEA, 2016).
- **Sweden** still has a nuclear electricity share of more than 50% in 2015, even though decisions were made to close four older reactors by 2020, removing already

Figure 3.7
Power generation using nuclear energy



Source: IAEA 2016

Figure 3.8
Global nuclear power capacity per country, 2015



Source: IAEA 2016

Table 3.5
Recent trend in nuclear power production in top-10 countries and the European Union (TWh)

Country	2010	2011	2012	2013	2014	2015	Change 2015–2014 (TWh)	Change 2015–2014 (%)	2015 share in total (%)	2015 share in national electricity generation (%)
European Union	917.3	907.3	883.2	877.6	877.1	857.8	-19.3	-2.2%	33.3%	26.5%
United States	849.4	831.8	809.8	830.5	839.1	839.1	0.0	0%	32.6%	19.5%
France	428.3	442.1	425.4	423.7	436.5	437.4	1.0	0.2%	17.0%	76.9%
Russian Federation	170.4	172.9	177.5	172.5	180.8	195.2	14.4	8.0%	7.6%	18.4%
China	73.9	86.4	97.4	111.6	132.5	170.8	38.3	28.9%	6.6%	2.9%
South Korea	148.6	154.7	150.3	138.8	156.4	164.8	8.4	5.3%	6.4%	31.5%
Canada	90.0	92.9	94.2	102.7	106.9	104.2	-2.7	-2.5%	4.0%	16.5%
Germany	140.6	108.0	99.5	97.3	97.1	91.5	-5.6	-5.8%	3.6%	14.1%
Ukraine	89.2	90.2	90.1	83.2	88.4	87.6	-0.8	-0.9%	3.4%	53.7%
United Kingdom	62.1	69.0	70.4	70.6	63.7	70.3	6.6	10.3%	2.7%	20.8%
Sweden	58.6	61.1	64.6	66.9	65.5	57.2	-8.3	-12.6%	2.2%	33.6%
Other countries	656.6	544.3	392.4	394.8	376.3	358.9	-17.4	-4.6%	13.9%	3.8%
Global total	**2,767.7**	**2,653.4**	**2,471.7**	**2,492.7**	**2,543.2**	**2,577.1**	**33.9**	**1.3%**	**100%**	**10.7%**

Source: BP (2016)

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).

8 TWh from 2014 to 2015. The country's 1997 energy policy allowed ten reactors to operate longer than envisaged in 1980 and at an uprated nominal power. The latter compensated for the premature closure of a two-unit plant (WNA-Sweden, 2016).

- **Slovakia** kept its four reactors up running, resulting in a 14% nuclear electricity share. It is constructing a new reactor, which is expected to connect to the grid in 2016 (IAEA, 2016).

Note

1 Note that natural gas (~15 kg C/GJ) per unit of energy contains roughly half the amount of carbon (C) compared to coal (~26 kg C/GJ), with the amount of carbon in oil products somewhere in between (~20 kg C/GJ). In other words, the combustion of coal produces per gigajoule about 75% more CO_2 than that of natural gas. In addition, since natural-gas-fired combined cycle power plants operate at a higher temperature, they can achieve up to almost 15% higher energy efficiency than coal-fired power plants. So, a coal-fired power plant emits about twice as much CO_2 per kWh produced than a gas-fired power plant.

Annex 1 Methodology and data sources

A1.1 Methodology and data sources over the 2012–2015 period

The basis for the data time series here is the new EDGAR 4.3.2 database of EC-JRC/PBL (2015) covering the period 1970-2012, based on the energy consumption data for the period 1970-2012 as published by the International Energy Agency in 2014 (IEA, 2014a). The recent trends for fossil fuel consumption were estimated using trends in most recent data on fossil-fuel consumption for 2013-2015 from the BP Review of World Energy 2015 (BP, 2016) and for 2012-2013 from the IEA (IEA, 2015c).

For the trend estimate for 2012-2015, the following procedure was used. Sources were disaggregated into five main sectors as follows (with the defining IPCC source category codes from IPCC (1996) in brackets):

(1) fuel combustion (1A+international marine and aviation bunkers);
(2) fugitive emissions from fuels (1B);
(3) cement production and other carbonate uses (2A);
(4) non-energy/feedstock uses of fuels (2B+2C+2D+2G+3+4D4);
(5) other sources: waste incineration, underground coal fires and oil and gas fires (1992, in Kuwait) (6C+7A).

For these main source sectors the following data was used to estimate 2012–2015 emissions:

(1) Fuel combustion (IPCC category 1A + international bunkers):
  - For energy, for 2012-2013, the most recent detailed CO_2 estimates compiled by the International Energy Agency (IEA) for fuel combustion by major fossil-fuel type (coal, oil, gas, other) for these years (IEA, 2015c) to calculate the trend per country and for international air and water transport.
  - For energy for, 2013–2015, the BP Review of World Energy 2016 was used to calculate the trend per country in fuel consumption per main fossil fuel type: coal, oil and natural gas (BP, 2016).
  - An exception are the CO_2 emissions from fossil-fuel combustion in China, for which we used for fossil fuel consumption the time series 2000-2014 just released by the IEA (2016c), in which the major revisions in 2015 of China's energy statistics, notably for coal consumption, are included. For 2015 we used the BP(2016) statistics as mentioned above.
  - For oil consumption, the BP figures were corrected for biofuel (fuel ethanol and biodiesel) which are included in the BP oil consumption data. See Section A1.2 for more details on the biofuel dataset.
  - 'Other fuels', which are mainly fossil waste combusted for energetic purposes, which is a very small fraction in most countries, were assumed to be oil products and the trend was assumed to follow oil consumption per country.
  - For the trend in international transport, which uses only oil as a fuel, we applied the trend in oil consumption per country according to BP for the sum of 10 and 12 countries which contributed most to global total marine and aviation fuel sales, respectively, according to IEA statistics.

(2) Fugitive emissions from fuels (IPCC category 1B):
  - Fugitive emissions from solid fuel (1B1), which for CO_2 refers mainly to coke production: trends per country for 2012–2015 are assumed to be similar to the trend in crude steel production for 2012–2014 from USGS (2016) and for 2014–2015 from the Word Steel Association (WSA, 2016).
  - Fugitive emissions from oil and gas (1B2), which refers mainly to leakage, flaring and venting. For EDGAR version 4.3.2 trends for flaring per country ware based on total amount of gas flared derived from satellite observation of the intensity of flaring lights for the most important 61 countries for 1994-2011 (NOAA, 2012b; Elvidge et al., 2009a,b), which were prepared for the World Bank's Global Gas Flaring Reduction Partnership (GGFR, 2012).

Combined with other data, the satellite data give robust information on the annual change in emissions. For 2012-2014 the new NOAA dataset was used based on new satellite data from NOAA (2016), which includes 29 more countries than the previous satellite dataset from NOAA that covered 1994 to 2011 (NOAA, 2016b; Elvidge et al., 2016), supplemented with 7 more countries from the CDIAC dataset (Boden et al., 2010) and 8 countries from EIA (2015e) statistics. For years before 1994 and for 20 other countries emissions or emissions trends were supplemented by CO_2 trends from CDIAC (Boden et al., 2010), EIA (2015e). For 2014 and 2015 we assumed constant emissions since updated NOAA data were not available, except for Iraq and Venezuela, which are large emitters and show a strong increase in previous years, which we extrapolated to 2015 (see Annex 2, Section A2.1).

(3) Cement production and other carbonate uses (2A):
- cement production (2A1)
- other carbonate uses, such as lime production and limestone use
- soda ash production and use.

CO_2 emissions from cement production amount to about 80% of the 2A category. EDGAR version 4.3.2 uses for CO_2 from cement clinker production the same method as version 4.2 based on the Tier 1 emission factor for clinker production (IPCC, 2006), but it uses an updated dataset with country-specific clinker fractions for 1990-2012 for all annually reporting countries and six other large countries, including China, and estimated fractions for other countries and for the years 1970-1989.
Cement clinker production is now calculated from cement production reported by the USGS (2016) and the implied clinker-to-cement ratio based on either clinker production data from UNFCCC reporting over the 1990–2012 period and the China Cement Almanac (CCA, 2016) for China over the 2002–2014 period and Xu et al. (2014) for China for 1990, 1995 and 2000. For other countries, we used ratios from the GNR database from the Cement Sustainability Initiative (CSI) of the World Business Council for Sustainable Development
(WBCSD). This CSI is a global effort by 24 major cement producers with operations in more than 100 countries and provides cement and clinker production data for 1990, 1995, 2000, and the 2005–2012 period for nine OECD countries, six other large countries and eight world regions (WBCSD-CSI, 2015).
In the previous data set clinker fractions were assumed constant from 2009 onward. For annually reporting countries, the country-specific annual clinker fractions include the effect of net clinker import. Due to the revision and update of clinker fractions up to 2012, global 2010 cement clinker emissions were found to have decreased by 2.7% and for China by 13.3%, where we made use of CCA (2016) and Xu et al. (2014).
In addition, we extrapolated the 2012-2015 trend in the clinker production, using the trend in cement production based on USGS (2016), except for China, for which we used CCA (2016) for the clinker production trend in 2013 and 2014, and NBS (2016a) for the cement trend in 2015. For all other sources in the minerals production category (2A), we used the trend in lime production data for 2012–2015 (USGS, 2016) as a proxy to estimate the trend in the other 2A emissions. All 2015 data are preliminary estimates.

(4) Non-energy/feedstock uses of fuels (2B+2C+2D+2G+3+4D4):
- ammonia production (2B1): net emissions, i.e. accounting for temporary storage in domestic urea production (for urea application see below);
- other chemicals production, such as ethylene, carbon black, carbides (2B other);
- blast furnace (2C1): net losses in blast furnaces in the steel industry, i.e. subtracting the carbon stored in the blast furnace gas produced from the gross emissions related to the carbon inputs (e.g., coke and coal) in the blast furnace as a reducing agent, since the CO_2 emissions from blast furnace gas combustion are accounted for in the fuel combustion sector (1A);
- another source in metal production is anode consumption (e.g., in electric arc furnaces for secondary steel production, primary aluminium and magnesium production) (2C);
- consumption of lubricants and paraffin waxes (2G), and indirect CO_2 emissions related to NMVOC emissions from solvent use (3);
- urea applied as fertiliser (4D4), in which the carbon stored is emitted as CO_2 (including emissions from limestone/dolomite used for liming of soils).

For the feedstock use for chemicals production (2B), ammonia production from USGS (2016) was used as proxy, assuming that the fraction of CO_2 produced in ammonia production that is stored in urea production remains constant fir the years 2012-2015. Since CO_2 emissions from blast furnaces are by far the largest subcategory within the metal production category 2C, for the trend in crude steel production was used to estimate the recent trend in the total emissions (USGS and WSA, see above under (1)). For the very small emissions in categories 2G and 3, the 2010–2012 trend was extrapolated to 2015. For simplicity, it was assumed that the small soil liming (4D4) emissions follow the gross ammonia production trend.

Table A1.1

Recent trends in biofuel use in transport in top-14 consuming countries and European Union, ranked according to 2015 consumption levels (in PJ)

Country	2010	2011	2012	2013	2014	2015	Change 2015–2014 (PJ)	Change 2015–2014 (%)	2015 share in total
United States	1,020	1,086	1,372	1,486	1,486	1,517	30.9	2.1%	45.7%
Brazil	589	540	500	580	637	746	109.2	17.2%	22.5%
European Union	567	585	615	554	600	581	-18.5	-3.1%	17.5%
France	101	101	111	113	122	122	0.7	0.6%	3.7%
Germany	132	125	129	118	123	115	-7.8	-6.3%	3.5%
Canada	49	67	73	77	78	74	-4.0	-5.1%	2.2%
China	68	67	73	71	71	74	3.1	4.4%	2.2%
Thailand	27	30	39	50	61	66	4.5	7.3%	2.0%
Argentina	23	34	39	41	51	56	4.0	7.9%	1.7%
Italy	59	59	57	52	45	45	0.8	1.8%	1.4%
Sweden	16	18	23	27	34	41	7.6	22.6%	1.2%
Spain	60	72	89	38	41	41	0.0	0.1%	1.2%
United Kingdom	48	45	37	41	47	39	-8.0	-17.1%	1.2%
Peru	4	6	14	15	15	32	16.8	110.3%	1.0%
Poland	37	39	34	31	30	29	-1.0	-3.5%	0.9%
Other countries	185	221	247	280	328	322	-6.1	-1.9%	9.7%
Global total	**2,417**	**2,509**	**2,837**	**3,021**	**3,167**	**3,318**	**150.7**	**4.8%**	**100%**

Source: IEA (2016c), EIA (2016s), USDA (2014, 2015, 2016)

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

(5) Other sources (6C+7A):
- waste incineration (fossil part) (6C);
- fossil fuel fires (7A).

The 2010–2012 trend was extrapolated to 2015 for the relatively very small emissions of waste incineration (6C) and underground coal fires (mainly in China and India). The oil and gas fires in Kuwait were kept allocated to 1992 (7A). CO_2 emissions from underground coal fires in China and elsewhere have been included in EDGAR 4.3.2, although the magnitude of these sources is very uncertain. Van Dijk et al. (2009) concluded that CO_2 emissions from coal fires in China are at around 30 million tonne CO_2 per year. This is equivalent to about 0.3% of China's CO_2 emissions in 2015.

A1.2 Dataset on biofuel use in road transport

This dataset is restricted to bioethanol (also known as 'fuel ethanol' or 'biogasoline'), biodiesel and 'other liquid biofuels' used in road transport as substitute for fossil oil products (petrol, diesel or LPG. Palm oil and solid biomass used in stationary combustion such as power generation was not considered, as it is not relevant for this study. Biofuel consumption data for road transport for 2000–2014 were compiled from the following data sources:

- OECD countries: For 2000–2014 we used for 30 OECD countries IEA statistics for Total Final Consumption (TFC) of bioethanol ('biogasoline'), biodiesel and other liquid biofuels from IEA(2016c). For 2015 we used per biofuel type the trend 2014-2015 of Total Primary Energy Supply (TPES) to estimate the consumption in 2015 (IEA, 2016d). For 2015 only TPES values are known in these IEA (2016c) statistics, however in most countries this is equal to road consumption or TFC.
- Four OECD countries reported no biofuel consumption in IEA (2016c), of which three were supplemented by biofuel consumption reported by EIA (2016f) for 2000–2012: Japan, Israel and Mexico (Chili does not use biofuels according to IEA and EIA). For these three countries consumption in 2013-2015 was estimated by extrapolation.
- Non-OECD countries: For 2000–2014 we used for 24 non-OECD countries IEA (2016d) for biogasoline and biodiesel consumption in road transport.
- These 24 non-OECD countries for which the IEA does report biofuel use were supplemented by 16 more countries for which biofuel consumption was reported by the EIA (2016x) for 2000-2012.

- For 2015 we used for non-OECD countries in the IEA dataset the trend 2014–2015 in USDA country reports (USDA, 2013, 2014, 2015) for the ten largest consuming countries: Argentina, Brazil, China, Colombia, India, Indonesia, Malaysia, Peru, Philippines and Thailand. The other non-OECD countries with reported biofuel consumption are: Barbados, Cambodia, Costa Rica, Ecuador, Ethiopia, Fiji, Guatemala, Honduras, Hong Kong, Pakistan, Macedonia, Malawi, Nigeria, Rwanda, Serbia, Singapore, South Africa, Tanzania, Trinidad and Tobago and Viet Nam. For these countries consumption in 2013-2015 was estimated by extrapolation.

We used this dataset of all transport biofuel types (bioethanol, biodiesel, other liquid biofuels) as value to correct the oil consumption numbers of BP (2016), which include liquid biofuel consumption. Although data for 2000 onwards were compiled, only 2012-2015 data are used in the CO_2 estimation method for fossil fuel combustion used in this study. For years up to 2012, the EDGAR 4.3.2 (JRC/PBL, 2016) data are used, which were calculated with fuel statistics from the IEA, in which fossil fuel data are separated from biofuel data (no mixing with reported oil consumption data as BP does).

A1.3 Other sources of CO_2 emissions: forest and peat fires and post-burn decay

The trend estimates of CO_2 emissions do not include the contribution of forest fires due to deforestation/logging, peat fires and the subsequent post-burn emissions from decay of remaining above ground biomass and from drained peat soils. CO_2 emissions from the decay of organic materials of plants and trees remaining after forest burning and logging are also not included due to their high uncertainty. Annual CO_2 emissions from peat fires in Indonesia estimated by Van der Werf et al. (2008) vary between 0.1 and 0.2 billion tonnes per year, except for peak years due to El Niño. For the very exceptional 1997 El Niño, they estimated peat fire emissions at 2.5 billion tonnes CO_2. Joosten (2009) estimated global CO_2 emissions from drained peatlands in 2008 at 1.3 billion tonnes CO_2, of which 0.5 billion tonnes from Indonesia. CO_2 removals from forest growth and afforestation are also excluded from our CO_2 estimates.

Annex 2 Other trends and CO_2 results

This annex presents the main results from other CO_2 sources than fossil fuel combustion. This can be distinguished into fossil fuel production (for CO_2 notably of oil and gas) and fuel transformation (such as coke production, oil refineries), which corresponds with IPPC category 1B, and other non-fuel combustion sources. Most sources of the second type are called 'industrial non-combustion processes', which corresponds with IPCC 1996 categories 2 and 3. Most important sources of this kind are cement production (in particular clinker production) and other processes where the calcium carbonate in limestone is calcinated to form lime (CaO) and CO_2 is generated as by-product. The second largest source is the use of fossil fuel as feedstock to produce chemicals such as ammonia (NH_3) from natural gas (which is mostly CH_4) and ethylene. The third largest non-combustion source of CO_2 is the use of fossil fuel as reductant, such as in steel production where in blast furnaces coke and coal are used as reducing agent in smelting iron ore to produce pig iron (IPCC, 2006).

Globally, both cement production and steel production are indicators of national construction activities, with cement mainly used in building and road construction, and steel also in the construction of railways, other infrastructure, ships, and machinery.

A2.1 CO_2 emissions from oil and gas production

For CO_2 emissions from flaring of so-called associated gas that is produced during oil production and gas exploration, that cannot be marketed, the amounts flared for 2012 to 2014 are now updated with new satellite data from NOAA (2016b), which includes much more countries than the previous satellite dataset from NOAA that covered 1994 to 2012 but generally with rather small amounts (Elvidge et al., 2016). Table A2.1 shows the recent trend in amounts flared for the top-20 of flaring countries.

Since global CO_2 emissions from gas flaring peaked a about 350 million tonnes in 2003, global emissions decreased to 280 million tonnes in 2010 and increased somewhat to about 290 million tonnes in 2014–2015.

The table clearly shows that the Russian Federation and Nigeria were in 2010 by far the largest flaring nations but managed to reduce the amount of gas being flared by 50% and 40%, respectively. At the same time we see that flaring Iraq, Venezuela and the United States has increased sharply. For 2015, flaring emissions in the Russian Federation and Iraq are estimated to have been 34 and 30 million tonnes of CO_2.

In the United States, marketed natural gas production from hydraulically fractured wells increased from 2000 to 2015 from 7% to two-thirds of total natural gas production (EIA, 2016e), whereas hydraulic fracturing accounts for about half of the present crude oil production (EIA, 2016a). The increase in oil production by hydraulic fracturing, which took off around 2007, increased US flaring emissions from about 5 million tonnes to 20 million tonnes of CO_2 in 2015. As a result, in 2015 the United States remained the largest producer of oil and natural gas, ahead of Russia and Saudi Arabia. Its oil and gas production first surpassed Russia in 2012, and the United States has been largest natural gas producer since 2011 and the world's largest oil producer since 2013 (EIA, 2016j).

A2.2 CO_2 emissions from cement production (non-combustion)

CO_2 emissions are generated by carbonate oxidation in the cement clinker production process, the main constituent of cement and the largest of non-combustion sources of CO_2 from industrial manufacturing, contributing to about 4.0% of the total global emissions in 2015. Fuel combustion emissions of CO_2 related to cement production are of approximately the same level,

Table A2.1

Recent trends in top-20 flaring countries and the European Union, ranked according to 2015 production levels (in PJ of gas flared)

Country	2010	2011	2012	2013	2014	2015	Change 2014– 2013 (PJ)	Change 2014–2013 (%)
Russian Federation *	1,225	1,286	823	723	666	609	-57	-8%
Iraq *	310	320	464	486	512	537	25	5%
Iran	401	402	417	412	450	450	38	9%
Venezuela *	113	140	323	372	408	444	36	10%
United States	159	243	300	279	367	367	88	32%
Nigeria	511	501	339	329	296	296	-33	-10%
Algeria	199	188	248	263	272	272	9	3%
Kazakhstan	210	264	241	230	236	236	6	3%
Mexico	98	75	158	158	179	179	21	14%
Malysia	52	57	80	99	119	119	20	20%
Indonesia	81	80	111	99	98	98	-1	-1%
Angola	140	141	111	87	94	94	6	7%
Egypte	55	55	88	78	92	92	14	17%
Oman	55	55	73	80	90	90	10	12%
Libya	131	76	205	141	89	89	-52	-37%
Tukmenistan	69	72	106	99	88	88	-11	-11%
Cameroon	90	82	81	82	85	85	3	4%
China	88	91	67	62	69	69	7	11%
Saudi Arabia	118	120	68	67	68	68	1	1%
Canada	88	85	40	45	65	65	20	45%
European Union	41	40	52	54	55	55	1	2%
Other countries	760	717	783	793	805	805	12	2%
Global total	**4,993**	**5,091**	**5,178**	**5,037**	**5,201**	**5,206**	**164**	**3%**

Notes:

* *Data on the largest flaring countries with continuous trend have been extrapolated to 2015. For all other countries we assumed that flaring 2015 = 2014.*
'Other countries' includes all countries not explicitly listed (including other EU countries)

so, in total, cement production accounts for roughly 8% of global CO_2 emissions. The combustion emissions of these activities are not included in this section but included under the industrial energy-related emissions. This section focuses on process emissions (i.e. emissions from carbonate oxidation).

China accounted for 58% of global cement production in 2015, followed by India (6.8%) and the United States (2.7%). However in China, for the first time in decades, cement production decreased by 5.7% compared to 2014, which was the top year of cement production (NBS, 2016a). The EU-28 accounted for 4.4% of the global total. In the European Union cement production increased by 4.5% in 2015, compared to an increase of 0.9% in 2014. According to USGS (2016) global cement production decreased by 1.9% in 2015, compared to an increase of 2.5% in 2014.

However, emissions are not directly proportional to cement production level, since the fraction of clinker – in this industry the main source of CO_2 emissions – in cement tends to decrease over time. A study by the Cement Sustainability Initiative (CSI) of the World Business Council on Sustainable Development (WBCSD, 2009) has shown that the share of blended cement has considerably increased in most countries relative to that of traditional Portland cement.

Consequently, average clinker fractions in global cement production have decreased between 60% and 80%, compared to nearly 95% for Portland cement with proportional decrease in CO_2 emissions per tonne of cement produced. Both non-combustion and combustion emissions from cement production occur during the clinker production process, not during the mixing of the cement clinker. This has resulted in about 20% decrease in CO_2 emissions per tonne of cement produced, compared to the 1980s. At that time, it was not common practice to blend cement clinker with other mixing material, such as fly ash from coal-fired power plants or blast furnace slag. In the case of China, the average clinker fraction in total national cement production

Table A2.2

Recent trends in cement production in top-10 producing countries and the European Union, ranked according to 2015 production levels (in million tonnes)

Country	2010	2011	2012	2013	2014	2015	Change in 2015 over 2014	Change in 2015 over 2014 (%)	2015 share in total
China	1,822	2,099	2210	2,411	2,492	2,350	-142	-5.7%	58%
India	220	240	270	280	256	270	14	5.6%	7%
European Union	189	193	170	166	167	175	7	4.5%	4%
United States	67	69	75	77	83	83	0	0.3%	2%
Turkey	63	63	64	71	71	77	6	8.0%	2%
Brazil	59	64	69	70	71	72	1	1.0%	2%
Russian Federation	50	56	62	67	69	69	0	0.7%	2%
Indonesia	39	45	52	57	58	65	7	12.1%	2%
Iran	61	66	70	69	66	65	-1	-1.5%	2%
South Korea	47	48	47	47	47	47	0	0.0%	1%
Other Countries	660	687	729	755	776	801	25	3.2%	20%
Total	**3,278**	**3,631**	**3,818**	**4,070**	**4,156**	**4,074**	**-82**	**-2.0%**	**100%**

Source: USGS (2016), NBS (2016a)

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

Table A2.3

Recent trends in emissions from cement production ranked according to 2015 emission levels (in million tonnes CO_2)

Country	2010	2011	2012	2013	2014	2015	Change 2015–2014 (Mt)	Change 2015–2014 (%)	2015 share in total
China	599	665	665	709	778	733	-44.3	-5.7%	51.1%
India	83	88	99	102	93	99	5.3	5.6%	6.9%
European Union	79	76	66	64	65	68	2.9	4.4%	4.8%
United States	31	32	35	36	39	39	0.1	0.3%	2.7%
Turkey	29	28	30	34	34	37	2.7	8.0%	2.5%
Russian Federation	22	25	26	28	29	29	0.2	0.7%	2.0%
Indonesia	18	20	23	24	25	28	3.0	12.1%	2.0%
Iran	27	28	30	29	28	28	-0.4	-1.5%	1.9%
Vietnam	25	26	24	25	26	26	0.2	0.8%	1.8%
Japan	25	25	26	27	27	26	-1.4	-5.0%	1.8%
Egypt	20	19	26	23	23	26	2.8	12.2%	1.8%
Other countries	329	335	335	344	353	364	11.4	3.2%	25.0%
Global total	**1,208**	**1,291**	**1,319**	**1,383**	**1,455**	**1,435**	**-20.4**	**-1.4%**	**100%**

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

decreased from about 76% in 2000, 72% in 2005, 63% in 2010 to about 60% in 2015 (USGS, 2016; CCA, 2016). According to EDGAR 4.3.2 data, this yielded an annual decrease of 250 million tonnes in CO_2 emissions, compared to the reference case of Portland cement production. The application of actual clinker fractions for 2010 in EDGAR 4.3.2 have reduced global cement clinker emissions another 130 million tonnes of CO_2 compared to EDGAR 4.2FT2010 data that was used previously. Consequently, a similar amount has been reduced in fuel combustion for cement production and related CO_2 emissions.

Therefore, CO_2 emissions from cement clinker production are not directly proportional to cement production and the shares and ranking of the top 10 cement producing countries in Table A2.2 is somewhat different from the related CO_2 emissions. China accounted for 51% of CO_2 emissions from global total cement clinker production in 2015, followed by India (7%), the United States (2.7%), Turkey (2.5%) and Russian Federation (2%) (see Table A2.3). The EU accounts for 4.4% of the global total. According to EDGAR 4.3.2 FT2015, global cement clinker production emissions declined by 1% in 2015, whereas emissions in 2014 still increased by 5%.

Table A2.4

Recent trends in crude steel production in top-10 producing countries and EU-28, ranked according to 2015 production levels (in million tonnes)

Country	2010	2011	2012	2013	2014	2015	Change 2015-2014 (Mt)	Change 2015-2014 (%)	2015 share in total (%)
China	637	685	717	779	823	804	-19	-2.3%	49.8%
European Union	167	171	165	162	163	160	-3	-1.9%	9.9%
Japan	110	108	107	111	111	105	-6	-5.0%	6.5%
India	69	73	78	81	87	89	2	2.4%	5.5%
United States	81	86	89	87	88	79	-9	-10.6%	4.9%
Russian Federation	67	68	69	69	71	71	-1	-0.8%	4.4%
South Korea	59	69	69	66	71	70	-1	-1.9%	4.3%
Germany	44	44	43	43	43	43	0	-0.6%	2.6%
Brazil	33	35	35	35	34	33	-1	-1.9%	2.1%
Turkey	29	34	36	35	34	32	-3	-7.4%	2.0%
Other Countries	180	189	181	184	181	171	-9	-5.2%	10.6%
Global total	**1,430**	**1,519**	**1,545**	**1,609**	**1,663**	**1,614**	**-49**	**-3.0%**	**100%**

Source: USGS (2016), WSA (2016)

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

A2.3 CO_2 emissions from iron and steel production

Steel production is related with non-combustion CO_2 emissions from blast furnaces where coke and coal is used as reductant for iron ore to produce pig iron and from conversion losses in coke manufacturing. In steel production, most CO_2 is generated in iron and steel making processes that use coke ovens, blast furnaces and basic oxygen steel furnaces. However, the share of electric arc furnaces and direct reduction in secondary and primary steel making, which generate much less CO_2 per tonne of crude steel produced, is increasing over time. This trend in the production mix will reduce the overall CO_2 intensity per tonne of steel produced.

China accounted for 50% of global crude steel production in 2015, followed by Japan (6.5%), India (5.5%), the United States (4.9%), the Russian Federation (4.4%) and South Korea (4.3%) (see Table A.2.4). The EU-28 accounted for 9.9% of the global total in 2015. According to WSA (2016) global crude steel production decreased by 3% in 2015, which marks a change from previous years in which global production steadily increased. Not only production in China decreased by 2% in 2015 (WSA, 2016; CCA, 2016; NBS, 2016a), but also in many other steel-producing nations. India, showing an increase in production of 2%, is an exception among the top-10 countries.

A2.4 CO_2 emissions from other industrial sources

Lime and ammonia production are other industrial sources of CO_2 emissions with emissions approximately proportional to the production levels of these commodities. However, in ammonia production we have corrected for the temporary storage of CO_2 in urea (CO_2 is an input in the urea production process) by country. In urea production CO_2 is one of the inputs, for which in general CO_2 released in the ammonia production process is used. The reason to correct for storage in urea production is that for various countries a significant part of total urea produced is exported to other countries, where the CO_2 is released again when the urea is used on arable land as fertiliser. In this way we account the CO_2 in the in which it is actually released into the atmosphere.

In 2015, lime production is estimated to decrease in most countries resulting in a global decrease of 0.6%. An exception is Poland where lime production increased by 6% (USGS, 2016).

Ammonia production increased in 2015 globally by 0.4%, with notable exceptions China (up 1.5%) and Russia (up 1.7%) (USGS, 2016).

Annex 3 Data quality and uncertainty

For countries with annual national emissions inventory reporting to UNFCCC (OECD-1990 countries and eastern European countries including Russia), total CO_2 emissions per country, according to EDGAR 4.3, for the 1990–2012 period, are generally within 3% of officially reported emissions, except for a few eastern European countries (see examples provided in Table A3.1). Also, most OECD countries estimate the uncertainty in their reported CO_2 emissions (excluding land use, IPCC sector 5) in the range of 2% to 5% (95% confidence interval, equivalent to 2 standard deviations).

The uncertainty in EDGAR's total national CO_2 emissions from fossil fuel use and other, non-combustion sources is estimated at about 5% for OECD countries and around 10% for countries of the former Soviet Union, such as Russia and the Ukraine. For other countries which are not annually reporting national emissions inventories to UNFCCC, the EDGAR uncertainty estimates of national CO_2 emissions vary between 5% for countries with well-developed statistical systems, such as India, and around 10% or more for countries with less-developed statistical systems. This is based on the uncertainty in the fuel data discussed in the 2006 IPCC Guidelines for greenhouse gas emission inventories (IPCC, 2006) and in the variation in the carbon content per fuel type, compared with IPCC default values (Olivier et al., 2010). Moreover, energy statistics for fast changing economies, such as China since the late 1990s, and for the countries of the former Soviet Union in the early 1990s, are less accurate than those for the other countries within the OECD (Marland et al., 1999; Olivier and Peters (2002). For China, we assume an uncertainty of 10%, based on considerations discussed below. The large difference in Table 2.9 for China is mainly due to the very recent revision included in the EDGAR 4.3.2 data set, whereas the officially reported emissions for 2005 were reported in 2012 (Government of China, 2012).

CO_2 emission trends over recent years, estimated using energy data published annually by BP, appear to be reasonably accurate for estimating global annual CO_2 trends. For example, based on older BP energy data, the increase in 2005 in global CO_2 emissions from fuel combustion compared to 2004 was estimated at 3.3%, globally. With more detailed statistics by the International Energy Agency (IEA) for 2005, which became available two years later, the increase is estimated at 3.2%. At country level, differences can be larger, particularly for small countries and countries with a large share in international marine fuel consumption (bunkers) and with a large share in non-combustion fuel use.

The uncertainty in CO_2 emissions from fossil-fuel combustion using international statistics is discussed in detail in Marland et al. (1999) and Andres et al. (2012), and general uncertainty characteristics in global and national emission inventories are discussed in Olivier and Peters (2002). Andres et al. (2012) evaluate several studies on the uncertainty of CO_2 emissions from fossil-fuel use and cement production and conclude that they range from between about 3% and 5% for the United States, to between 15% and 20% for China, based on a comparison of CO_2 estimates based on national coal statistics and on the sum of provincial coal statistics (Gregg et al., 2008), to estimates of 50% or more for countries with poorly maintained statistical infrastructure (Marland et al., 1999). In spite of the large national efforts to provide accurate estimates, emission inventories in non-OECD countries are generally less accurate than those in OECD-1990 countries.

Studies on uncertainty about China's coal statistics and CO_2 emissions

In recent years, the uncertainty in the CO_2 estimates for China was the subject of several studies. The uncertainty estimate by Gregg et al. (2008) was based on revisions of energy data for the transition period of the late 1990s, which may not be fully applicable to more recent energy statistics, since the revisions made by the National Bureau of Statistics of China in 2006 and 2010 (Tu, 2011). Also in 2011, Wang and Chandler (2011) gave a good description of the revision process for energy and GDP

Table A3.1

Differences between EDGAR national total CO_2 emissions and official NIR/CRF submissions for Annex I countries and for other major countries (excluding LULUCF emissions, IPCC sector 5) (in % of NIR/CRF data)

Differences Per year	1990	1995	2000	2005	2008	2010	2011	2012	Average	Reported uncertainty (95% CI)	Note on uncertainty
United States	-2%	-1%	1%	-3%	-8%	0%	-6%	-8%	-3%	4%	for minimum: -2%
Canada	-2%	1%	1%	-4%	-5%	0%	0%	1%	-2%	2.4%	for energy sector
European Union	-2%	-1%	-1%	-2%	-3.4%	2.0%	-5%	-2%	-2%	2%	for EU15
Russian Federation	-5%	6%	13%	12%	10%	12%	12%	11%	7%	4%	
Ukraine	8%	13%	17%	8%	0%	11%	10%	1%	9%	3.7%	
Japan	3%	3%	4%	3%	-4%	9%	7%	6%	3%	1%	
Australia	0%	3%	5%	9%	9%	5%	7%	7%	6%	4 to 5%	
Total	**-1.8%**	**0.7%**	**2.4%**	**-0.3%**	**-3.5%**	**3.2%**	**-1.3%**	**-1.6%**	**-0.5%**		
China				12%							
India			3.3%								

Note: Reported uncertainty estimate cf. IPCC definition: 95% confidence interval, CI).
Source: EDGAR 4.3.2: EC-JRC/PBL (2016); NIR/CRF data: UNFCCC (2014); for other countries: Second National Communication.

statistics by the NBS, also in response to the results from the two National Economic Censuses.

Interestingly, a recent study by Guan et al. (2012), continuing the comparison made by Gregg et al. (2008), points out the large difference between total provincial coal consumption statistics and national total statistics, whereas Tu (2011) attributes the discrepancy for a large part to the unreported coal production by small private coal mines in Shanxi in Inner Mongolia that continued producing although officially they had to shut down, together with staffing shortage at the National Bureau of Statistics of China. Tu claims that, therefore, China's coal statistics have been seriously underreported since 1998. He also mentions that in 2006 the NBS of China made statistical revisions for the 1999–2004, which were particularly large in the years between 1999 and 2001, and once more in 2010, with smaller revisions for the 1998–2007 period (see Figure 5.2 in Tu (2011)). The question remained whether these revisions capture all discrepancies.

In 2012, Guan et al. (2012) conclude that this is not the case, stating a 1.4 billion tonnes CO_2 gap for 2010, between estimates based on national coal statistics and on provincial data. Guan et al. (2012) also compare with other reported estimates for China's CO_2 emissions over the 2007–2010 period, including EDGAR 4.2 data. They show that for 2008, EDGAR CO_2 emissions are one of the highest being compared and are actually almost equal to the higher estimate by Guan, based on the provincial coal statistics. For 2007 the EDGAR estimate is also closer to the higher 'provincial' CO_2 estimate than to the estimated 'national total'. Thus, it could be tentatively concluded that the uncertainty range of the EDGAR 4.2 data for China may be not symmetrical, but may have a larger uncertainty to the low end than to the high end of the range.
In May 2015, the National Bureau of Statistics of China (NBS) published revised energy balances for the 2000–2013 period, on an aggregate level only, based on results from the last National Economic Census (NBS, 2015c). As of 2016, the IEA has incorporated these changes accordingly in revised detailed energy balance statistics for China for the 1990–2013 period (IEA, 2016c), and included all NBS revisions in detail. Apart from revisions of volumes of coal in tonnes, also the heat content of coal has been revised in the IEA data set. For more information on how the IEA included the revised detailed energy balances of NBS, see IEA (2016d).

Since 2014, several studies on the accuracy of energy statistics on China and its CO_2 emissions have shed new light on this issue (e.g. Ma et al., 2014; Liu et al., 2015; Ma and Zheng, 2016; Korsbakken et al., 2016). We discussed the study by Liu et al. in detail, in last year's report (Olivier et al., 2015), and concluded that, if the paper would correctly compare only the CO_2 emissions from combustion between data sets, the differences would be much smaller than suggested in their paper. The study also showed a new analysis of the energy content and carbon content of two large samples of coal mined in China. Unfortunately, the samples were only for one year. They also used a high fraction of 8% for carbon non-oxidised during the combustion, without reference to how this fraction was determined. The Liu et al. study underlines the importance to have accurate data on the heat content, the carbon content and the fraction of carbon not oxidised – also over time – in addition to the uncertainty in coal consumption in tonnes. Korsbakken et al. (2016) built on and extended the study by Wang and Chandler (2011), and compared the impact of various revisions of coal statistics by the NBS, following each of the three National Economic Censuses, and compared national and total provincial statistics with correlated economic statistics, such as on fossil-fuel-fired power generation and cement and crude steel production, over the 1995–2015 period.

From these recent studies on the accuracy of the data on China's CO_2 emissions (Tu, 2011; Andres et al., 2012; Guan et al., 2012; Liu et al., 2015; Korsbakken et al., 2016), and taking into account the uncertainty in the default coal emission factors of the order of 5% or more, based on OECD countries (Olivier et al., 2010), and the major revision by NBS in 2015 of the coal statistics going back to 2000, we concluded that the uncertainty in the present EDGAR 4.3.2 CO_2 estimates for China is about ±10%. This conclusion was also based on subsequent revisions of CO_2 emission estimates made by the IEA.

General conclusion

Our assessment of recent literature on the accuracy of CO_2 emissions, also for other countries than China, yielded an uncertainty for our estimates of CO_2 emissions of about 5% for most OECD countries, and in the range of 10% for China, the Russian Federation and most other non-OECD countries. Our preliminary estimate of total global CO_2 emissions in 2015 is believed to have an uncertainty of about 5%, and our estimated emission decrease of 0.1% may be accurate to within ±0.5%.

Annex 4 Global and regional temperatures

The weather in 2014 and 2015

This Annex summarises the regional winter and summer temperatures in 2015 and compares them with 2014, as this is relevant for inter-annual changes in de demand for energy for space heating and air conditioning.

NOAA (2016a) recorded 2015 as the hottest year since records began in 1880. The 16 warmest years ever recorded are also in the 1998–2015 period. The year 2015 was characterised by one of the strongest El-Niños and record warmth in the global oceans (with an annually averaged temperature for ocean surface waters around the world that was 0.74 °C higher than the 20th century average). Europe experienced a relatively mild winter in 2015, and accumulated less than 3% more heating degree days than in 2014. The United States and Russia, and other former Soviet Union countries, had a milder winter in 2015 than in 2014, and recorded 9% fewer heating degree days over the year (NOAA, 2016a).

Heating Degree Days as a proxy for the demand for space heating

Winter temperatures can vary considerably from year to year and can have a significant impact on the energy demand for space heating of houses and offices. Therefore, winter temperature is one of the main variables influencing inter-annual changes in fuel consumption on both a national and global scale.

Other key explanatory variables are economic growth and trends in fuel prices. Indicators used for estimating the difference between the winters of 2009 and 2008 are the annual number of Heating Degree Days for particular cities or countries, and spatial temperature anomalies across the globe.

The number of *Heating Degree Days* (HDD) at a certain location, or a population weighted average over a country, is defined as the number of days that the average temperature is below a chosen threshold, for instance 15 pC, below which space heating is assumed to be applied. The number of HDD for a particular day is defined as the difference between the threshold temperature and the average temperature that day. Although the HDD method is a proxy for the energy demand for space heating and does not give precise values, it is often used in trend analyses of energy consumption. In Table A4.1 the number of *Heating Degree Days* in 2013, 2014 and 2015 is shown in or near selected cities as an indicator of winter temperatures in these countries or regions. The absolute numbers indicate the amount of fuel required for space heating per household (e.g., much more in Moscow than in Los Angeles or New Delhi). From the table it can be concluded that the United States experienced a relatively warm winter in 2015, with HDDs about 9% lower than in 2014 (weighted for population), and that parts of China (Beijing) had a somewhat colder winter than in 2014.

Table A4.1

Heating Degree Days (HDD-15) for selected cities, the United States and the European Union

Country	City	2013	2014	2015	Trend last year
China	Beijing	2,492	2,163	2,257	4%
	Shanghai	1145	998	994	0%
United States	New York	2,026	2,212	1,990	-10%
	Washington, D.C.	1,677	1,764	1,593	-10%
	Atlanta	1,122	1,246	931	-25%
	Los Angeles	318	178	244	37%
United States (AGA, 2016)		**4,338**	**4,423**	**4,045**	**-9%**
Italy	Rome	1,092	868	1,012	17%
Germany	Berlin	2,553	2,016	2,138	6%
	Düsseldorf	2,298	1,655	1,889	14%
Netherlands	Amsterdam	2,331	1,679	1,907	14%
United Kingdom	London	2,057	1,511	1,611	7%
EU-28 (Eurostat, 2016g)		**3,158**	**2,809**	**2,904**	**3%**
India	New Delhi	269	304	227	-25%
	Mumbai	0	0	0	
Russia	Moscow	3,773	3,826	3,489	-9%
Japan	Tokyo	1,071	1,076	962	-11%
	Osaka	1,326	1,297	1,099	-15%
South Korea	Seoul		2257	2187	-3%
Canada	Montreal		3,714	3,641	-2%
	Toronto		3,315	3,039	-8%
	Calgary		4,353	3,712	-15%
	Vancouver		1,956	1,787	-9%
Canada (Statistica, 2016)		**4,094**	**4,271**	**4,030**	**-6%**
Brazil	Rio de Janeiro		0	0	
	Sao Paulo		73	49	-33%
Indonesia	Jakarta		0	0	
Saudi Arabia	Riyadh		225	212	-6%
	Jeddah		0	0	

Source: http://www.degreedays.net/ for cities. For country averaged values: see table.

List of abbreviations and definitions

AGA	American Gas Association
ACP	Atmospheric Chemistry and \physics
IAI	International Aluminium Institute
AR5	Fifth Assessment Report of IPCC
BP	BP plc (energy company; formerly British Petroleum Company plc)
CCA	China Cement Association
CPP	Clean Power Plan of US EPA
CCS	Carbon Capture and Storage
CDD	Cooling Degree Day
CDIAC	Carbon Dioxide Information Analysis Centre (at ORNL)
CLIMA	DG Climate Action, European Commission
COP22	UNFCCC Conference of the Parties 22nd Session
CSA	China Statistical Abstract
CSI	Cement Sustainability Initiative (of WBCSD)
CSP	Concentrated Solar Power
EC	European Commission
EDGAR	Emission Database for Global Atmospheric Research
EIA	Energy Information Administration (of the U.S.)
EPA	Environmental Protection Agency (of the U.S.)
EIT	Non-EU economies in transition
EU ETS	EU Emissions Trading System
EU/EU-28	European Union with 28 Member States
Eurostat	Statistical Office of the European Union
G20	Group of Twenty: 19 countries: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, United Kingdom, United States, and European Union.
GCP	Global Carbon Project
GDP	Gross domestic product
GNP	Gross national product
GFED	Global Fire Emissions Database
GFRA/FRA	*Global Forest Resources Assessments*
GJ	Gigajoule (= 109J)
GHG	Greenhouse Gas
Gt	Gigatonnes (1,000 megatonnes = 109 metric tonnes)
GW	Gigawatt (1 billion W = 109 W) (unit of power, sometimes denoted as GWe)
GWth	Gigawatt thermal (unit of power input, as opposed to GWe, which refers to electricity output)
GWEC	Global Wind Energy Council
HDD	Heating Degree Day
IAEA	International Atomic Energy Agency
ICRA	Information and Credit Rating Agency of India Limited
IEA	International Energy Agency (Paris)
IHA	International Hydropower Association
IMF	International Monetary Fund

INDC	Intended Nationally Determined Contribution (national emission mitigation action plan under the Paris Agreement)
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
JRC	Joint Research Centre of the European Commission
LCOE	Levelised costs of electricity
LPG	Liquefied Petroleum Gas
LNG	Liquefied Natural Gas
LULUCF	Land use, land-use change and forestry
MATS	Mercury and Air Toxics Standards
Mt/Mton	Megatonnes (1 million metric tonnes = 106 metric tonnes)
MJ	Megajoule (= 106 J)
MW	Megawatt (1,000 KW = 106 W) (unit of power, sometimes denoted as MWe)
NBS	National Bureau of Statistics of China
NDC	Nationally Determined Contribution (national emission mitigation action plan under the Paris Agreement)
NMVOC	Non-methane volatile organic compounds
NOAA	U.S. National Oceanic and Atmospheric Administration
NOAA/NCDC	U.S. National Oceanic and Atmospheric Administration/National Climatic Data Centre
OECD	Organisation for Economic Co-operation and Development
OECD-1990	Countries that are members of the OECD in 1990 (i.e. excluding newer members Chili, Czech Republic, Estonia, Hungary, Mexico, Poland, Slovakia, Slovenia, South Korea)
OPEC	Organisation of Oil Exporting Countries
PBL	PBL Netherlands Environmental Assessment Agency
PPP	Purchasing Power Parity
PV	Photovoltaic
PJ	Petajoule (= 1015J)
SNA	2008 UN System of National Accounts
SYB	Statistical Yearbook (China)
TFC	Total Final Consumption
TJ	Terajoule (= 1012J)
TPES	Total primary energy supply
TW	Terawatt (1,000 GW = 1012 W) (unit of power, sometimes denoted as TWe)
TWh	Terawatt hour (1000 billion W hour = 1012 Wh = 3.6 Petajoule, PJ)
UN	United Nations
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
UNEP	United Nations Environment Programme
UNPD	United Nations Population Division
USD	U.S. Dollar
USA	United States of America
USGS	United States Geological Survey
WBCSD	World Business Council on Sustainable Development
WDI	World Development Indicators (of the World Bank)
WNA	*World Nuclear Association*
WMO	*World Meteorological Organization*
WG III	Working Group III of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC)
WPP	World Population Prospects of UNPD
WSA	Word Steel Association
WTO	World Trade Organization

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