TRENDS IN GLOBAL CO_2 EMISSIONS

2015 Report

BACKGROUND STUDIES

PBL Netherlands Environmental Assessment Agency

European Commission
Joint Research Centre

Trends in global CO_2 emissions: 2015 Report

Background Study

Trends in global CO_2 emissions: 2015 Report

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This CO_2 report 2015 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 of global CO_2 emissions from fossil fuels and cement. CO_2 emission estimates have been made by PBL and the JRC on the basis of energy consumption data for the period 1970-2012 published by the International Energy Agency (IEA), and for the period 2013-2014 published by British Petroleum, except for coal consumption in China over the 2012–2013 period, for which data published by the National Bureau of Statistics of China were used. The estimations are also based on production data for 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, which was developed jointly by the JRC and PBL. The greenhouse gas emissions of from the EDGAR 4.2 FT2012 dataset have also been used for the global emissions overviews in the annual UNEP Emissions GAP Report. All reports are available from http://edgar.jrc.ec.europa.eu/whats_new.php?p=3 and http://www.pbl.nl/en/publications/trends-in-global-co2-emissions-2015-report.

PBL Netherlands Environmental Assessment Agency is the national institute for strategic policy analyses in the fields of the environment, nature and spatial planning. It contributes to improving the quality of political and administrative decision-making, by conducting outlook studies, analyses and evaluations in which an integrated approach is considered paramount. Policy relevance is the prime concern in all our studies. PBL conducts solicited and unsolicited research that is both independent and always scientifically sound.

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle. Its work has a direct impact on the lives of citizens, as its research outcomes contribute to a healthy and safe environment, secure energy supplies, sustainable mobility and consumer health and safety. Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

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Summary and main findings

Growth in global CO_2 emissions almost stalled in 2014

After a decade of annual increases of 4%, on average, and two years (2012 and 2013) of slowing down to about 1%, the growth in global CO_2 emissions almost stalled, increasing by only 0.5% in 2014 compared to the record level in 2013. In that year, emissions from fossil-fuel combustion and from industrial processes (production of cement clinker, metals and chemicals) totalled to 35.7 billion tonnes CO_2. At the same time, the world's economy grew by 3%, showing a partial decoupling between the growth in global CO_2 emissions and that in the economy.

Primary energy consumption decreased

Global CO_2 emissions mainly reflect the world's fossil energy consumption. In 2014, per capita primary energy consumption decreased compared to the previous year, for the first time since 1998 (excluding the recession year of 2009). The mild winter considerably helped to limit fossil-fuel demand for space heating, particularly in Europe. 2014 was the warmest year globally since records began in 1880, even in the absence of El Niño conditions, which would have caused even higher temperatures. This decrease in per capita primary energy consumption was not reflected in a decrease in power generation, but in a modest increase in power generation of only 350 TWh or 1.5%, which is the smallest increase since 2001 (except for the recession year 2009). Two-thirds of the global increase in power generation was supplied by renewable energy. Shifts towards low-carbon fuels have been observed in different world regions. Since 2004, when wind and solar power had a share of 0.5% in global power generation, the share doubled every four years, up to almost 4% in 2014. Although in the same period hydropower increased globally by almost 40% since 2004, its share remained the same at about 16%. The share of nuclear power decreased in this period by 5%, from about 16% to 11%. In East Asia (notably China and Japan), the phasing in of nuclear energy will also further help to reduce CO_2 emissions.

China, United States, EU-28 and India account for 61% of all emissions

The top 4 emitting countries/regions, which together account for almost two thirds (61%) of the total global CO_2 emissions are China (30%), the United States (15%), the European Union (EU-28) (10%) and India (6.5%). China saw no growth in coal demand in 2014 and increased its CO_2 emissions by only 0.9% compared to 2013, which is the lowest annual increase over the last decade. The United States increased its CO_2 emissions by only 0.9%, which is lower than in the previous two years. This was mainly the result of a small drop in coal-fired power generation and an increased use of natural gas for space heating due to a colder winter than in 2013. The pace of the continued reduction in emissions in the EU-28 was increased in 2014 to 5.4%, mainly because of the decrease in fossil-fuel consumption for power generation and manufacturing, but also because of the 10% lower demand for space heating. Other non-OECD-1990 countries and Russia showed smaller decreases: Japan decreased by 2.6%, Australia by 2.1% and Russia by 1.5%. In contrast, CO_2 emissions in most other non-OECD-1990 countries increased (e.g. by 7.8% in India, by 3.3% in Brazil and by 3.2% in Indonesia). Most of the increase in emissions since the late 1990s has occurred in non-OECD 1990 nations, which contributed to 61% of the global emissions in 2014, compared to 32% in 1990, the baseline year of the Kyoto Protocol. China, which accounted for almost half of the 61% share, has recently put a considerable effort in revising its energy statistics for the period 2000 to 2013. This has definitely resulted in better estimates of the real fossil-fuel consumption in this period, even though uncertainty levels may not have decreased by much. Comparisons of different bottom-up inventories for China have backed our uncertainty range of 10%.

Revision of China's coal statistics

The major revision of China's coal statistics for the 2000–2013 period, which was published in May 2015, showed coal consumption to be 7% to 13% higher than previously reported for the 2005–2012 period. This resulted in total national CO_2 emissions from fossil-fuel combustion that are estimated to be 6% to 11%

higher for that period compared to emissions based on International Energy Agency (IEA) statistics released in 2014, and global CO_2 emissions increased accordingly by a few per cent. These new figures have been used in this report, which shows accumulated CO_2 emissions for China to be 5 gigatonnes greater than our estimates published last year. In terms of accumulative global emissions, this historical revision means a shift of two months before the 'carbon budget' for the period to 2050 is reached that is considered safe for meeting the 2 °C target. For the most accurate estimate of China's CO_2 emissions from fossil-fuel combustion for 2011 to 2013 and recent updates for other countries up to and including 2013, we refer to the IEA's 2015 edition of 'CO_2 emissions from fossil fuel combustion'.

China largest emitter, but United States tops per capita emissions

The new data show China's CO_2 emissions currently to be twice as high of those in the United States, exactly 10 years after its emissions equalled those of the United States. China's high ranking is mainly caused by the sheer size of its population and economy and the fact that its energy mix is strongly reliant on coal. China's per capita emissions are similar to those of the European Union, while per capita emissions in the United States are twice as high as those of both China and the European Union. However, there are many indications that the growth in China's emissions is also stalling: the share of Gross Domestic Product (GDP) of its growing service sector has surpassed that of the much more energy-intense industrial sector's share and preliminary 2015 statistics of key indicators (such as the production of electricity, steel and cement) show all zero or negative growth rates. This report also assesses and largely dismisses conclusions in a recent paper on China's CO_2 emissions, which claimed that international inventories such as EDGAR are far too high.

Structural changes in global CO_2 emission trends still uncertain

The slowdown of the growth in China's CO_2 emissions since 2012 reflects structural changes in China's economy towards a less energy-intensive service sector and high value-added manufacturing industry that is more focussed on domestic consumption, with more energy efficiency and towards a low-carbon energy mix. On a global scale, the slowdown that has also lasted three years now, to a large extent, can be explained by the changes in China's economy and the associated energy consumption. However, it is uncertain whether these changes also reflect structural changes in the wider *global* economy, *global* energy efficiency improvements and in the energy mix of other key world players such the United States, European Union, India and Russia. What we do know is that it is very likely that the very high global annual emission growth rates of, on average, 3% per year observed in the years 2003 to 2011 are definitely over for many years to come (even 4% per year when excluding the global recession years 2008 and 2009), whereas the average global growth rate over the 1980–2002 period was 1.2% per year.

PBL and JRC co-production

The preliminary CO_2 emission estimates in this report have been made by PBL Netherlands Environmental Assessment Agency and the European Commission's Joint Research Centre (EC-JRC), on the basis of fossil-fuel consumption data from the International Energy Agency (IEA) for the 1970–2012 period and revised coal consumption data for the 2000–2012 period, very recently published by the National Bureau of Statistics of China. The fossil-fuel estimates for 2013 and 2014 were based on trends in consumption data published by energy company BP. The estimates are also based on gas flaring and production data for cement, lime, ammonia and steel. The emissions per country from 1970 to 2012 are part of the *Emission Database for Global Atmospheric Research* (EDGAR) version 4.3, which is a project run by the EC-JRC with support of PBL.

Supplementary information

Supplementary information of key tables and figures in this publication can be downloaded from the PBL website: http://www.pbl.nl/en/publications/trends-in-global-co2-emissions-2015-report.
The CO_2 emissions over the 1990–2014 time series, for all countries, can be downloaded from the EDGAR website: http://edgar.jrc.ec.europa.eu/overview.php?v=CO2ts1990-2014.
For a concise summary of this report see the infographic on global CO_2 emission trends at: http://infographics.pbl.nl/website/globalco2-2015/.

Introduction

This report presents the results of a trend assessment of global CO_2 emissions from fossil fuel and cement up to 2014, and updates last year's assessment (Olivier et al., 2014). This assessment focuses on the changes in annual CO_2 emissions from 2013 to 2014, and includes not only fossil-fuel combustion on which the BP (2015) 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 and 2014, more details are provided in Annex A1.1.

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 publishes comprehensive assessments of the global carbon budget, including all CO_2 sources and sinks (GCP, 2014; Le Quéré et al., 2014).

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 production and use, non-fossil energy and other CO_2 sources. This chapter also summarises the main conclusions on trends, mitigation achievements and prospects, and the main conclusions of the *Fifth Assessment Report* (AR5) of *Working Group III* (WG III) of the *Intergovernmental Panel on Climate Change* (IPCC) (IPCC, 2014a) regarding global greenhouse gas emissions (Section 2.1). Section 2.2.1 presents our assessment of a recent paper on CO_2 emissions in China of Liu et al. (2015) that suggested that several other inventories substantially overestimate China's CO_2 emissions from fossil fuel and cement production. In this section we also present our latest estimate of China's CO_2 emissions, including the impact of the substantial revision of China's coal balances from 2000 onwards, of which annual totals were published in May 2015. The data quality and uncertainty estimates of countries and global emission estimates are discussed in Section 2.6, including a comparison of Emissions Database for Global Atmospheric Research (EDGAR) data with official reports of national emissions.

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. In addition, the extent to which structural changes have caused the observed slowdown in the increase in global CO_2 emissions is discussed. For more information on energy efficiency improvements and carbon capture and storage (CCS) activities, please see the 2013 edition of the Global CO_2 emissions report (Olivier et al., 2013).

Chapter 4 presents the context of the present report. The relationship between CO_2 emissions and total greenhouse gas emissions and pledges made by countries for 2020 under the Copenhagen and Cancun Agreements and the mitigation commitments of national governments for 2025 or 2030 'INDCs', which are discussed at the 21st Conference of the Parties of the UNFCCC in Paris this year. This chapter also discusses other government authorities, such as municipalities, and groups within society which are equally important for realising national and collective global commitments to mitigate greenhouse gases.

National CO_2 emissions are accounted for in accordance with the official Intergovernmental Panel on Climate Change (IPCC) reporting guidelines, which are approved and used by countries to report their national greenhouse gas emissions to the UNFCCC and Kyoto Protocol, and are based on domestic activities that generate greenhouse gas emissions ('actual' national emissions) (IPCC, 2006). However, due to the use of other data sources and emission factors, the data reported here will differ somewhat from the emissions officially reported by individual countries to the UNFCCC. Nevertheless, data are generally consistent within the related uncertainty estimated for both datasets (see Section 2.6). A detailed comparison of the EDGAR emissions data used in the Fifth Assessment Report of Working Group III of the IPCC (IPCC, 2014a) and those of the *Carbon Dioxide Information Analysis Centre* (CDIAC) used in the *Global Carbon Project* (GCP, 2014) is provided in Annex A1.5.

1.1 Methodology and data sources used

This report assesses the trend in global CO_2 emissions with a focus on the contribution of fossil fuel use. 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 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 Fifth Assessment report of Working Group III 'Mitigating of Climate Change' of the IPCC (2014a) and the Emissions Gap Reports of UNEP (2014, 2015b), for which data from EDGAR 4.2 and EDGAR 4.2FT2010, respectively, were provided.

For global CO_2 emissions from 1970 to 2012, we use the EDGAR 4.3 dataset (EC-JRC/PBL, 2015) for greenhouse gases, which results from a project of the European Commission's Joint Research Centre (JRC) with assistance from the PBL Netherlands Environmental Assessment Agency (forthcoming in 2015), because it covers all countries with a detailed sectoral breakdown and consistent time series. This dataset provides greenhouse gas emissions per country and on a 0.1 x 0.1 degree grid for all anthropogenic sources identified by the IPCC (2006) (EC-JRC/PBL, 2015) for the 1970–2012 period. The CO_2 emissions from fuel combustion in EDGAR are based in the International Energy Agency (IEA) energy statistics for fossil fuel consumption released in 2014 (IEA, 2014a). However, for China we included the impact on coal emissions of the major revision of coal consumption statistics released by the Chinese National Bureau of Statistics in May 2015 (NBS, 2015b). For the most accurate estimate of the CO_2 emissions from fuel combustion of China, including this revision, and of other countries due to updated fuel statistics that include 2013, we refer to the 2015 edition of the IEA report 'CO_2 emissions from fuel combustion', which uses the same IPCC methodology and identical IPCC default CO_2 emission factors as used in the EDGAR 4.3 dataset (IEA, 2015b). In particular Part III of this IEA report on total greenhouse gas emissions describes the greenhouse gas emissions data of EDGAR 4.3 FT2010, documented with references to data sources and methodologies (Olivier and Maenhout, 2015).

EDGAR 4.3 includes CO_2 emission factors for cement production per tonne of cement produced, taking into account the decreasing share of clinker in cement. This is a significant improvement on most other global CO_2 inventories (such as CDIAC and GCP), in particular those of countries such as China where the clinker fraction continues to decline, also in recent years. These shares have been updated from 1990 onwards and extended from 2008 to 2012 with country-specific data for all countries reporting annually their emissions inventories to the UNFCCC (mostly OECD1990 countries, Eastern European countries and Russia) and six other large countries, whereas regional estimates were used for the remaining countries. In addition to cement production, EDGAR 4.3 also includes other non-combustion industrial processes, such as the production of lime and soda ash (IPCC category code 2A) and carbon used in metal production (IPCC category code 2C). 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, which are not estimated in most other CO_2 datasets (see Table A1.3 in Annex A1.5).

The core EDGAR 4.3 dataset on CO_2 emissions was extended to 2014 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. The 2012 CO_2 emissions have been aggregated into five main source sectors (with corresponding IPCC category codes in brackets):

(1) fossil-fuel combustion (1A), including international 'bunkers', (marine and aviation),
(2) fugitive emissions from fuels (1B),
(3) cement production and other carbonate uses (2A),
(4) feedstock and other non-energy uses of fossil fuels (2B+2C+2G+3+4D4),
(5) waste incineration and fuel fires (6C+7A).

Box 1.1 Why do CO_2 emissions in this report differ from other data sets?

There are two 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, although differences are generally well within the uncertainty estimates (see Section 2.6). Emissions are generally calculated using statistics on activities (e.g. TJ of coal consumption) and so-called emission factors (e.g. kg CO_2/TJ coking coal combusted). 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.
Even when different emission data sets were compiled using the same method and level of detail (e.g. of fuel types considered) for the calculation, differences will occur for the follow main reasons:

- The statistics used may differ somewhat due to different data sources, different release dates and different sources for the conversion factors used. Each of them may have different revisions included. For example, we incorporated the very recent major revision of China's coal statistics in our data set.
- Countries will generally use country-specific emission factors for key sources, whereas international data sets generally use 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 should be used, according to the IPCC guidelines (IPCC, 2006).
- The definitions used for specific emission sources may differ between CO_2 emission data sets. 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.
- 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 EIA includes these emissions in fossil-fuel CO_2 emissions.
- Some international data sets, notably those of 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.
- CO_2 emissions from fossil-fuel combustion for 2013 and 2014 in this report are calculated by extrapolation from the EDGAR 4.3, fossil-fuel CO_2 emissions per country for 2012 (based on detailed IEA fuel data for combustion purposes), using the 2012 to 2014 trends in total coal, oil and gas consumption in energy units as reported by BP. These combined with the total CO_2 emissions per country in 2012 by main fuel type. Some countries have relatively large shares of oil sales for international transport or relatively large shares of non-energy uses of gas and oil products. In those cases, the annual BP trends may reflect the trends in the domestic fuel combustion part less accurately, when annual changes in these other uses are much different from those in the main use of domestic combustion.

Differences between official national CO_2 emissions are generally within 5% for OECD-1990 countries and around 10% for countries with less well-developed statistical systems (for details see Section 2.6). Main differences in allocation, methods and level of detail of major international data sets and of official national emission inventories are summarised in Annex A1.5.

For the fuel combustion emissions (IPCC category code 1A) that account for about 90% of total global CO_2 emissions, excluding forest fires, emissions per country for 2012 were divided into four main fuel types for 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 2012–2014 trend was based on BP fossil fuel consumption data released in June 2015 (BP, 2015). However, as detailed in Annex A1.1, the energy statistics of BP (2015) have been corrected: (i) in the national oil consumption data with corrections for biofuel and other fossil waste fuels, and (ii) with oil consumption data for international shipping and international aviation extrapolated from IEA bunker fuel statistics with the BP (2015) oil consumption trend.

For the other emissions, (IPCC category codes 1B, 2, 3, 4, 6, 7), 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 USGS (2015), WSA (2015) trends. The USGS (2015) commodity statistics were also used for the trends of the feedstock use and ammonia production. Only for the urea production data from IFA (2015) were used. For flaring we assumed that the updated data of NOAA (2012) were constant for 2013-2014.

More details on the methodology and data sources are presented in Annex A1.1. Data quality and uncertainty in the data are discussed in Section 2.6. The uncertainty in CO_2 emissions from fossil-fuel combustion using international statistics is discussed in detail by Marland et al. (1999) and Andres et al. (2012), and general uncertainty characteristics in global and national emission inventories by Olivier and Peters (2002).

This study provides time series of CO_2 emissions from fossil fuel use and industrial processes for 1990–2014 per country, per capita and per unit of GDP, which are also available on http://edgar.jrc.ec.europa.eu/overview.php?v=CO2ts1990-2014.

Results

2.1 Increase in global CO_2 emission growth almost stalled

In terms of CO_2 emissions, energy consumption and the weather, 2014 was a remarkable year, on both global and regional levels. The increase in global CO_2 emission growth almost stalled, per-capita energy consumption decreased, and it was the warmest year on record.

After a decade of very high annual growth rates of global CO_2 emissions of 4% on average, followed by two years of slowdown to about 1%, the growth in emissions almost stalled in 2014 with an increase of only 0.5% to 35.7 billion tonnes (Gt) CO_2 (Figure 2.1). At the same time, the world's population and economy continued to grow by 1% and 3%. Apart from the recent two years of recession, the 0.5% emission growth in 2014 was the lowest global growth rate since 1998. Where, in the previous years, it was debated whether or not the slowdown was accidental, now, after three years and trends over two or three quarters of 2015, we can conclude that the global slowdown is very likely due to structural changes. The slowdown in emissions and the continuing economic growth suggests a partial decoupling of the trend in global CO_2 emissions from that of the global economy. China, with 10.6 Gt CO_2 and a share of 30% in global CO_2 emissions, plays a pivotal role in this respect.

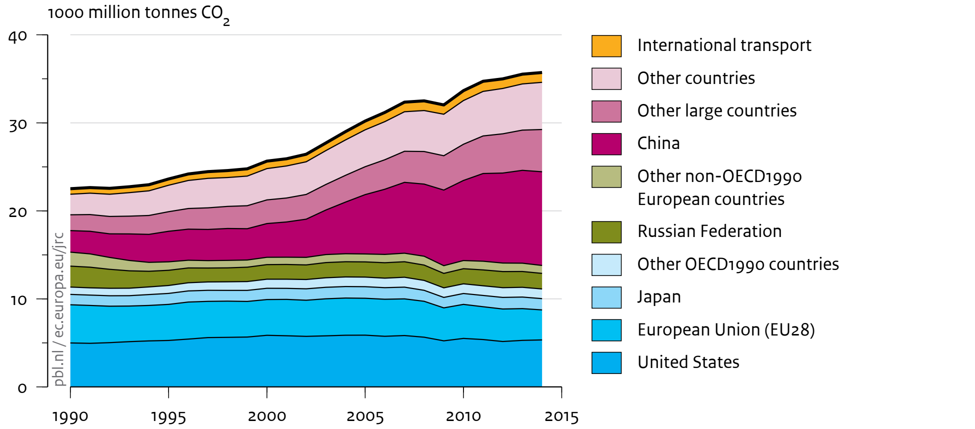
In 2014, global primary energy consumption, per capita, decreased for the first time since 1998 when Russia and the 'Asian tiger' countries were in recession (excluding the global recession year of 2009) (BP, 2015). Fossil fuel prices changed substantially during the year, (shale) oil production in the United States increased in combination with continuous production in OPEC member countries, and there was no growth in the demand for coal in China. In addition, increasing renewable power production, accounting for two-thirds of the increase in global power production, also played a role. As for the weather, 2014 was the warmest year, globally, since records began in 1880. Including 2014, 9 of the 10 warmest years in the 135-year period on record occurred in this century. A large drop in demand for space heating (by 10%) in the European Union (EU-28) due to the warmest winter months on record contributed to plummeting gas consumption and the large drop (by 5%) in the EU's CO_2 emissions in 2014.

Major changes in fossil-fuel statistics of China, the country with the highest CO_2 emissions

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. Over the past three years, China's economy has continued to become more oriented on service and domestic consumption. As a percentage of GDP, the service sector started to grow again about five years ago and, at 48%, has now surpassed the industrial sector as the largest economic sector (see Figure 2.5). Nevertheless, the smoothness of the transition is difficult to predict, especially as China still has extraordinarily high annual growth rates in all sectors. However, general trends are clear, as can be seen in countries that started earlier in their development from a mainly agricultural economy via industrial development towards a service-oriented economy.

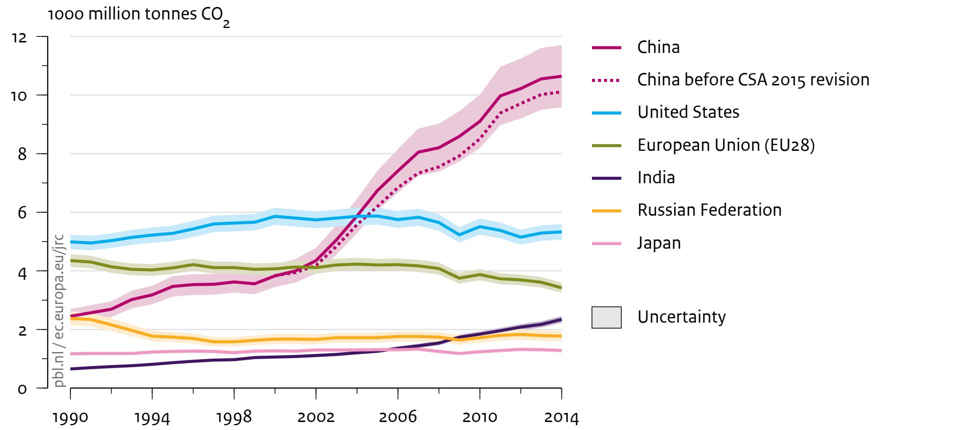
China's CO_2 emissions have grown extraordinarily rapidly since it started on its fast industrialisation path and after it joined the World Trade Organization (WTO) in 2003 (Figure 2.2). In 1990, its emissions were exactly half of those of the United States that, at the time, was the largest emitter of all countries in the world. Fourteen years later, in 2004, it surpassed the United States as the largest emitting country, and after yet another 10 years, in 2013, China's emissions had increased by 80% and were twice the amount of those of the United States, whose emissions had decreased by 10% since 2004. In 2014, China's CO_2 emissions increased by only by 0.9%, compared to 2013 levels, due to increasing consumption of oil products and natural gas, whereas coal consumption (in energy units) remained constant.

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



Source: EDGAR 4.3 (JRC/PBL, 2015) (1970-2012; notably IEA 2014 and NBS 2015); EDGAR 4.3FT2014 (2013-2014): BP 2015; GGFR 2015; USGS 2015; WSA 2015

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



Source: EDGAR 4.3 (JRC/PBL, 2015) (1970-2012; notably IEA 2014 and NBS 2015); EDGAR 4.3FT2014 (2013-2014): BP 2015; GGFR 2015; USGS 2015; WSA 2015

Note: For the uncertainty ranges see Section 2.6. For a description of the revision of China's coal statistics see Annex A1.4.

These numbers are based on our latest estimate from EDGAR 4.3 of countries' CO_2 emissions, using IEA's latest data set on fossil fuel with data through 2012 (IEA, 2014a), but modified to include a large revision of China's coal consumption statistics over the 2000–2013 period, as announced in May 2015 (NBS, 2015b), and extrapolated with BP data to 2014 (BP, 2015). Annex A1.4 provides more details on the method used and the impact on both China's and global CO_2 emissions.
Moreover, other CO_2 emission sources have been updated with the latest statistics of, notably, cement clinker and lime production (UNFCCC, 2014; CCA, 2015; USGS, 2015). We assessed a short paper on China's present CO_2 emissions, published in *Nature* in August 2015, and concluded that most claims should be dismissed. For a more accurate calculation of the revised CO_2 emissions from fossil-fuel combustion in China over the 2011–2013 period, based on detailed revised energy balances published by China using the same method and emission factors as in this report, we refer to the 2015 edition of the annual IEA report 'CO_2 emissions from fuel combustion' (IEA, 2015b).

Other global players determining global CO_2 emissions in 2014

The very low global growth rate in 2014 was accompanied by a large drop in CO_2 emissions of 5.4% to 3.4 Gt CO_2 in the European Union (EU-28), which was mainly due to a decrease in fossil-fuel consumption for electricity generation and in manufacturing industries, and by a 10% lower demand for space heating than in 2013. The estimated growth of 0.9% to 5.3 Gt CO_2 in 2014 for the United States was largely due to the increasing demand for natural gas for space heating, partly compensated by a small drop in coal used in power generation. Together, the United States and the EU-28 account for a quarter of global CO_2 emissions. The large decrease in EU-28 emissions especially contributed to the low global growth in emissions by 0.5%; for example, with the EU-28 compensating for the 7.8% growth shown by India, the fourth largest emitter with 2.3 Gt CO_2, when we put the European Union as a group in third place. If India's CO_2 emissions would continue to grow at the same average rate of 7% as they have over the past 10 years, they will surpass the current EU-28 emissions by 2020.

Largest emitting countries

In summary, the six largest emitting countries/regions in 2014 were: China (with 30%), the United States (15%), the European Union (EU-28) (9.6%), India (6.6%), the Russian Federation (5.0%) and Japan (3.6%) (Figure 2.2). Remarkable trends were seen in the top three emitting countries/regions, which account for 54% of total global emissions. In China and the United States, emissions increased by 'only' 0.9%. The European Union saw a large decrease of 5.4% in 2014, compared to 2013, which offset the 7.8% growth in India. The Russian Federation and Japan saw their CO_2 emissions decline by 1.5% and 2.6%, respectively.

Trends in global energy consumption

The shifts in energy production and consumption had major effects on energy prices as well as on the fuel mix. Of the three fossil fuels, global oil consumption increased by 0.8% in 2014, compared to 2013, mainly due to increased consumption in China (3%), Saudi Arabia (5%) and Brazil (3%), but for a large part this was offset by decreases in Japan (-5%) and the European Union (-1.5%). Oil prices fell sharply later in 2014, largely driven by the abundant supply, as production in the United States grew by a record amount while OPEC countries, by and large, maintained their output levels. For coal, growth in China's consumption stalled in 2014 causing coal imports to plummet. The small increase in global coal consumption of 0.4% was mainly due to increases in India (+11%) and some smaller Asian countries, but was largely compensated by a 7% decrease in the EU-28. The 0.4% growth in the consumption of natural gas was also small, since increases in the United States (3%), Iran (7%) and China (9%) were largely counterbalanced by the large fall of 11.6% in gas consumption in the European Union that was triggered by the exceptionally warm European winter. Renewable energy (excluding traditional fuelwood) was the fastest growing form of energy, accounting for one third of the increase in overall primary energy use (using the fossil fuel equivalency approach) and two thirds of the increase in power generation. Of the last, two thirds of the increase was in wind and solar energy, and one third in additional hydropower. Renewable energy currently accounts for a record 22.5% of global power generation (of which 16.5% is hydropower), but for only 9.8% of primary energy consumption (BP, 2015).

2014 was the warmest year on record

Winter temperatures that are lower or milder than usual have an impact on the demand for space heating and thus on CO_2 emissions. Higher or cooler summer temperatures have a similar impact the demand for air-conditioning, which is relevant for countries where many of these electrical appliances are used, such as in the United States, Japan and parts of China. We have not performed any sophisticated statistical analyses (apart from considering *Heating Degree Days* (HDD) for regions for which these are relevant and available), but find it important to highlight that the year 2014 was the warmest year, globally, since records began in 1880. The annually averaged temperature was 0.7 °C above the 20th century average of 13.9 °C, easily breaking the previous records of 2005 and 2010. Including 2014, 9 of the 10 warmest years in the 135-year period on record have occurred in the 21st century, i.e. in the past 14 years. This is the first time since 1990 that the high temperature record was broken in the absence of an *El Niño* event, which generally tends to increase global temperatures (NOAA, 2015).

Temperatures are rising at a faster pace in the northern latitudes of the Northern Hemisphere compared with other parts of the globe. According to NOAA's 2014 Arctic Report Card, the Arctic on average is warming more than twice as fast as regions at lower latitudes. For more information on regional weather conditions in 2014 in the main energy-consuming countries and regions, and a comparison with 2013, see Annex 1.6.

Trends over the last decades

The moderate increases in global CO_2 emissions in 2012, 2013 and 2014 of around 1% (0.5% to 1.5%) seem remarkable in times when global economic growth was

Box 2.1 Relationship between CO_2 emissions and GDP and global atmospheric CO_2 concentrations

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 less energy-intensive 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 and related CO_2 emissions (i.e. single year trends) are generally only 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 concentration 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. In addition, the total absorption of atmospheric CO_2 by the oceans also varies over time.

3% annually, compared to average annual growth levels of 4% in emissions and 4.5% in GDP in the previous decade (with the exception of the recession years). In other words, a partial decoupling of global GDP and CO_2 emissions can be observed over the past three years, similar to the 1990s that saw average annual emission increases of 1.3%. Within these percentages, however, there are notable differences in the performance of various countries. The service sector is not energy-intensive and currently contributes about 70% to global GDP. Therefore, increases in total energy consumption are not always closely related to overall economic growth, since total energy consumption is dominated by more energy-intensive sectors (e.g. power generation and the manufacturing industry) that make up only a relatively small share of total global GDP in most 'developed' countries (World Bank, 2015a). Since the share of the service sector at country level ranges from 20% to 87%, differences in growth rates between countries also help explain why CO_2 emissions and GDP are only very weakly related on a global level, as explained in Box 2.1. This also explains why annual growth rates in CO_2 emissions and CO_2 concentrations in the atmosphere also are only weakly related.

Energy-intensive activities are of the highest relevance for CO_2 emission trends, and fossil-fuel combustion accounts for 90% of total CO_2 emissions (excluding those from deforestation and other land uses). Power generation remains the most important sector with respect to fossil-fuel consumption; therefore, the power sector's choice to use fossil fuel is of the utmost importance. More details on recent energy trends are presented in Chapter 3, and Table 3.1 gives details on sector-specific shares of CO_2 emissions.

Structural changes in global CO_2 emission trends still uncertain

Reports published in recent years (Olivier et al., 2013, 2014) suggested that the small increases in CO_2 emissions registered in 2012 and 2013 – currently estimated at 0.8% and 1.5% – could be signs of a permanent slowdown in the increase in global CO_2 emissions. The 2014 growth rate of merely 0.5% is a continuation of the slowdown of the annual growth rate of emissions. Moreover, after three years of relative low growth rates in the previous decade, China's growth in energy consumption and industrial production in the first three quarters of 2015 is stalling while the share of renewable energy continues to increase. Thus, we can conclude that the slowdown since 2012 of China has not been an accidental, temporary effect, as it has lasted for three years already. This reflects structural changes in China's economy towards a less energy-intensive service sector and a high value-added manufacturing industry that is focused more on domestic consumption, with more energy efficiency, and towards a low-carbon energy mix.

On a global scale, however, the slowdown since 2012, which has also lasted for three years now, can be largely explained by the changes in the economy of China and the associated energy consumption. Whether these changes also reflect structural changes in the *global* economy, *global* energy efficiency improvements and in the energy mix of other key world players, such the United States, European Union, India and Russia, is uncertain.

However, further mitigation of fossil-fuel use will be needed to absolutely decrease global greenhouse gas emissions, which is necessary to substantially mitigate

Box 2.2 Main conclusions on anthropogenic global greenhouse gas emissions from the IPCC's Fifth Assessment Report (IPCC, 2014a,b)

- 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.
- Substantial emission reductions over the next few decades can reduce climate risks in the 21st century and beyond.
- Without additional mitigation efforts to those in place today, and even with adaptation, warming by the end of the 21st century will lead to high and very high risks of severe, widespread, and irreversible impacts, on a global scale.
- There are multiple mitigation pathways that can limit the increase in global mean temperature to 2 °C above pre-industrial levels. These pathways would require substantial reductions in emissions over the next few decades, and near zero emissions of CO_2.
- Many adaptation and mitigation options can help address climate change, but no single option would be sufficient by itself. Mitigation options are available in every major sector.

anthropogenic climate change within this century, as was concluded by the IPCC (2014a,b). Technically, these reductions are still feasible (IPCC, 2014a; UNEP, 2014), but would need to be widely implemented soon if future global greenhouse gas emission levels need to be compatible with pathways that could limit global warming to 2 °C by the end of the 21st century, compared to the pre-industrial global mean temperature (see Box 2.2).

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 change, 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 is shown in Figure 2.3. This figure illustrates that CO_2 emissions from fossil-fuel use and industrial processes covered in this report represent two-thirds of global total greenhouse gas emissions, with the other sources of greenhouse gas emissions contributing the remaining third. Comparison between the global shares and those of the United States and the European Union in Figure 2.3 also illustrates that the non-OECD countries, in particular tropical countries, have a relatively large share in CO_2 emissions from forests (fires and deforestation) and from large methane (CH_4) sources, such as rice, cattle, sheep and wastewater.

The differences in total greenhouse gas emissions per capita as estimated in the EDGAR 4.2 FT2010 data set for 2010 are presented on the map shown in Figure 2.4. More information on recent trends in other sources can be found, for example, in national reports to the UNFCCC and in the EDGAR data set (EC-JRC/PBL, 2015), available at country and source level.

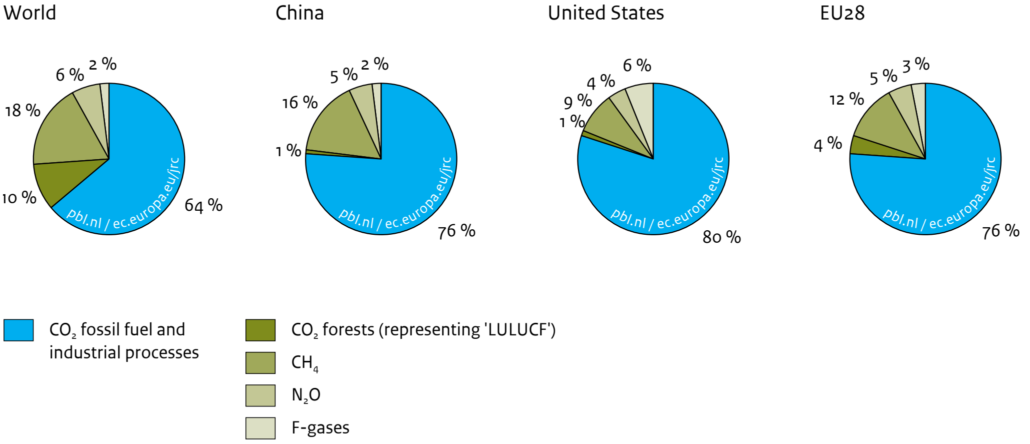
How do these trends relate to the COP21 climate conference in Paris?

For a first analysis of the targets and actions announced for the COP21, we refer to the UNFCCC (2015) and UNEP (2015c), amongst others, which has also analysed whether the new approach may result in a breakthrough on national emission targets for mitigating climate change, at the international negotiations in Paris, in December 2015.

For an analysis of the more recent trends in all greenhouse gas emissions in all major countries, including CO_2 emissions from forest fires and other land-use change and non-CO_2 greenhouse gases, the pledges by the countries following the Copenhagen/Cancun Agreements to mitigate national emissions by 2020 and an assessment of the resulting national emission trend by 2020, we refer to PBL (2015) and UNEP (2015b).

Figure 2.3

Shares of greenhouse gas emissions, 2010

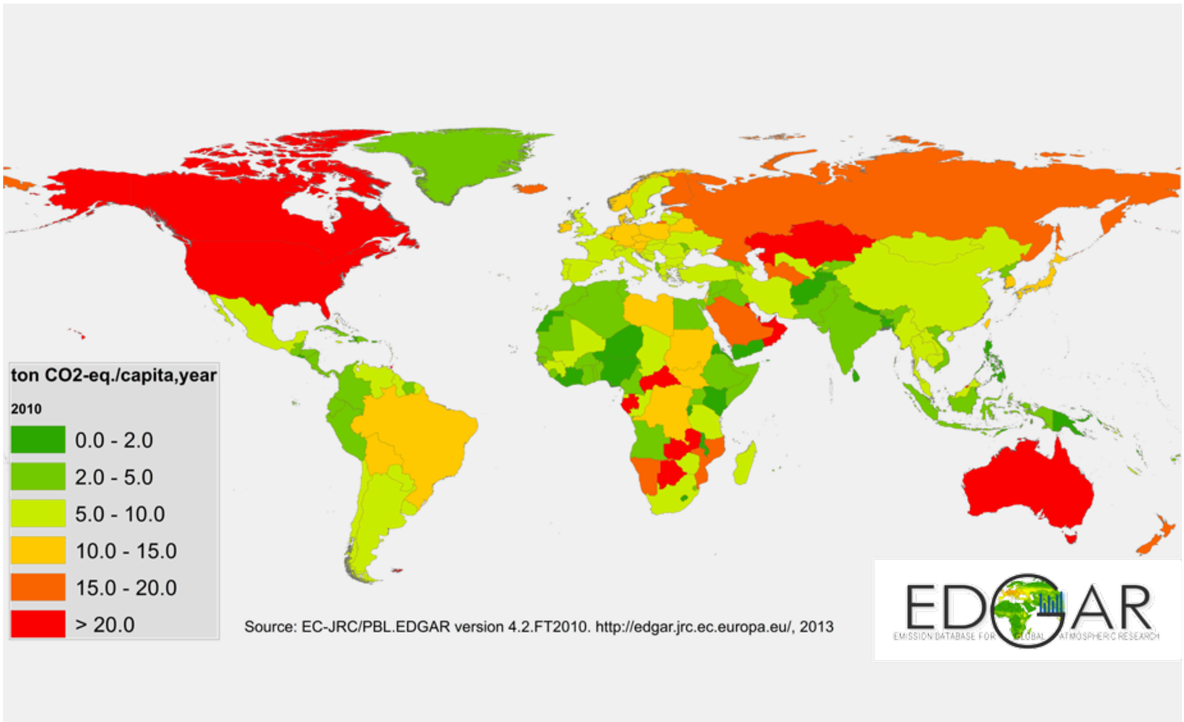


Source: CO_2 fossil and processes: EDGAR 4.3 (JRC/PBL, 2015); others: EDGAR 4.2 FT2010 (JRC/PBL, 2012)

Note: In this report, CO_2 emissions are provided for Fossil fuel+Industrial process ('FF+IP emissions'), and other sources of emissions; CO_2 from forest fires and deforestation ('Forests', representing the emissions part of 'LULUCF'), methane (CH_4), nitrous oxide (N_2O) and the F-gases HFCs, PFCs, and SF_6 as shares in total greenhouse gas emissions (excluding CO_2 removals such as forest growth and afforestation and using GWP-100 values from the Fourth IPCC Assessment Report). The source used for other emission sources is EDGAR 4.2 FT2010 (EC-JRC/PBL, 2012).

Figure 2.4

Geenhouse gas emissions per capita, 2010



Source: http://edgar.jrc.ec.europa.eu/overview.php?v=GHGt

Note: Including emissions from forest fires/deforestation (emissions component of 'LULUCF'). Excluding CO_2 removals from forest growth and afforestation. For non-CO_2 greenhouse gases, the GWP-100 values were used from the Second IPCC Assessment Report.

For an evaluation of the Intended Nationally Determined Contributions (INDCs) of countries, see Den Elzen et al. (2015b) and Climate Action Tracker (2015). In addition, the PBL Climate Pledge INDC tool (Den Elzen et al., 2015b) shows the projected impact of the emission reduction proposals (pledges or Intended Nationally Determined Contributions) and domestic policies, per country, on greenhouse gas emissions for 2020 and 2030. More specifically, the tool shows the effect of: (a) Pledges: national and global greenhouse gas emission projections for 2020, assuming that countries' pledges will be fully achieved; (b) *Intended Nationally Determined Contributions* (INDCs): national and global greenhouse gas emission projections for 2030, assuming that countries' INDCs will be fully achieved; (c) Measures: the impact of the most effective national climate and energy policies, such as carbon taxes, feed-in tariffs, or standards on emission levels for 2020 and 2030, for 19 major emitting countries and regions.

Further analysis may also show whether the recent national CO_2 trends as estimated in this report fit into the total national greenhouse gas emission trends expected from analyses of the Cancun pledges for 2020 and INDCs and other country pledges for 2025 or 2030 (e.g. see Admiraal et al., 2015; Carbon Action Tracker, 2015; UNEP, 2015b; IEA, 2015e).

The main question is that of how fast global CO_2 emissions will level off and start to decrease in absolute terms. Future global emission trends will be determined by the collective emissions from all countries and all greenhouse gases, partly due to developments that are controlled by government policies, actions by non-state actors and more autonomous economic and technological developments, which all have inherent uncertainties. The recent global emission trend shows that national policies collectively do reduce the rate of increase in global CO_2 emissions. Examples of economic and technological developments are the dependence of the use of new technologies on the oil price, as this may affect the economic feasibility of new energy sources, such as shale oil production and the production of shale gas, which may affect natural gas prices worldwide; increased transport and storage capacity of liquefied natural gas (LNG) may expand intercontinental trade in LNG, and thus influence continental natural gas markets; and overcapacity in power generation may cause rapid changes in the fuel mix used by utilities in the event of changes in the relative prices of gas and coal. These examples show both the potential and the uncertainty in reducing the rate of increase and curbing global CO_2 emissions in the near future.

Uncertainties in emissions

We note that all national emission inventories are subject to uncertainty. Uncertainties in national CO_2 emissions vary 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) and Liu et al. (2015). Moreover, in general, 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 of energy and GDP statistics. For China and the Russian Federation, we assumed 10% uncertainty, whereas for the European Union, the United States, Japan and India, a 5% uncertainty was assumed. Our preliminary estimate of total global CO_2 emissions in 2014 is believed to have an uncertainty of about 5%, and our estimated emission increase of 0.5% may be accurate to within ±0.5%. For more details, see Section 2.6.

2.2 Different trends in the six largest emitting countries/regions

This section analyses the emissions from the six largest emitting countries/regions in descending order of importance. The largest CO_2 emitting country by far is China, whose share of 30% in 2014 was twice as large as the second-largest, the United States, at 15%. Third is the European Union, at almost 10% (Figure 2.2).

A comparison of the shares of national GDP (on the basis of Purchasing Power Parity (PPP)) in global GDP expressed in USD showed that the top three countries/regions are very close (World Bank, 2015a): the shares in the world economy of both the European Union and China was 17%, and the United States' share was 16%. These three are followed at a distance by India (7%), the Russian Federation (3%) and Brazil (3%). However, when looking at their contributions to global economic growth over the past ten years (which was 62% since 2002), China contributed 31%, India 11%, the United States 9%, the European Union 6% and the Russian Federation and Indonesia 3% each. Therefore, China contributed to halt or global economic growth lack in the past decade.

In 2014, the growth in the world economy was around 3.3%, apart from the global credit crunch years of 2008 and 2009, but with large differences between the largest countries/regions. The economy of the United States increased by 2.4% in 2014 (compared to the annual average of 1.8% over the last decade), whereas the EU-28 economy grew by 1.4%, which is similar to its average historical growth rates. China's annual economic growth in 2014 of 7.2% was similar to the growth reported for 2012 and 2013 (IMF, 2015) and only about three-quarters of the ten-year annual average of 10%. By contrast, the economic growth of the Russian Federation (0.6%) and Brazil (0.1%) in 2014 was much lower than the average of the previous decade. The economic growth rate in 2014 of India (7.2%) was similar to its annual average over the previous ten years (World Bank, 2015a).

Please note that for most OECD countries these GDP statistics reflect the revisions of the definition of the *Gross National Product* (GNP) as adopted in the updated international guidelines for national economic accounts of the *2008 UN System of National Accounts* ('SNA 2008') (UN, 2009). However, the World Bank data for Russia, China and Brazil do not yet include these revisions (World Bank, 2015a).

For most OECD-1990 countries, the past decade has been strongly influenced by the 2008–2009 recession, and has since been slowly recovering. In 2014, countries such as Spain and Australia saw their historical economic growth rates continued. The growth in the GDP of the United States, Canada, Germany and the United Kingdom was higher than their historical average growth rates, whereas economic growth in Italy and Japan was negative in 2014.

2.2.1 China

China is by far the largest CO_2 emitting country. This high ranking is mainly due to the size of its population and economy, but also because of the high share of coal in its energy mix, as it is has much more coal reserves than oil and gas.

For China, the trend in CO_2 emissions in 2014 has been widely discussed since the end of 2014, as first analyses suggested that coal consumption had decreased over 2014, after a very long period of continuous increases. In August 2014, Myllyvirta (2014) suggested that coal consumption may have dropped in the first half of 2014. In January 2015, he announced that China's apparent coal consumption had fallen in 2014 by 3.5% based on data reported by China's Coal Industry Association (Myllyvirta, 2015a). In February 2015, the National Bureau of Statistics of China (NBS) published a statistical communiqué with preliminary estimates that stated that coal consumption had declined by 2.9% in 2014. In addition, NBS reported that coal production in 2013 had been revised upwards by 7.9% based on the results of the Third National Economic Census (NBS, 2015a). In March 2015, the International Energy Agency (IEA) announced that preliminary data indicated that China saw less burning of coal and that global CO_2 emission growth had stalled in 2014 (IEA, 2015c). In May 2015, NBS published a new preliminary estimate of total coal consumption in 2014 and a major revision of total fossil-fuel consumption by main fuel type dating back to 2000. Finally, a paper by Liu et al. (2015) published in August claimed that the best estimate of China's current CO_2 emissions from fossil fuels and cement production was 14% lower than reported by other inventories such as EDGAR, CDIAC and emissions that China officially reported to the UNFCCC. Their paper gave rise to much public debate (Reuters, 2015) .

We have evaluated these claims and the main conclusions of our assessments are:

- A decrease in coal consumption of 2.9% (NBS, 2015a) in tonnes of mass may very well be consistent with a conversion to amounts in physical energy units (Joules or Standard Coal Equivalents), resulting in a 0.1% growth over 2014 (NBS, 2015b) if the average heat content of the coal increased by a few per cent in 2014. The U.S. Energy Information Administration (EIA) made an assessment and concluded that a change in the energy content could well explain a difference in the trend estimates in tonnes of mass and in energy units (EIA, 2015j). Lower coal prices and stricter enforcement of environmental regulations in 2014 make it economically acceptable to use higher quality coal. Average heating values implied in past Chinese Statistics have suggested 2% or higher changes from one year to another, reflecting changes in coal washing ratio and lignite use.
- A paper by Liu et al. (2015) published in August claims that China's national coal consumption statistics used in the inventories are too low and that the '*apparent consumption*' is a more accurate estimate of actual consumption. Extensive measurements made by the authors show that the average energy content and carbon fraction of the coal is much lower than the IPCC default value, which is primarily caused by the low quality and high ash content of Chinese coal. Moreover, they claim that the fraction of carbon that is not oxidised to CO_2 during combustion is about 8%, which is much higher than the IPCC default value, resulting in a significantly lower net emission factor in kg CO_2/GJ. The authors suggest that other emission inventories have substantially overestimated CO_2 emissions in recent years. After a critical review of the paper and the supplementary data provided, we find several of these statements to be in error regarding the numbers or the comparisons. After a correct

comparison we conclude that the new estimate presented in this paper is only 6% lower than the EDGAR estimate, which is largely due to the 8% correction of the CO_2 emission factor for the fraction that was not oxidised. However, the oxidation factor data presented and used in the paper suggest only an average correction of about 4% at most, and the authors provide no further references to evaluate the accuracy of the numbers. We therefor conclude that Liu et al. do not provide good evidence to prove that present international CO_2 emissions inventories such as CDIAC, IEA and EDGAR are systematically and substantially too high. For more details of this assessment, see Box 2.4 in Section 2.6.

– The energy consumption statistics published by NBS in the *China Statistical Abstract 2015* in May 2015, of which only the resulting total coal consumption was implicitly published as a percentage of total energy consumption in energy units (NBS, 2015b), show a substantial revision. From this new data one could conclude that coal consumption in energy units increased in 2014 by about 0.1%. Since the revision changes the coal consumption levels back to 2000, and as we want to show the latest CO_2 trends, we have estimated the impact of the coal consumption revisions on CO_2 emissions from fossil-fuel combustion based on the method described by EIA (2015j). This resulted in increases of 0.5 to 0.7 Gt CO_2 per year for the years 2005 to 2012 (8% on average) for CO_2 from total fossil-fuel combustion, and decreasing back to 2000. Details of our estimation method are provided in Annex A1.4.

The result of our assessment – including the estimated impact of the revision of coal statistics – is that in 2014 China's CO_2 emissions increased by 0.9% to 10.6 billion tonnes when using the 0.1% increase in coal consumption inferred from data (in energy units) reported in the *China Statistical Abstract 2015* published in May (NBS, 2015b). These CSA coal consumption data are also reported by BP (2015) and used in an analysis of the revision of China's coal statistics by the U.S. Energy Information Administration (EIA, 2015j)[1]. Note that although the increase in coal consumption essentially stalled in China in 2014, the consumption of oil products and natural gas continued to increase by 3.3% and 8.6%, respectively (NBS, 2015a; BP, 2015), and the CO_2 emissions of gas and oil together account for about 20% of total CO_2 emissions from fossil-fuel combustion. In addition, cement production increased by 2.3% (NBS, 2015a) and CO_2 emissions associated with the calcination process of the limestone used in the production of cement clinker account for 7% of China's total CO_2 emissions from fossil-fuel use and industrial processes.

Together with the 2.6% increase in 2012 and 3.2% in 2013, the past three years show the slowest annual rate of increase in emissions in a decade, compared with the annual average increase of 9.7% in the years since 2003, even including the global credit crunch years 2008 and 2009. The average absolute annual growth over the past three years was one third of that in the previous decade (about 0.2 versus 0.6 Gt CO_2), and one quarter when comparing average annual growth in percentages: 2.2% compared to 9.7%.

The relatively small increase of about 1% in CO_2 emissions in 2014 was mainly due to a virtual standstill (+0.1%) in the increase in coal consumption, while coal consumption in 2012 and 2013 increased by 1.4% and 2.0%, as reported in energy units by BP (2015) and NBS (2015b). In the decade preceding 2012 the average annual growth rate was mostly around 10% (See Table 2.1). Coal consumption, which makes up 73% of fossil-fuel consumption, is responsible for about 83% of China's CO_2 emissions from fossil-fuel combustion. In contrast, the increase in natural gas consumption was 8.6% in 2014, following increases of 12% and 13% in 2012 and 2013, which is a slowdown in the annual increase compared to the average increase of about 18% from 2003 to 2011. Furthermore, cement production increased by 2.3% in 2014, so CO_2 emissions from the calcination of limestone during cement clinker production, which make up about 7% of China's total CO_2 emissions, also increased. Therefore, we estimate that total Chinese CO_2 emissions increased by approximately 1% in 2014. The increases of the past three years were the lowest since 2001, the year after which the average annual increase in Chinese emissions accelerated from about 3% to 10%. Even in the two recent credit crunch recession years, China's CO_2 emissions continued to increase by about 6% per year.

This small emission increase of 1% in 2014 is consistent with the small *decrease* of 0.3% in thermal power generation (predominantly coal-fired power plants) reported by the National Bureau of Statistics of China (NBS, 2015a). The decrease in the power generated by coal-fired power plants, which produce about three-quarters of total electricity (NBS, 2015a) and which contribute to about half of the country's CO_2 emissions from fossil-fuel combustion (Table 3.1), was due to the still relatively 'small' growth rate of total power consumption of 3.8% in 2014, compared to the previous decade that showed double-digit growth figures (the lowest since 2000).

Moreover, hydropower generation increased by 16% in 2014 due an expansion of installed capacity of 8% by the end of 2014 and to favourable weather conditions. Hydropower accounted for two-thirds of the no-coal

Table 2.1

Growth rates in recent years of selected energy trend indicators in China, compared to average growth rates since 2002

Indicator	Average annual growth rate 2002–2011 (±1 SD*)	2012**	2013	2014	Growth rate H12015 compared to 2014	Growth rate Q1-3 2015 compared to 2014
CO_2 emissions	9.7% ± 4.9%	2.6%	3.2%	0.9%		
GDP	10.4% ± 1.8%	7.5%	7.6%	7.2%	7.0%	6.9%
Coal consumption	10.0% ± 5.8%	1.4%	2.0%	0.1%	-5.8%	-3.6%
Oil product consumption	7.4% ± 5.0%	4.9%	4.3%	3.3%	3.2%	
Natural gas consumption	17.0% ± 5.5%	12.1%	13.0%	8.6%	1.4%	
Electricity consumption	12.4% ±3.4%	5.9%	7.5%	3.8%	0.6%/1.3%	-0.1%/0.8%
Cement production	12.3% ±3.8%	5.3%	9.3%	2.3%	-5.3%	-4.6%
Steel production	16.5% ± 7.4%	4.6%	13.8%	0.9%	-1.2%	-2.0%
Aluminium production	19.3% ±11.2%	12.2%	8.9%	10.2%	18%	18%

** Standard Deviation*
*** Leap year, so 0.3% higher than normal.*
H1 = First half year
Q1-3 = First three quarters; for coal, cement and electricity M1-10 (= first ten months).
Electricity: values for 2015 are production/consumption changes

Sources:

2002–2012: GDP (constant prices) (World Bank, 2015a), cement, crude steel and aluminium (USGS, 2015), coal, oil, gas consumption, electricity (IEA, 2014a).

2013 and 2014: same data sources and NBS (2014, 2015a,b,c) and WSA (2015).

2015: H1 2015 (first half year): GDP (NBS, 2015e); energy consumption (EnerData, 2015); cement (NBS, 2015g); steel, aluminium (WSA, 2015; IAI, 2015).
Q1-3 2015 (first three quarters): GDP (NBS, 2015f); coal *production* (NBS, 2015h); electricity consumption (WSJ, 2015), cement (NBS, 2015g); steel, aluminium (WSA, 2015; IAI, 2015).

power growth, and almost 20% of total power generation. In addition, wind, solar and nuclear power together accounted for almost one quarter of the total growth (Myllyvirta, 2015b). Thus, about 90% grid-connected wind and solar power capacity increased by 26% and 67%, respectively, and nuclear power generation increased by 19% following a 36% expansion of installed capacity by the end of 2014 (NBS, 2015a). Thus, the 'small' increase in power generation was for about 90% generated by the growth in zero-CO_2 sources: hydropower, wind, solar and nuclear energy (Myllyvirta, 2015b).

The slowdown in the growth in electricity demand was driven by the slowdown in industrial demand; in particular for basic materials, which consume more than half of all electricity produced, as indicated by the production of metals, chemicals and minerals such as cement (see Table 2.2). In addition to the slower increase in output, the electrification (share of electricity in total energy demand) of the industrial sector has also been steadily increasing over time and as such implicitly increased the energy efficiency (Table 2.1 and Davidson, 2014).

After years of double-digit increases in GDP, China's increase in 2012, 2013 and 2014 was only about 7% (World Bank, 2015a). In the literature, there is some debate on the quality of China's GDP figures (see e.g. Wang and Chandler, 2011; Rosen and Bao, 2015). However, also other countries revise their GDP numbers when new information becomes available (see also Box 2.3 in Section 2.3).

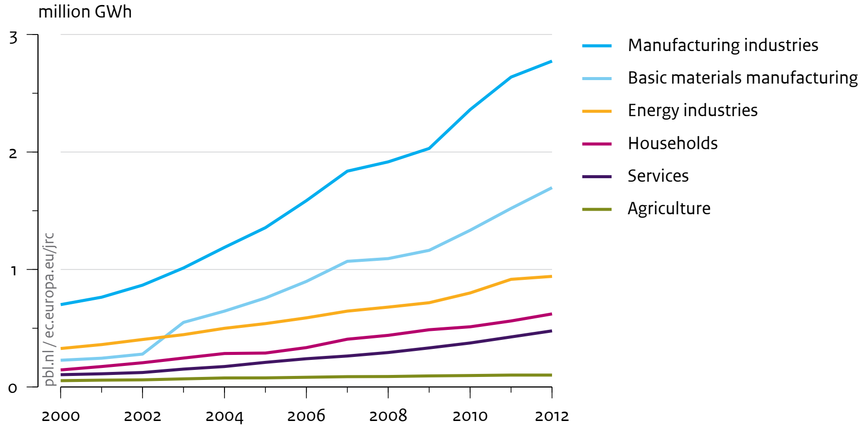
Unlike in developed countries, China's manufacturing industry is the sector with the largest consumption of electricity and fuels. Therefore, the demand for energy in general is largely driven by trends in basic materials production (Table 2.1 and Figure 2.5). As Table 2.2 indicates, there has been a substantial slowdown in the growth rate of the demand for materials, halving the growth in this sector since 2012. First reports on 2015 show a further slowdown or even decrease in most indicators. Thus, not only the growth in the Chinese economy but also in other key energy trend indicators, such as production of cement, steel and electricity, decreased significantly in 2012, 2013 and 2014 compared to the high annual growth rates over the 2002–2011 period. The growth rate of cement, steel and electricity production was almost half that observed in most previous years (except for 2007–2008[2]) (see Table 2.1). Nevertheless, China's 2012 to 2014 annual GDP growth

Table 2.2
Shares of sectors in total electricity consumption in China in 2000 and 2012

Sector	2000	2012
Agriculture	4%	2%
Manufacturing industries	52%	56%
of which: Smelting of Ferrous Metals	8%	10%
of which: Basic Chemical Materials	9%	8%
of which: Smelting of Non-Ferrous Metals	5%	8%
of which: Non-Metallic Mineral Products	6%	6%
of which: Textile	3%	3%
of which: Metal products	1%	2%
of which: Total basic materials manufacture	29%	34%
Energy industries (includes transport losses)	24%	19%
Services	8%	10%
of which: Offices	4.6%	6.2%
of which: Wholesale, Retail, Hotels, Restaurants	3.1%	3.4%
Households	11%	12%

Source: NBS, 2015c

Figure 2.5
Power consumption per sector in China



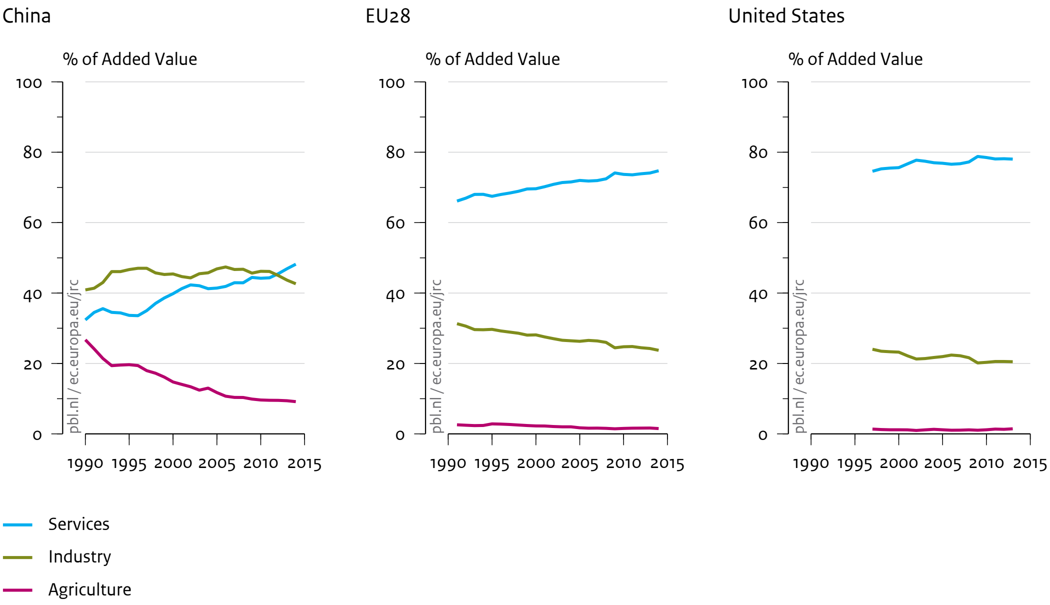
Source: NBS 2015

rate of about 7% was only about 3% lower than the previous decadal average of around 10%.

The slowdown in the growth in CO_2 emissions in China, which was first observed in 2012, has continued, with the indicators for 2015 showing a further slowdown or even negative growth figures. To sum up, we are witnessing a structural change in the trend in China's CO_2 emissions, in line with its 'energy consumption control target' for 2015 and its shift to gas, to achieve a natural gas share of 10% by 2020. These are goals of China's 12th Five-Year Plan for Energy (Song, 2013). As already discussed in detail in last year's report, this is corroborated by Provincial Environmental Plans with coal consumption targets (Shuo and Myllyvirta, 2014) and a structural change in the economy from energy-intensive fossil-fuel industries, such as production of cement, steel and glass and coal-fired power plants, towards less energy-intensive activities such as services (Guay, 2014). For further details, please see Olivier et al. (2014).

The recent trend of a decreasing industrial share in GDP being substituted by an increasing services share started in 2011. Between 1995 and 2011, the share of industry

Figure 2.6
Shares of services, industry and agriculture in GDP



Source: World Bank 2015

remained rather constant over time, while the service sector's share was increasing, reflecting a downward trend in agriculture (see Figure 2.6). In comparison with the European Union and the United States, the present share of services in China is about 20% lower and the share of industry is 20% higher. However, from the historical trends it is clear that further structural changes towards more service- and less energy-intensive but more high-value-added industries will likely occur over time.

The service sector started to grow again about five years ago in terms of percentage of GDP. At 48%, it has now surpassed the industrial sector as the largest sector. If the current rate of increase continues, the share of the service sector in about 10 years could be at the level it was in the EU-28 around 1990, i.e. about 65%. Nevertheless, the smoothness of the transition, i.e. the exact rate of change, is particularly difficult to predict for China, given its extraordinarily high annual growth rates in all sectors. However, the general trends are clear, as can be seen in countries that started earlier in developing from a mainly agricultural economy, to an industrial economy, and further to a service-oriented economy.

Outdated industries are a major source of pollution and lower the energy efficiency and, therefore, China has been eliminating excessive production since 2011. Until 2014, China scrapped over 77 Mt of outdated steel plant capacity and 365 Mt of cement plant capacity (Government of China, 2015), which is roughly equivalent to about 10% and 15%, respectively, in annual production. China is also utilising supercritical coal plants for new and replacement capacity (Barnes, 2015). Combined with the scrapping of older, less efficient coal plants, this improved the efficiency of thermal power plants from 37.4% in 2000 to 43% in 2012 (NBC, 2015c). These measures also contribute to making the economy less energy- and CO_2-intensive.

For a more detailed discussion on the uncertainty in Chinese fuel consumption data as reported by different sources, we refer to Section 2.6. This discussion, which includes conclusions from the recent literature on the accuracy of China's CO_2 emissions (Tu, 2011; Andres et al., 2012; Guan et al., 2012; Liu et al., 2015) yields an uncertainty for our estimates of about 5% for most OECD-1990 countries, and in the range of 10% for China and the Russian Federation.

2.2.2 United States

In the United States, in 2014, CO_2 emissions increased by 0.9% to 5.3 billion tonnes, following a 3.5% increase in 2013, from the 2012 level of 5.15 billion tonnes, which was the lowest since 1993. In these years, GDP increased at a similar rate in 2014 and 2013, with 2.4% and 2.2%, respectively. CO_2 emissions from fossil-fuel combustion, their main source, increased by 0.9% in 2014, compared to 2013, but are still below the 2011 level. 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 7% in this period (for more details, see Section 2.3).

As we will show below, the striking difference between *CO_2 and GDP trends* in these years is largely due to differences in weather conditions (EIA, 2015f). Although the winter months of 2013 and 2014 were generally about average, the number of Heating Degree Days (HDD), a measure of the demand for space heating, was about 7% higher in 2014 than in 2013 (see Annex A1.6, Table A1.4). However, both were much higher than in 2012, which had a very mild winter. Similarly, the number of cooling degree days (CDD), a measure of the demand for electricity for air-conditioning, was about 15% higher in 2012 than in 2013 and 2014 (EIA, 2015n). Moreover, for OECD-1990 countries, the coupling between the annual trend in GDP and total CO_2 emissions is rather weak, since most energy (i.e. fuel) intensive activities (in the resource and power sectors) only represent a small fraction of GDP. In the United States, the service sector (with energy mostly used for space heating, cooling and electrical appliances) accounts for 78% of GDP, with total industry only making up 20%, and the remaining few percent being contributed by agriculture (see Figure 2.6).

The increase in CO_2 emissions in 2014 was mainly due to an increase of 2.9% in the use of *natural gas* (BP, 2015), one third of which was used by the residential and commercial sectors (predominantly for space heating), one third for power generation and another third by the manufacturing industry and own use in the energy sector (EIA, 2015k). The somewhat colder winter months of 2014 compared to 2013 caused an increase in gas consumption of 4% and 5% in residential and commercial sectors, respectively. Industrial gas consumption increased by 2.7% in 2014, similar to 2013, and also contributed to the overall increase in gas consumption of 2.9% in 2014. In power generation, gas consumption remained at about the level of 2013, but still 8% above the 2011 level. In 2012, gas consumption for power generation jumped by 20% due to the low price of natural gas resulting from the very low demand for space heating, and it subsequently dropped to 10% again in 2013.

By contrast, CO_2 emissions from *coal* combustion decreased by 0.3% in 2014 (BP, 2015). Coal-fired power generation covers about 95% of total coal consumption in the United States. Although consumption by power plants decreased by 0.8% (in mass), coal-fired power generation increased by 0.3%, which may be explained by an increase in the heat content and a higher overall conversion efficiency in the remaining power plants following the closure of the least competitive ones (EIA, 2014a). The relatively low coal consumption by industry decreased by 2% in 2014.

CO_2 emissions from the combustion of *oil products* increased by 0.5% in 2014 (BP, 2015). CO_2 emissions from road transport accounted for two-thirds of total oil combustion emissions, with the remainder split in fairly equal shares between manufacturing industries, other domestic transport, the residential and commercial sector (i.e. buildings) and refineries (see Table 3.1 and IEA, 2014b). Petrol consumption for road transport, which accounted for about 75% of total oil consumption for road transport, predominantly for passenger cars, increased by 0.9% in 2014, which is a slowdown compared with the 1.6% increase in 2013. This is in contrast to most preceding years up to 2007, in which annual petrol consumption decreased by 1.3%, on average, which was mainly due to the increased energy efficiency of vehicles over time, but also aided by the increase in bioethanol use in transport. However, consumption of low-sulphur diesel, primarily for freight transport (and a small fraction for European diesel cars) increased by 7.4% in 2014, three times as much as the 2.4% increase of 2013 (EIA, 2015l). By contrast, oil consumption in the manufacturing industry decreased by 2.7%, whereas there was no change in oil consumption in the building sector in 2014. It is interesting to note that after a long period of steadily increasing vehicle kilometres travelled per capita, this increase stalled in the mid-2000s and started to decline from 2008 onwards. This resulted in almost constant total vehicle kilometres travelled since 2008. This occurred at a time when petrol retail prices increased within a few years from about USD 1 per gallon to between USD 2.50 and 4 per gallon (EIA, 2014d).

Biofuel use for transport (fuel ethanol and biodiesel) increased by 1.3% in 2014, increasing its share of transport fuels to nearly 5%. However, it appears that the growth in this share is levelling off. The growth in the share of biomass combustion in industrial energy consumption also appears to have stalled, after having steadily increased since 2001. By contrast, the share of renewable energy in power generation is still increasing over time (in 2014 by 3.4%), reaching a share in of 13.2% in power generation. In 2014, the share of hydropower for the first time was exceeded by the other renewable power sources (biomass, biofuel, solar power, wind power, landfill gas and geothermal sources). Wind and solar power together increased by 13% in 2014, whereas hydropower dropped by 3.7% (EIA, 2015e).

In 2014, power utilities added capacity in natural-gas-fired, solar and wind plants (EIA, 2014b), while the closure of coal-fired power plants is continuing (EIA, 2014a). The large number of recent closures of coal-fired power plants is mainly due to the publication Mercury and Air Toxics Standards (MATS) by the United States Environmental Protection Agency's (US EPA), which standards 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 units would be too costly and have instead chosen to retire the plants (EIA, 2015e).

After a steady increase, CO_2 emissions from power generation peaked in 2005. Since then, they have been steadily decreasing over time, reaching 15% below 2005 levels in 2013 and 2014. With some fluctuations, electricity demand has remained almost constant over the past decade, with small declines in the industrial sector outweighing the slight increases in demand from residential and commercial sectors. The further decrease of 15% in 2013 and 2014 was due to the substitution of natural gas with coal and the growth in renewable energy, particularly wind- and solar-powered electricity. Compared to 2005, CO_2 emissions from coal-fired power generation decreased by about 20%, while emissions from gas-fired power generation increased by about 40% (EIA, 2014c).

In August 2015, the US EPA announced and finalised the Clean Power Plan Rule to reduce CO_2 pollution by existing power plants, under Section 111(d) of the Clean Air Activity (US EPA, 2015a). The EIA estimates that, in a base policy case which includes the proposed rule, CO_2 emissions from the power sector will be 25% below 2005 levels by 2020, and 34% below 2005 levels by 2030 (EIA, 2015g). Currently, coal-fired power plants are emitting about 30% of total fossil-fuel-related CO_2 emissions in the United States, which are mainly caused by 63% of the coal-fired plants that are over 40 years old. The proposal reflects that different states have a different mix of sources and opportunities, and reflects the important role that states have in reducing pollution as partners of the Federal Government. The proposal affects mainly coal-fired power plants and has generated much debate from industry groups, environmental organisations and politicians, at both state and national levels. Due to the expected legal challenges by politicians and industrial interest groups, the implementation of the proposed reduction policy is still uncertain (Eilperin and Mufson, 2014). For other analyses of the impact of the growing share of natural gas and renewable power in substituting coal power, see the BNEF White Paper (Annex, 2015), the Union of Concerned Scientists (UCS, 2015) and the Carbon Tracker report by Sussams and Grant (2015).

For a discussion of oil and gas production trends and gas flaring, including the role of hydraulic fracturing, see Section 2.4.

2.2.3 European Union

In 2014, the European Union (EU-28) continued to decouple its slow-moving economic growth from decreasing CO_2 emissions; while the EU-28's GDP increased by 1.4% compared to 2013 (Eurostat, 2015a), CO_2 emissions decreased by 5.4%. The EEA (2015b) estimated a 4% decrease in all greenhouse gas emissions in 2014 compared to 2013, yielding a 2014 total that is 23% below the 1990 level, which is even more than the EU's 2020 target.

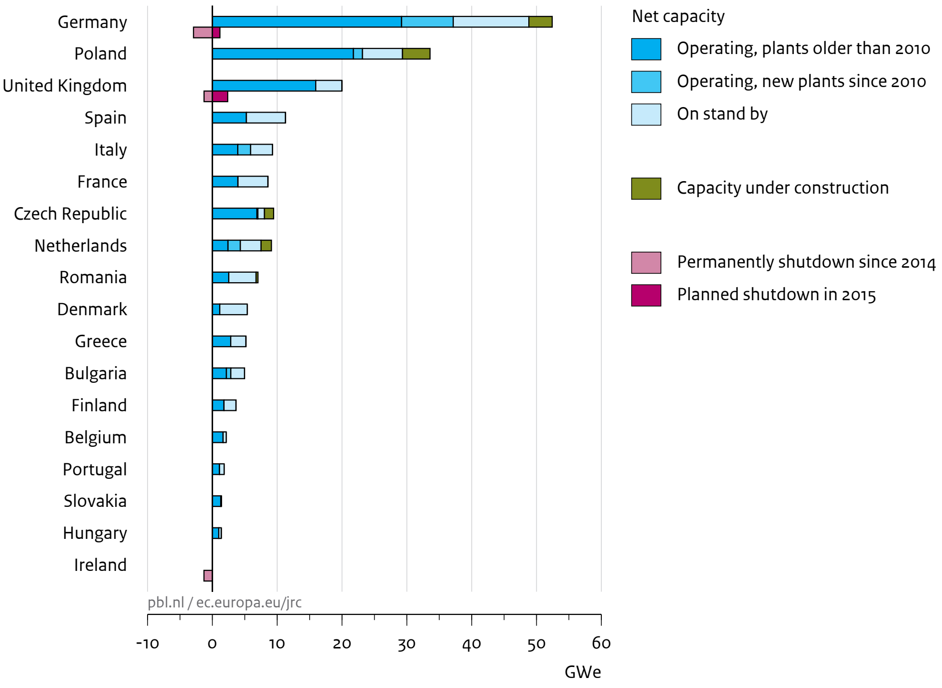
At 9.6%, the EU's share in total global CO_2 emissions declined for the first time to just under 10% of total global CO_2 emissions, to which Germany contributed 2.2%, the United Kingdom 1.2%, Italy and France 0.9% each, and Spain 0.7%. Most of the EU Member States show a decreasing CO_2 trend between 2013 and 2014, with decreases for Slovakia (10.6%), the United Kingdom (9.0%), Denmark (8.8%), France (8.4%), Italy (7.7%), Finland (6.9%), Greece (6.3%), Austria (6.0%), Germany (5.6%), the Netherlands (5.3%), Portugal (3.6%) and Poland (3.4%). The two exceptions, with increasing emissions, in the EU-28 are Bulgaria (6.9%) and Cyprus (0.5%).

The European Union continued its trend of decreasing CO_2 emissions, with a drop of 5.4% in 2014, which is much more than the decreases in 2012 and 2013 of 0.4% and 1.4%, respectively. Eurostat, the statistical office of the European Union, estimates a decrease in 2014 of 5% for CO_2 from fossil-fuel combustion compared to a decrease of 2.5% in 2013 (Eurostat, 2015a). Reductions in CO_2 emissions from fossil-fuel combustion in 2014 were reported by Eurostat (2015a) for most countries, with the largest decreases estimated for Slovakia (14.1%), Denmark (10.7%), Slovenia (9.1%), the United Kingdom (8.7%) and France (8.2). Increases were reported for Bulgaria (7.1%), Cyprus (3.5%), Malta (2.5%), Lithuania (2.2%), Finland (0.7%) and Sweden (0.2%).

For cement and lime production, EU's emissions only increased by 0.5% between 2013 and 2014, with increases mainly in the United Kingdom (1.8%), Finland (2.9%) and Poland (1.6%), and slight decreases in Germany and France (both 0.2%) and Spain (1.5%) (USGS, 2015).

The main causes of the decline over 2014 are, firstly, a reduction of 4.5% in CO_2 emissions from industrial

Figure 2.7
Coal-fired power generation in EU28, 2014



Source: Global Coal Plant Tracker 2015; Bundesnetzargentur 2015; DECC 2015

facilities and power plants that are part of the EU Emissions Trading System (EU ETS), secondly, a much lower demand for space heating in the building sector due to the very mild winter of 2014 (the warmest on record), also compared to the colder-than-average winter months in 2013 (see Annex 1.6), and, thirdly, a reduction in the EU's oil consumption in transport by 0.5%, as indicated by petrol and diesel use. Although total oil consumption decreased in 2014 by 1.5% to its lowest level since 1969, at 37% of total primary energy consumption it remains the dominant fuel used within the EU-28. The emissions from installations participating in the EU ETS are estimated to have decreased by about 4.5% last year (EC, 2015).

The EU's primary energy consumption of gas, coal and oil each decreased in 2014 by 11.6%, 6.5% and 1.5%, respectively (BP, 2015). For the space heating of residential housing and offices, *natural gas* is the main fuel in several countries, with 75% of the EU demand for gas coming from Germany, the United Kingdom, Italy, France, the Netherlands and Spain. In 2014 demand decreased to the lowest level since 1995, according to Jones et al. (2015). Very warm weather in 2014, including in the winter months (see Annex A1.6 and Table A1.4), caused a substantial reduction of about 10% in the overall EU demand for space heating, thereby affecting the total demand for natural gas (EEA, 2015b; Eurogas, 2015). In addition, the 2013 winter was colder than average, resulting in a large decrease in gas consumption of 11.2% in 2014, compared to 2013. In addition, the six largest EU importers have energy efficiency and renewable energy deployment programmes in place, which might further decrease demand in the future. Only 7% of the EU demand for gas comes from eastern European countries, which depend on Russian imports for more than two thirds of their supply (Jones et al., 2015). In response to energy security concerns, the EU is promoting new pipelines and LNG terminals through the Connecting Europe Facility and the European Fund for Strategic Investment.

The decrease in CO_2 emissions from the power sector was mainly driven by the following two factors: a 3% reduction in power generation (mainly by coal-fired power plants), which is a further continuation of the decrease seen in 2013 of 1.2%, and a strong increase in the use of renewable energy (8.3%) (BP, 2015). Cornot-Gandolphe (2014) pointed out that the flexible power generation as back up for the intermittent renewable energy sources is at risk, given that unprofitable gas-fired power plants are being closed and old coal-fired stations are being retired. The relatively high gas prices (compared to coal) and the collapse of the CO_2 prices in 2012 eroded the competitiveness of gas-fired power generation. Coal is three times cheaper than natural gas per unit of energy, even after the 29% drop in prices in the first four months of 2014. Coal prices fell by 32% between 2011 and 2013, mainly because of coal imports from the United States, whereas gas prices increased by 42% between 2010 and 2013, in line with oil prices.

Nevertheless, the consumption of *hard coal* in the EU decreased in 2014, which is a continuation of the decrease in 2013, after small upward trends between 2010 and 2012 (Eurostat, 2015b). With a gross domestic consumption of hard coal of 285 Mt, the EU reached its lowest level in 2014, which is 44% below 1990 levels. In addition to the lower consumption of coal in power generation, the production of coke in coke ovens also decreased by 2.6% in 2014, compared to 2013. Coal consumption decreased in most EU countries, except for the Netherlands where consumption increased by 10% – which, in absolute amounts, is 50% more than the absolute increases seen in Spain, Belgium and Bulgaria in 2014. The largest absolute reductions are seen in the United Kingdom (20%), France (5%), Germany (3%) and Poland (3%) (BP, 2015). With EU's Industrial Emission Directive replacing its Large Combustion Plant Directive in January 2016, further restrictions of emission limits will cause a phasing out of about one third of the coal capacity by 2023, according to Cornot-Gandolphe (2014). Current national statistics partially reflect this, as is shown in Figure 2.7.

The production of hard coal in the EU has plummeted even further, from 74% of domestic consumption in 1990 to only 28% in 2014 (Eurostat, 2015b,c), and a further decrease is expected when the subvention of coal production in Germany ends in 2018. Lignite consumption followed the same trends, with a large decrease in the 1990s, a more stable period from 2000 to 2007, a further decrease from 2007 to 2010, an increase from 2010 to 2013, and a 2.5% decrease in 2014. Almost 100% of lignite is supplied through indigenous production, which also declined in 2014. Most of the EU's hard coal imports in 2014 came from Russia (29%), the United States (21%) and Colombia (20%). The 1.3% decrease in 2014, compared to 2013, was mainly due to reduced imports from Colombia and Russia (Eurostat, 2015c).

More than half of the consumption of *oil products* in the European Union consists of petrol and diesel used in road transport (diesel is also used in shipping and rail transport). Total consumption of these two fuels fell by 0.5% in 2014, continuing the decreasing trends of 2.4% in 2012 and 0.8% in 2013 (Eurostat, 2015c). Interestingly, the drop in petrol consumption (e.g. 1.5% in 2014) was much larger than in diesel consumption (0.2% in 2014), suggesting a greater decrease in passenger transport than in freight. According to the International Transport Forum (2015), the tonne per km volume of freight transport in the EU increased for road (2.1%) and rail (0.7%) transport but decreased for shipping (-0.6%). As the building sector accounts for about a tenth of total EU oil consumption in space heating, it oil consumption as a result of the very warm winter of 2014 will also have been reduced.

By the end of 2014, international air and sea freight transport to and from the EU reached the pre-crisis level of July 2008, according to the International Transport Forum (2015). However, according to reporting guidelines, the related greenhouse gas emissions are not allocated to the EU's emissions, but are reported separately under international transport emissions.

2.2.4 India

India, where domestic demand makes up three-quarters of the national economy (Damodaran, 2011), has been relatively unaffected by the global financial recession, although it did stimulate the already high share of domestic consumption in total national expenditure. From 2003 to 2010, India's annual GDP growth was between 8% and 10% (except for 2008) and has slowed down somewhat since then. For the years 2011, 2012, 2013 and 2014, GDP increased by 6.6%, 5.1%, 6.9% and 7.2%, respectively (World Bank, 2015a).

India's CO_2 emissions in 2014 continued to increase by 7.8% to about 2.3 Gt CO_2. This increase, about 170 million tonnes, made India the largest contributor to global emissions growth in 2014, effectively cancelling out a similar amount reduced by the EU-28. India is the fourth largest CO_2 emitting country, following closely behind the European Union, and ahead of the Russian Federation (Figure 2.2). This high ranking is partly due to the size of its population and economy. The workforce, which increased by 4% over the 2008–2013 period (World Bank, 2015), is expanding in the industrial and service sectors, partially because of international outsourcing. Per capita, India's CO_2 emissions are much lower than those of most developed countries and China (Figure 2.11).

The increase in CO_2 emissions in 2014 was mainly caused by an 11.1% increase in coal consumption, which accounted for 61.4% of India's fossil-fuel primary energy consumption and 56.5% of its total primary energy consumption (BP, 2015). This growth rate was above the 10-year average of 7%. At 61.4%, the coal share in India's fossil-fuel mix is smaller than that of China and South Africa (74% share of coal in their fossil-fuel mixes) but similar to that of Poland and Kazakhstan, and of other countries with large coal resources, and much larger than the global 2014 average of 19%. In India, further increases are expected in coal demand over the coming years. Coal demand is expected to increase by 6.4% over the 2014–2015 period (Coal India, 2015). If India's CO_2 emissions continue to grow at the same average rate (7%) as over the past 10 years, they will surpass the present EU-28 emissions by 2020. However, in its INDC contribution to the UNFCCC, India's power generation target for 2030 is to have 40% non-fossil energy sources compared to the current 19%, 3% of which is now in nuclear power (UNFCCC, 2015).

2.2.5 Russian Federation

In 2014, Russia's CO_2 emissions decreased by 1.5% to about 1.8 billion tonnes, following on from the reduction in 2013, when emissions dropped by 1.9%. After the drop in emissions in 2009 due to the global recession, Russia recorded increases in emissions in the years 2010 to 2012. Russia contributed 5% to global CO_2 emissions in 2014 (similar to its share of 5.1% in 2013). The decrease in CO_2 emissions in 2014 was mainly due to a decrease in the consumption of coal and natural gas, by 5.8% and 1.0%, respectively. Gas remains Russia's leading fuel, accounting for 54% of primary energy consumption. This decrease was partly counterbalanced by an increase in oil consumption of 0.9% due to increasing demand for petrol and fuel oil (BP, 2015). The difficult economic circumstances in 2014 are reflected in Russia's GDP, which only increased by 0.9% in 2014, a quarter of their average historical growth rate.

Oil production in Russia grew by 0.6%, whereas natural gas production declined by 4.3% (BP, 2015). The latter will be partly have been caused by lower exports to European countries due to lower demand for space heating. CO_2 emissions from the flaring of associated gas from oil production have been reduced by 40% from 2005 to 2012 (see Section 2.4). Since 1 January 2012, 95% of the gas associated with oil production needs to be captured, which in 2013 ramped up the environmental expenditure of half of the companies, according to Deloitte (2014). Technical regulations require oil companies to upgrade their facilities by 2016 and to switch to the production of modern types of fuel. Oil refineries owned by large state-owned companies are not prepared to produce higher quality fuel in the necessary volumes.

In 2014, Gazprom produced 444 billion cubic metres of gas, which was 3.9% less than in 2013. This figure is expected to increase slightly again in 2015, according to Gazprom (2015a). The other Russian producers increased their production by 9.4% to a total of 198 billion cubic metres of gas. In total, Russia is exploring 17% of the global reserves. Russian gas production covers more than its consumption, which decreased over the past three years by 1.5% to 0.7%. Gazprom has expanded the Russian gas transmission system in 2014 from 168.9 to 170.7 thousand kilometres; in particular, from the well with the highest productivity level in the Ural Federal District towards the Arctic Sea. In 2014, Russia's first Arctic offshore oil was produced and sold on the global markets. Russia exports 25% of its natural gas to EU countries and 7% to the newly independent states. In 2014, for its natural gas sales, Gazprom reported a significant decrease of 8% to foreign countries and 19% to the newly independent states, which is likely due to the depreciation of the rouble and due to the sanctions implemented by the United States and the European Union over the course of the Ukrainian conflict, according to Statista (2015). Gazprom (2015b) claimed that its increase in gas reserves due to exploration was 90% of the overall industrial growth in Russia, which levelled off its economic growth rate at 0.6% in 2014, compared to 2013.

2.2.6 Japan

Japan's share of global CO_2 emissions decreased slowly, from 5.2% in the 1990s, to 4.5% in the following decade, to 3.8% in the 2011–2013 period, and further down to 3.5% in 2014. After its highest CO_2 emission level in 2012, which resulted from the economic recovery following the recession of 2009 and the closure of nuclear power plants after the Fukushima accident in 2011, Japan is back on track with a 2.6% reduction in its CO_2 emissions in 2014, compared to 2013. This is a more significant downward trend than that of 2013, which only saw a small decline of 0.4%, compared to 2012. The economic growth of 1.7% in 2012 and 2013 was also reduced to near zero (-0.06%) in 2014.

The decrease in CO_2 emissions in 2014 was mainly due to a 5.2% decline in oil consumption. Consumption of coal and natural gas also fell in 2014, but only by 1.6% and 0.9%, respectively. Oil products remained Japan's leading fuel, at 42% of its total fossil-fuel consumption. In power generation, prior to the Fukushima accident and the shutdown of the country's nuclear fleet, about 60% of Japan's power generation mix was composed of fossil fuels. In 2013, when the entire nuclear fleet was shut down, fossil fuels contributed more than 86% to the power production (EIA, 2015c). In 2014, Japan's nuclear power generation was zero, while solar and wind power increased by 22% and hydropower by 4%. In 2015, Japan restarted some nuclear plants that adhered to more stringent safety regulations to address issues dealing with tsunamis and seismic events (EIA, 2015i).

In 2014, Japan imported 214 million tonnes of oil equivalent, which is as much as India, and this represents 7.7% of the total global oil and oil products exported (BP, 2015). In addition, Japan remains the world's largest importer of LNG, with 121 billion cubic metres, which is 36% of the world's total LNG imports. Moreover, Japan is also the second-largest coal importer in the world, because its very limited domestic energy resources have been able to meet less than only 9% of the country's primary energy use since 2012 (compared to about 20% before the shutdown of the nuclear power plants) and, according to the EIA (2015o), Japan is only able to produce 3% of its domestic gas consumption and 0.3% of its domestic oil consumption. After the 6.6% rise in Japan's oil consumption in 2012, this began to decline in 2013 and 2014, in particular in the power sector, as Japan relied more on gas and coal as the substitutes for nuclear energy. Japan's current government intends to resume the use of nuclear energy as a baseload power source with necessary safety measures. It is expected that the nuclear capacity will be back online in 2015.

2.2.7 Other OECD and eastern European countries

In 'Other OECD-1990 countries'[3], which are not included in the group of the six largest emitting countries/regions, CO_2 emissions decreased 0.1% in 2013 and 1% in 2014. Their share in global CO_2 emissions was 3.1% in 2014, with the largest contributions coming from Canada (1.6%), Australia (1.1%) and Turkey (1%). Compared to 2013, emissions in 2014 increased by 7.3% in Turkey and by 0.2% in Canada, and decreased by 2.1% in Australia.

The eastern European countries, excluding the Russian Federation and the EU's latest 13 Member States, recorded a decrease of 4.2% in 2014, following a decrease of 3.2% in 2013 and large increases in CO_2 emissions in 2010 and 2011, of about 5.8% and 6.3%, respectively. This group of countries accounted for 2.5% of global CO_2 emissions, with the largest emitting countries being the Ukraine (0.7%) and Kazakhstan (0.6%). In 2014, the Ukraine recorded a decrease in emissions of 16.4% and Kazakhstan an increase of 6.8%.

2.2.8 Other remaining countries

In 2014, emissions in countries from the category of 'Other large countries'[4] represented 13.5% of total global CO_2 emissions, and the 'Remaining countries'[5], in Latin America, Africa and Asia, contributed 15% to the total. The first category includes South Korea (with a share of 1.7% of the global total), Brazil (1.4%), Indonesia and Saudi Arabia (1.4% each) and Mexico (1.3%). After the economic recovery in most of these countries following the recession of 2009, large increases in CO_2 emissions were recorded. After the large jump of 5.2% in 2010, total CO_2 emissions in these 'Remaining countries' increased by 1.9% in 2012, 1.8% in 2013, and 2.2% in 2014, as a result the economic recovery in these countries after the global recession of 2009. Of the larger countries, CO_2 emission levels in 2014 decreased in Mexico by 1.6%, and increased in Brazil (3.3%), South Korea (0.2%), Indonesia (3.2%) and Iran (2.6%).

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 2.3 and Figure 2.8), in both relative and absolute figures, the picture is different for CO_2 emissions per capita (see Table 2.4 and Figure 2.9) and per unit of GDP (Figure 2.10). Where, since 1990, in the European Union CO_2 emissions decreased from 9.2 to 6.7 tonnes per capita, and in the United States from 19.6 to 16.5 tonnes per capita, they increased in China from 2.1 to 7.6. As such, Chinese citizens, together representing 19% of the world population, on average emitted about 1 tonne of CO_2 per capita more in 2014 as the average European citizen. In contrast, India's emissions of 1.8 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 2.11 (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 Figure 2.9 the lowest levels of CO_2 per capita of OECD-1990 countries are those of France (5.0 tonnes CO_2/cap because of the amount of nuclear energy used in that country) and the highest levels were seen in Australia (17.3 tonnes CO_2/cap because of its very high share of coal in power generation). The per-capita CO_2 emissions in the United States has remained stable in 2013 and 2014 at 16.5 tonnes CO_2/cap, and decreased in Japan to 10.1 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 (+38% between 1990 and 2014), in Canada (+28%) and in the United States (+27%). The populations of the European Union and Japan, however, increased much less (by 8% and 4%, respectively), and the Russian Federation even saw a decline of 4%. In comparison, the population of China increased by 20%, India 46% and Brazil 35% since 1990 (see Table 2.4).

Table 2.3
Trends in CO_2 emissions per region/country, 1990–2014 (unit: billion tonnes of CO_2), also available on http://edgar.jrc.ec.europa.eu/overview.php?v=CO2ts1990-2014

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
United States	**5.0**	**4.9**	**5.0**	**5.1**	**5.2**	**5.3**	**5.4**	**5.6**	**5.6**	**5.7**	**5.9**
EU-28	**4.3**	**4.3**	**4.1**	**4.0**	**4.0**	**4.1**	**4.2**	**4.1**	**4.1**	**4.0**	**4.1**
France	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*
Germany	*1.0*	*1.0*	*0.9*	*0.9*	*0.9*	*0.9*	*0.9*	*0.9*	*0.9*	*0.9*	*0.9*
Italy	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.5*	*0.5*
Netherlands	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*
Poland	*0.4*	*0.4*	*0.3*	*0.3*	*0.3*	*0.4*	*0.4*	*0.4*	*0.3*	*0.3*	*0.3*
Spain	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.3*	*0.2*	*0.3*	*0.3*	*0.3*	*0.3*
United Kingdom	*0.6*	*0.6*	*0.6*	*0.6*	*0.6*	*0.5*	*0.6*	*0.5*	*0.5*	*0.5*	*0.5*
Japan	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.3**	**1.3**	**1.2**	**1.3**	**1.3**
Other OECD	**0.8**	**0.8**	**0.8**	**0.9**	**0.9**	**0.9**	**0.9**	**1.0**	**1.0**	**1.0**	**1.0**
Australia	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.4*	*0.4*
Canada	*0.4*	*0.4*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.6*
Russian Federation	**2.4**	**2.3**	**2.2**	**2.0**	**1.8**	**1.7**	**1.7**	**1.6**	**1.6**	**1.6**	**1.7**
Other eastern Europe	**1.6**	**1.5**	**1.3**	**1.2**	**1.0**	**1.0**	**0.9**	**0.8**	**0.8**	**0.8**	**0.8**
Ukraine	*0.8*	*0.7*	*0.6*	*0.6*	*0.5*	*0.5*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*
China	**2.4**	**2.6**	**2.7**	**3.0**	**3.2**	**3.5**	**3.5**	**3.5**	**3.6**	**3.6**	**3.8**
*Of which cement **	*0.1*	*0.1*	*0.1*	*0.1*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*
India	**0.7**	**0.7**	**0.7**	**0.8**	**0.8**	**0.9**	**0.9**	**1.0**	**1.0**	**1.0**	**1.1**
Other big countries	**1.8**	**1.9**	**2.0**	**2.0**	**2.1**	**2.2**	**2.3**	**2.5**	**2.5**	**2.6**	**2.7**
Brazil	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*
Mexico	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.4*	*0.4*	*0.4*
Iran	*0.2*	*0.2*	*0.2*	*0.2*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.4*
Saudi Arabia	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.3*
South Africa	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*
Remaining countries	**2.3**	**2.4**	**2.5**	**2.7**	**2.8**	**3.0**	**3.2**	**3.4**	**3.3**	**3.4**	**3.6**
Asian Tigers	**0.7**	**0.8**	**0.8**	**0.9**	**1.0**	**1.1**	**1.2**	**1.3**	**1.2**	**1.3**	**1.3**
South Korea	*0.3*	*0.3*	*0.3*	*0.3*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.5*
Indonesia	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.3*	*0.3*	*0.3*	*0.3*
Taiwan	*0.1*	*0.1*	*0.1*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*
Thailand	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*
International transport	**0.6**	**0.6**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0.8**	**0.8**	**0.8**	**0.8**
Total	**22.5**	**22.6**	**22.6**	**22.7**	**23.0**	**23.6**	**24.2**	**24.5**	**24.6**	**24.8**	**25.6**

Note: the category Other eastern European countries includes Turkey and all other countries of the former Soviet Union except Russia; Asian Tigers here are: Indonesia, Singapore, Malaysia, Thailand, South Korea and Taiwan; Other large countries are: Brazil, Mexico, South Africa, Saudi Arabia, India and Iran. Remaining countries are the remaining non-OECD countries in Latin America, Africa and Asia.

All rows in black and italics are countries or groups of countries that are summarised in the row with blue label of the country group above. (Sub)totals may not match precisely due to independent rounding.

** Cement only refers to non-combustion emissions from limestone used in cement clinker production.*

2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
5.8	**5.7**	**5.8**	**5.9**	**5.9**	**5.8**	**5.8**	**5.6**	**5.2**	**5.5**	**5.4**	**5.2**	**5.3**	**5.3**
4.1	**4.1**	**4.2**	**4.2**	**4.2**	**4.2**	**4.2**	**4.1**	**3.7**	**3.9**	**3.7**	**3.7**	**3.6**	**3.4**
0.4	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.3*
0.9	*0.9*	*0.9*	*0.9*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*
0.5	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.3*
0.2	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*
0.3	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*
0.3	*0.3*	*0.3*	*0.3*	*0.4*	*0.4*	*0.4*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.2*	*0.2*
0.6	*0.5*	*0.6*	*0.6*	*0.6*	*0.6*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.4*
1.3	**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**
1.0	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**
0.4	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*
0.5	*0.5*	*0.6*	*0.6*	*0.6*	*0.5*	*0.6*	*0.6*	*0.5*	*0.5*	*0.6*	*0.6*	*0.6*	*0.6*
1.7	**1.7**	**1.7**	**1.7**	**1.7**	**1.8**	**1.8**	**1.7**	**1.6**	**1.7**	**1.8**	**1.8**	**1.8**	**1.8**
0.9	**0.9**	**0.9**	**0.9**	**0.9**	**1.0**	**1.0**	**0.9**	**0.9**	**1.0**	**1.0**	**0.9**	**0.9**	**0.8**
0.4	*0.4*	*0.4*	*0.4*	*0.3*	*0.4*	*0.4*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.2*
4.0	**4.3**	**5.0**	**5.8**	**6.7**	**7.4**	**8.0**	**8.2**	**8.5**	**9.1**	**9.9**	**10.2**	**10.5**	**10.6**
0.3	*0.3*	*0.3*	*0.4*	*0.4*	*0.5*	*0.5*	*0.5*	*0.5*	*0.6*	*0.7*	*0.7*	*0.7*	*0.8*
1.1	*1.1*	*1.1*	*1.2*	*1.3*	*1.4*	*1.4*	*1.5*	*1.7*	*1.8*	*2.0*	*2.1*	*2.2*	*2.3*
2.7	**2.8**	**2.9**	**3.0**	**3.2**	**3.3**	**3.5**	**3.7**	**3.9**	**4.1**	**4.3**	**4.5**	**4.6**	**4.8**
0.3	*0.3*	*0.3*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.5*	*0.5*	*0.5*
0.4	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*
0.4	*0.4*	*0.4*	*0.4*	*0.5*	*0.5*	*0.5*	*0.5*	*0.6*	*0.6*	*0.6*	*0.6*	*0.6*	*0.6*
0.3	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.4*	*0.4*	*0.4*	*0.4*	*0.5*	*0.5*	*0.5*
0.3	*0.3*	*0.3*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*
3.6	**3.7**	**3.9**	**4.0**	**4.2**	**4.3**	**4.5**	**4.7**	**4.7**	**5.0**	**5.1**	**5.2**	**5.2**	**5.4**
1.4	**1.4**	**1.5**	**1.6**	**1.6**	**1.6**	**1.7**	**1.7**	**1.7**	**1.8**	**1.8**	**1.8**	**1.9**	**1.9**
0.5	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.6*	*0.6*	*0.6*	*0.6*	*0.6*	*0.6*
0.3	*0.3*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.5*
0.2	*0.2*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*
0.2	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.3*	*0.3*	*0.3*	*0.3*
0.8	**0.9**	**0.9**	**0.9**	**1.0**	**1.0**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**
25.9	**26.4**	**27.7**	**29.0**	**30.2**	**31.1**	**32.3**	**32.5**	**32.0**	**33.6**	**34.7**	**35.0**	**35.5**	**35.7**

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 more uncertain than population 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 are being accounted for, whereas in practice there are always illegal or unrecorded economic activities that could range from a few per cent to much more than 10 per cent, of which only estimates can be made.

For example, when converting the GDP at PPP prices from constant USD of 2005 to prices of 2011 in this report, the changes in many OECD countries are in the same range as those in the United States, about 20%, but for some countries the changes are much larger; for example, of the top-25 countries, about 50% for India and Russia and about 100% for Indonesia and Saudi Arabia.

Note that for many OECD countries present World Bank and IMF GDP statistics do now include the recent revision of the definition of the Gross National 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 economic activities.

OECD countries that have published GDP revisions to include the SNA 2008 guidelines generally showed increases up to 3%. Notable exceptions are Italy, the UK and the Netherlands with increases of the time series of about 4, 5 and 6%, respectively. Also South Africa (+3%) and India (-2%) have revised their GDP numbers according to the World Bank.

Another indicator of the CO_2 intensity of a country is the ratio of *CO_2 emissions over GDP* as shown in Figure 2.11 (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 Tables 2.2 and 3.1). 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 2.11 (right) shows that over the past decade, most top 5 emitting countries and the EU-28 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. 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 2014, 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 2.11 as the country with the largest emissions related to GDP. The 3.0% global economic growth in 2013 and 3.3% in 2014 was about two-thirds of the average growth level since 2003 (4.3% per year), excluding the recession years 2008 and 2009.

Table 2.4

CO_2 emissions in 2014 (million tonnes CO_2) and CO_2/capita emissions, 1990–2014 (tonnes CO_2 per person)

Country	Emissions 2014	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	Change '90-'14	Change '90-'14 in %	Change in CO_2 1990-2014 in %	Change in population 1990-2014 in %
United States *	5,330	19.6	20.6	17.6	16.5	16.5	-3.1	-16%	7%	27%
EU-28	3,420	9.2	8.4	7.7	7.1	6.7	-2.5	-27%	-21%	8%
- Germany	770	*12.5*	*10.3*	*9.7*	9.8	9.3	-3.2	-26%	-24%	3%
- United Kingdom	420	*10.1*	*9.3*	*7.9*	7.2	6.5	-3.6	-35%	-28%	11%
- Italy	340	*7.5*	*8.0*	*7.0*	6.0	5.5	-1.9	-26%	-20%	7%
- France	320	*6.7*	*6.7*	*6.0*	5.5	5.0	-1.7	-25%	-15%	14%
- Poland	300	*9.4*	*8.1*	*8.4*	8.1	7.8	-1.6	-17%	-17%	0%
- Spain	240	*5.8*	*7.6*	*6.1*	5.2	5.1	-0.7	-12%	7%	21%
- Netherlands	160	*10.7*	*10.8*	*10.9*	10.0	9.4	-1.3	-12%	0%	13%
Russian Federation	1,770	16.1	11.3	12.0	12.5	12.4	-3.7	-23%	-26%	-4%
Japan	1,280	9.6	10.1	9.8	10.3	10.1	0.5	5%	9%	4%
Canada	570	16.2	17.9	16.0	16.1	15.9	-0.3	-2%	26%	28%
Australia	410	16.1	18.5	18.7	17.9	17.3	1.2	7%	48%	38%
Ukraine	250	15.1	7.2	6.6	6.6	5.5	-9.6	-63%	-68%	-13%
Other countries:										
China	10,590	2.1	2.9	6.6	7.5	7.6	5.5	262%	333%	20%
India	2,340	0.8	1.0	1.5	1.7	1.8	1.1	146%	259%	46%
Iran	620	3.6	5.3	7.7	7.8	7.9	4.3	117%	203%	39%
South Korea	610	6.2	10.4	12.3	12.4	12.3	6.1	98%	128%	15%
Brazil	500	1.5	1.9	2.2	2.4	2.5	1.0	71%	131%	35%
Saudi Arabia	490	10.4	12.9	15.5	16.0	16.8	6.5	62%	194%	81%
Mexico	460	3.4	3.6	3.8	3.8	3.7	0.3	10%	58%	44%
Indonesia	450	0.9	1.4	1.7	1.8	1.8	0.9	101%	184%	42%
South Africa	390	7.3	6.8	7.9	7.3	7.4	0.1	1%	46%	44%
Taiwan	280	6.2	10.5	11.8	11.8	11.8	5.7	91%	121%	16%
Thailand	270	1.6	2.7	3.7	3.9	4.0	2.4	147%	193%	19%

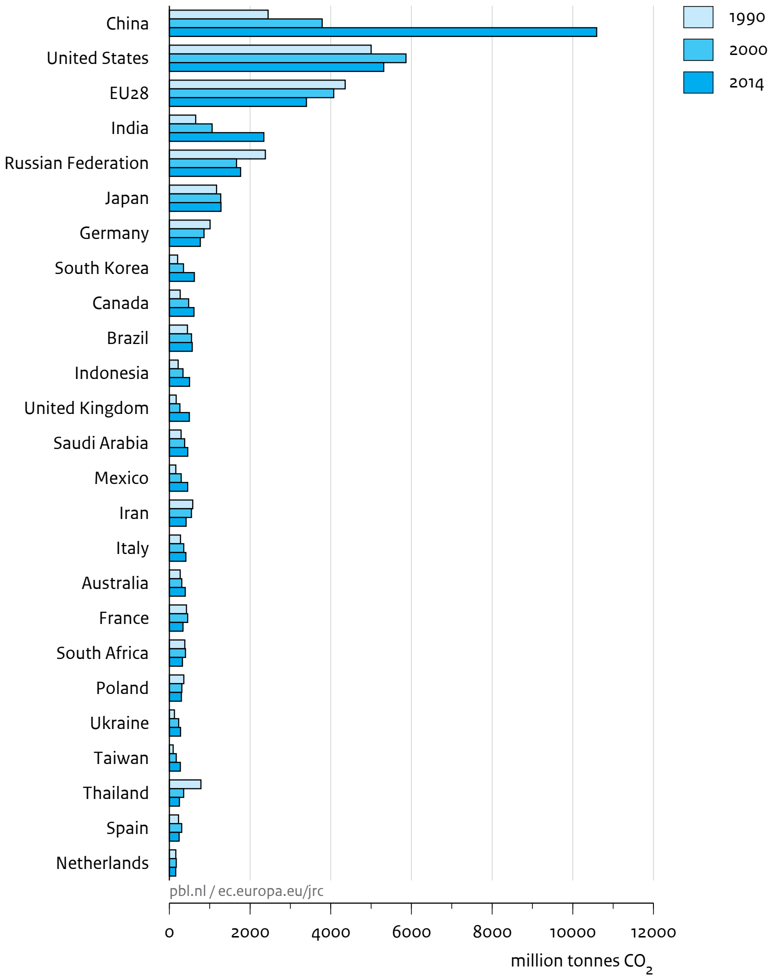
Source of population data: UNPD, 2013 (WPP Rev. 2012)

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 five per cent for some countries. These elements add further uncertainty to the comparisons of CO_2 intensities relative to GDP between countries (see Box 2.5).

In addition Figure 2.12 shows the CO_2 intensity relative to *total primary energy supply* (TPES). It indicates that so far China's total primary energy supply was over the past two decades increasing in carbon intensity. Since 2010, the carbon intensity of the primary energy supply stabilised, but at levels much higher than in Europe or the United States. The large and increasing energy demand in China was mainly supplied with many new coal power plants. India is also showing a similar increasing carbon intensity, but hopefully does not grow to a similar level as China has today. Europe has the lowest carbon intensity of the primary energy supply, followed by the Russian Federation and the United States. All three show a slowly but steadily decreasing carbon intensity (with the exception of 2013 for the United States).

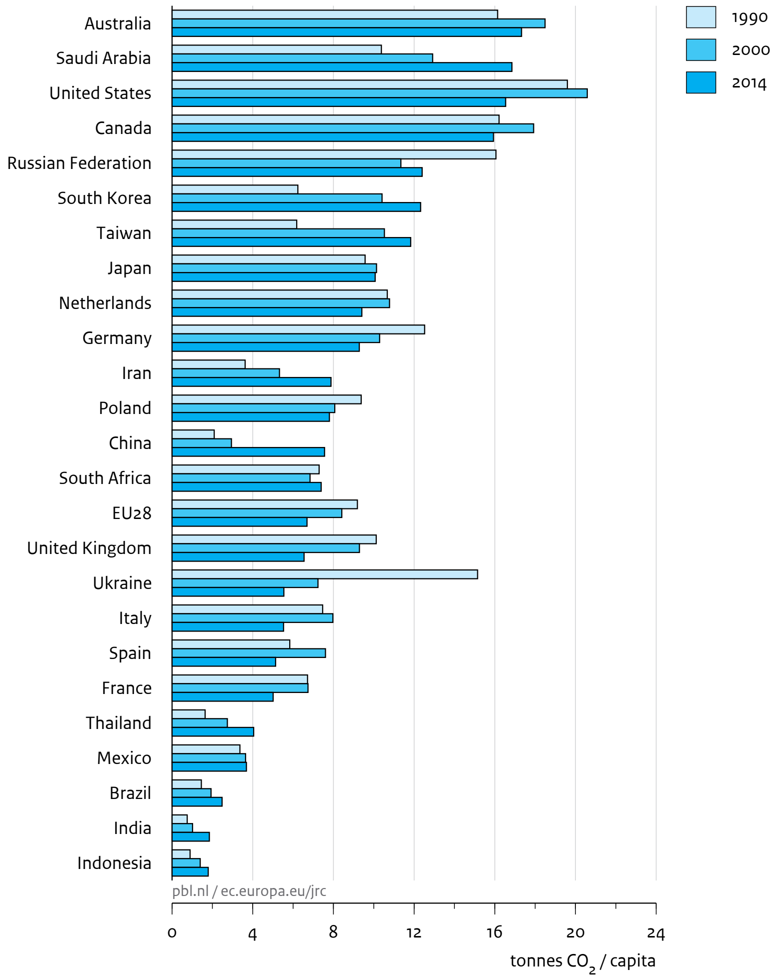
Figure 2.11 and Table 2.4 below shows the change in per capita CO_2 emissions for 1990–2014 and of population for a numbers of countries. The emissions are excluding LULUCF emissions ('IPCC sector 5'). These tables and the figures used in Figures 2.1 to 2.12 can also be found as spreadsheet on the PBL website: http://www.clo.nl/nl0533 and on the EDGAR website at JRC: http://edgar.jrc.ec.europa.eu.

Figure 2.8
CO_2 emissions per country from fossil-fuel use and cement production



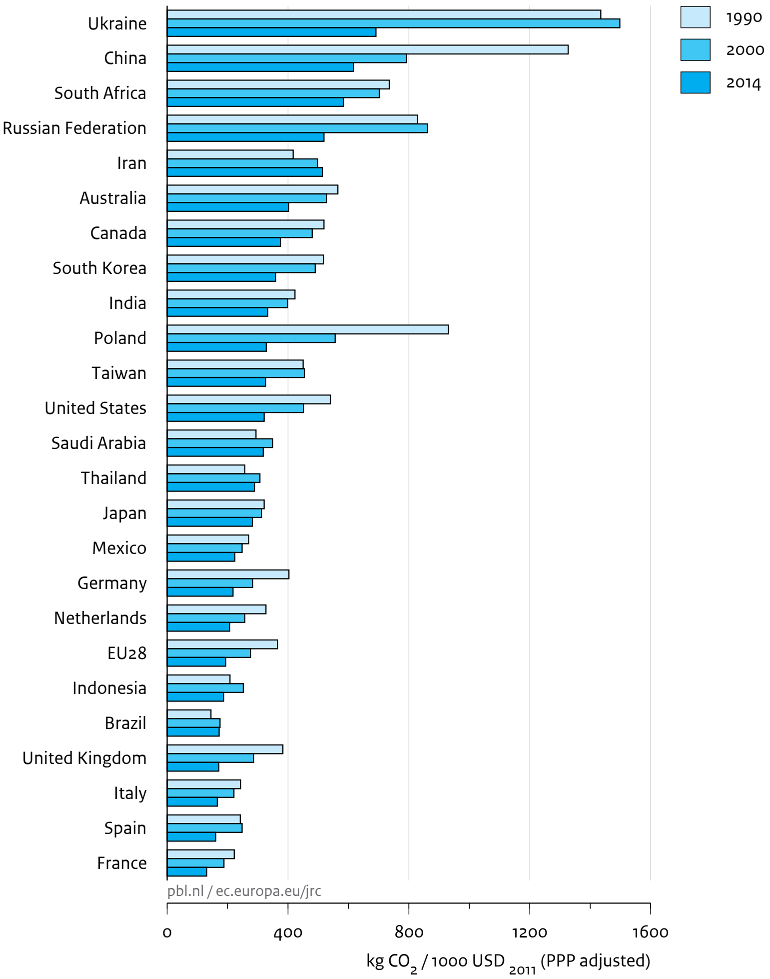
Source: EDGAR 4.3 FT2014 (JRC/PBL, 2015) (notably IEA 2014, NBS 2015 and BP 2015)

Figure 2.9
CO_2 emissions per capita from fossil-fuel use and cement production



Source: EDGAR 4.3 FT2014 (JRC/PBL 2015) (notably IEA 2014, NBS 2015 and BP 2015); UNPD 2013 (WPP, Rev. 2013)

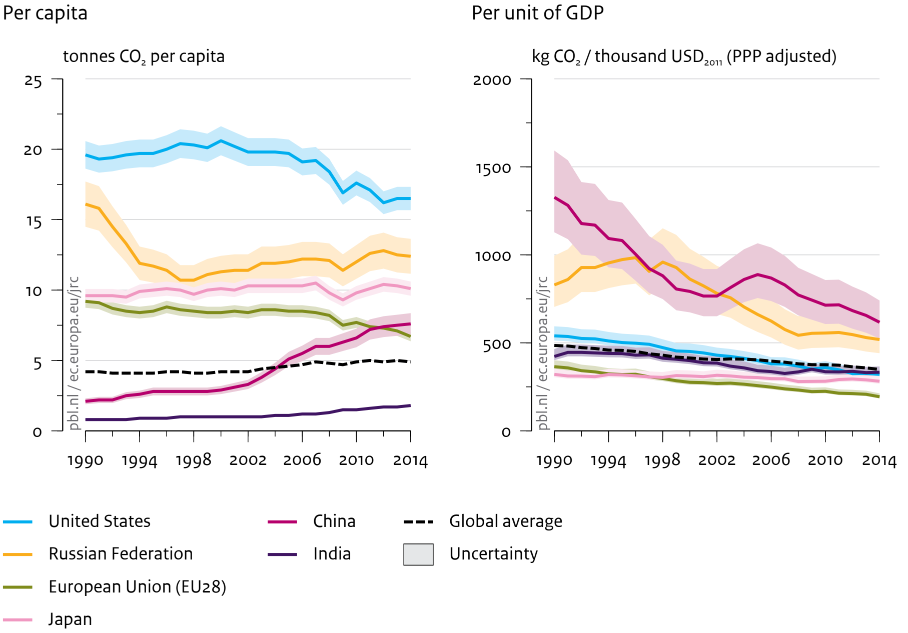
Figure 2.10
CO_2 emissions per unit of GDP from fossil-fuel use and cement production



Source: EDGAR 4.3 FT2014 (JRC/PBL, 2015) (notably IEA 2014, NBS 2015 and BP 2015); World Bank 2015; IMF 2015

Figure 2.11

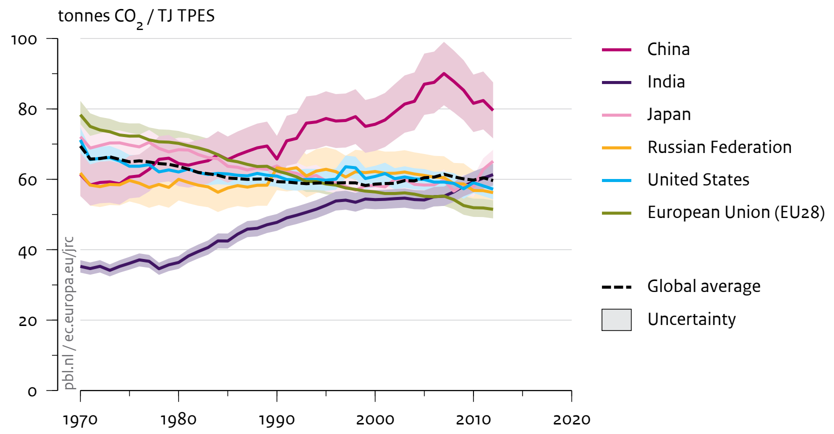
CO_2 emissions from fossil-fuel use and cement production in the top 5 emitting countries and the EU



Source: EDGAR 4.3 FT2014 (notably IEA 2014, NBS 2015 and BP 2015); UNPD 2013 (WPP, Rev. 2013) World Bank 2015; IMF 2015

Figure 2.12

CO_2 emissions per unit of Total Primary Energy Supply (TPES) in the top 5 emitting countries and the EU



Source: IEA 2014; BP 2015

Note: Using substitution method for nuclear, hydro and other non-biomass renewables as in BP (2015) (i.e. assuming 38% conversion efficiency).

2.4 CO_2 emissions from oil and gas production

When natural gas is co-produced during conventional or unconventional oil production and cannot be marketed, this waste stream of gas is either vented or flared. Venting or flaring occurs in areas that are remote from market demand and from gas transport infrastructure. Both practices lead to emissions of greenhouse gases: methane from venting and CO_2 from flaring.

After a steady decrease by about a one fifth since 2003, the present global CO_2 emissions (of about 275 million tonnes) from the flaring of unused gas during oil production – comparable in magnitude with total CO_2 emissions in a medium-sized country such as Spain – did not significantly change in 2012. These estimates for natural gas flaring were derived from DMSP-OLS and MODIS satellite measurements for 1994-2011, analysed by the US National Oceanic and Atmospheric Administration (NOAA) and supported by the Global Gas Flaring Reduction (GGFR) Partnership, a public–private partnership which is led by the World Bank. The night-time light emitted from gas flares observed by the satellites provides an estimate of the amounts of gas flared for about 60 countries, after calibration to reported flaring volumes available from the GGFR Partnership (Elvidge et al., 2009a). However, a new sensor incorporated by NOAA in 2012 needs to be corrected for clouds and calibrated to known flared gas volumes. This dataset was supplemented with other datasets that often include the venting of associated gas (see Annex A1.1). For 2012, preliminary data was used for the top-20 flaring countries, as estimated by the GGFR (2015). Due to a lack of information, we assumed for all countries that CO_2 emissions in 2013 and 2014 did not change compared to 2012.

The countries with the largest satellite-observed flaring emissions are the Russian Federation and Nigeria, which account for about one quarter and one tenth of total global flaring emissions, respectively (see Table 2.5), followed by Iran (7.5%), Iraq (7%) and the United States (5.6%) (GGFR, 2015). The Russia and Nigeria also contributed the most to the global emission decrease over the past decade.

Satellite information on gas flaring in the United States showed that flaring emissions are on the rise, with increases of up to 30% from 2009 onwards. The main cause of the jump in emissions was the country's recent massive increase in the use of hydraulic fracturing, or fracking, and other advanced drilling techniques for oil production and the ensuing flaring of co-produced gas (Nicholson, 2012), particularly in North Dakota and Texas. However, it was noted that the satellite used at the time, which uses mainly visible light to estimate flare volumes, overestimated the volumes in some areas, notably shale oil production in North Dakota and Texas. Furthermore, full coverage of flaring in US data was not possible since in many onshore production areas there are too many other light sources. Therefore, in EDGAR version 4.3, we used 2012 data adjusted by the GGFR (GGFR, 2015) for flaring in the United States in 2009, based on reported data as a guide. The US EPA notes that there is still considerable uncertainty in the reported emissions and trends, due to the incompleteness of the reporting and different tiers of methodologies used (US EPA, 2015b). However, the latest EPA estimates based on reporting by the oil and gas industry show that greenhouse gas emissions from associated gas flaring and venting activities (excluding venting from fracturing of oil wells) increased between 2011 and 2014 from 8.1 to 13 megatonnes of CO_2 eq (US EPA, 2015b). Other large increases compared to 2005 are seen in Iraq, Venezuela and Canada (Table 2.5).

Recent attention at policy level
The 'Zero Routine Flaring by 2030' Word Bank initiative brings together governments, oil companies, and development institutions who agree to cooperate in order to eliminate routine flaring no later than by 2030 (Dandashly, 2015). This initiative only addresses routine flaring and not flaring for safety reasons or non-routine flaring, which nevertheless should be minimised.
The routine flaring of gas is flaring during normal oil production operations in the absence of sufficient facilities or suitable geology to re-inject the produced gas, utilise it on-site or transport it to a market (World Bank, 2015b). Governments that endorse the initiative will provide support via upstream investments, and the development of viable markets for utilisation of the gas and the infrastructure necessary to deliver the gas to these markets.

The Oil and Gas Climate Initiative (OGCI), a collaboration of 10 of the largest oil companies, aims to make an effective and sustainable contribution to help address climate change. One of these is to collaborate with the World Bank's 'Zero Routine Flaring initiative'. Data of seven OGCI companies show that the total amount of gas flared has almost halved over the past six years. Although it is a real challenge to find solutions in countries where there is no gas infrastructure or market for natural gas, the initiatives proposes a number of workable approaches for several countries (OGCI, 2015).

Shale gas and tight oil (shale oil and tar sands)
Currently, only four countries produce shale gas and shale oil on an industrial scale: the United States, Canada,

Table 2.5

Recent trends in CO_2 emissions from gas flaring in the top-15 producing countries, ranked by 2012 emissions (unit: Mt CO_2).

Country	2005	2007	2009	2010	2011	2012	Change in 2012 rel. to 2005 (%)	Share in global total in 2012 (%)
Russian Federation	110.8	99.3	88.7	67.8	71.2	66.3	-40%	23%
Nigeria	42.2	32.3	29.6	29.8	29.2	29.2	-31%	10%
Iran	23.9	22.1	22.4	23.1	23.1	21.6	-9%	7.5%
Iraq	14.1	13.5	16.3	18.1	18.8	20.7	46%	7.2%
United States	4.9	5.0	6.2	8.7	12.3	16.3	232%	5.6%
Algeria	12.9	12.6	11.1	11.4	10.8	10.6	-18%	3.7%
Venezuela	5.4	5.5	6.7	6.7	8.3	10.0	85%	3.5%
Kazakhstan	12.4	11.0	10.1	7.7	9.4	9.3	-25%	3.2%
Saudi Arabia	8.2	8.8	8.4	8.0	8.3	9.1	12%	3.2%
Angola	9.5	7.2	6.9	8.3	8.3	7.7	-19%	2.7%
Libya	9.3	7.8	7.1	7.8	4.4	6.6	-29%	2.3%
Canada	3.2	4.7	4.9	5.2	5.0	6.1	93%	2.1%
Indonesia	6.4	5.5	6.0	4.7	4.6	5.2	-18%	1.8%
China	7.2	6.9	6.4	6.0	6.2	5.1	-30%	1.8%
Kuwait	6.4	5.6	4.6	4.5	4.4	4.7	-27%	1.6%
Total top 15	276.6	247.9	235.5	217.7	224.2	228.4	-17%	79%
Global Total	348.8	315.0	304.2	281.3	283.7	288.1	-17%	100%

Source: EDGAR 4.3 (EC-JRC/PBL, 2015)

China and Argentina. The United States is by far the largest producer of both shale gas and tight oil, with shale gas now making up half of total natural gas production, and tight oil almost half. Canada also produces both shale gas and tight oil (tar sands), which make up the largest part of its total oil and gas production. China currently produces as much shale gas as Canada, which contributes 1.5% to total natural gas production, while Argentina produces a small amount of tight oil (EIA, 2015d).

Decreasing costs of wells, increasing experience in shale gas development, probably supported by expertise gained from China's investment in US shale gas exploration, and government subsidies will support the further development of commercial shale gas production. It is expected that the share of shale gas will have increased to 4% by the end of 2015 (EIA, 2015m).

Australia and Russia also use hydraulic fracturing techniques to produce natural gas and tight oil, but not from low-permeability shale formations. Exploration activities in shale formations have also begun in a number of other countries, including Algeria, Argentina, Australia, China, India, Mexico, Poland, Romania, Russia, Saudi Arabia, Turkey, Ukraine and the United Kingdom. However, underground and aboveground conditions may not be as favourable in these countries as in the four countries currently producing natural gas and tight oil.

For a detailed discussion on the development in the United States and Canada and on the environmental concerns around fracking and oil sands production, see previous reports (Olivier et al., 2013, 2014). Here, we only briefly summarise a few of the latest developments.

Methane emissions from new production techniques

Concerns regarding the impact of fracking and shale gas and oil production on greenhouse gas emissions relate to the higher energy intensity of the fracking and production process and to possibly larger emissions of methane (CH_4, the second most important greenhouse gas, has a global warming potential ('GWP') which, per kilogramme, is 25 times that of CO_2), or additional CO_2 emissions from the flaring of gas that cannot be economically utilised due to a lack of infrastructure. However, the knowledge on current and future emission levels from flaring (CO_2) and venting (CH_4) related to oil and shale gas hydraulic fracturing, as well as from other oil and gas activities, is still highly uncertain (Olivier et al., 2013, 2014). According to the official reports by OECD-1990 countries, Russia and other and eastern European countries to the UNFCCC, the methane share in total greenhouse gas emissions from venting and flaring greatly varies between countries; for example, in the Russian Federation and the European Union, this is about a quarter, in Canada it is about half, and in the Ukraine about 90% (UNFCCC, 2014).

New reports on methane emissions in the United States
Methane emissions from the total petroleum and natural gas sectors decreased by 13% from 2011 to 2014, and emissions from hydraulic fracturing plummeted substantially. Between 2012 and 2014, reported methane emissions fell by 81% (Brown, 2015; US EPA, 2015b). In 2013, these figures were 12% (petroleum) and 73% (natural gas) (Snow, 2014). However, Lyon et al. (2015) reported on a measurement and modelling study of methane emissions from the oil and gas sector in the Barnett Shale Region in October 2013, and concluded that their estimate was a factor 1.5 to 2.7 higher than US EPA estimates. This was primarily due to the use of more comprehensive activity factors and to including emissions from so-called fat-tail sites: relatively rare sources that contribute a large fraction to total emissions. In this study, about 20% of the emissions were from fat-tail sites while these represent less than 2% of the sites. The largest difference with US EPA data was concerned data on gathering compressor stations, which accounted for 40% of the total in this study, of which on third was from fat-tail sites.

Peischl et al. (2015) report on a widespread measurement campaign carried out in 2013 that represented over half of the shale gas production sector. They found generally lower loss rates than those reported in earlier studies of regions that made smaller contributions to total production, and conclude that the national average methane loss rate from shale gas production may be lower than values extrapolated from the earlier studies. However, the uncertainty in the results is about 50% (66% confidence interval), and as the measurements were only taken on one day in early summer they may not be fully representative of the total annual emissions rate, so the results are not very conclusive.

2.5 CO_2 from cement and steel production (non-combustion)

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

2.5.1 Cement production

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 4.1% of the total global emissions in 2014. Fuel combustion emissions of CO_2 related to cement production are of approximately the same level, 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 59% of global cement production in 2014, followed by India (7%) and the United States (2%) (see Table 2.6). The EU-28 accounted for 4% of the global total. In the EU cement production decreased by 1.6% in 2014, compared to a decrease of 2.1% in 2013. According to USGS (2015) and NBS (2015a) global cement production increased by 1.8% in 2014, compared to 3.6% in 2013.

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 to 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. According to EDGAR 4.3 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 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.

Table 2.6

Recent trends in cement production in top-10 producing countries and EU-28, ranked to 2014 production (in million tonnes).

Country	2010	2011	2012	2013	2014	Change in 2014 (%)	Share in global total in 2014 (%)
China	1,880	2,100	2,210	2,315	2,365	2.3%	58.5%
India	220	250	270	280	280	0.0%	6.9%
European Union	188	193	169	165	163	-1.6%	4.0%
United States	66	68	74	77	83	7.7%	2.0%
Iran	61	66	70	72	75	4.2%	1.9%
Turkey	63	63	64	71	75	5.1%	1.9%
Brazil	59	64	69	70	72	2.9%	1.8%
Russian Federation	50	56	62	66	69	3.9%	1.7%
Saudi Arabia	48	51	56	57	63	10.5%	1.6%
Indonesia	39	45	51	56	60	7.1%	1.5%
Vietnam	56	58	56	58	60	3.4%	1.5%
Global Total	**3,350**	**3,650**	**3,835**	**3,975**	**4,045**	**1.8%**	**100%**

Source: USGS (2015), NBS (2015a)

Table 2.7

Recent trends in CO_2 emissions from cement clinker production in top-10 producing countries and EU-28, ranked to 2014 emissions (unit: Mt CO_2).

Country	2010	2011	2012	2013	2014	Change in 2014 (%)	Share in global total in 2014 (%)
China	604	684	712	745	762	2.3%	52.7%
India	83	92	99	102	102	0.0%	7.1%
European Union	78	76	65	64	63	-1.6%	4.4%
United States	31	32	35	36	39	7.7%	2.7%
Turkey	29	28	30	34	36	5.1%	2.5%
Iran	27	28	30	31	32	4.2%	2.2%
Russian Federation	22	25	26	28	29	3.9%	2.0%
Japan	25	25	26	27	27	1.0%	1.9%
Saudi Arabia	21	21	24	24	27	10.5%	1.9%
Vietnam	25	26	24	25	26	3.4%	1.8%
Indonesia	18	20	22	24	26	7.1%	1.8%
Global Total	**1,220**	**1,315**	**1,370**	**1,420**	**1,445**	**1.9%**	**100%**

Source: EDGAR 4.3 (EC-JRC/PBL, 2015)

Table 2.8
Recent trends in crude steel production in top-10 producing countries and EU, ranked to 2014 production (in million tonnes).

Country	2010	2011	2012	2013	2014	Change in 2014 (%)	Share in global total (%)
China	637	685	717	815	823	0.9%	49%
European Union	170	174	168	164	167	1.8%	10%
Japan	110	108	107	111	111	0.1%	7%
United States	80	86	89	87	88	1.7%	5%
Indonesia	68	74	78	81	83	2.3%	5%
South Korea	59	69	70	66	71	7.5%	4%
Russian Federation	67	68	69	69	71	2.6%	4%
Germany	44	44	43	43	43	0.7%	3%
Turkey	29	34	36	35	34	-1.8%	2%
Brazil	33	35	35	34	34	-0.7%	2%
Ukraine	34	35	33	33	27	-17.1%	2%
Global	**1,430**	**1520**	**1,550**	**1,645**	**1,665**	**1.1%**	**100%**

Source: USGS (2015), WSA (2015)

Therefore, CO_2 emissions from cement clinker production are not directly proportional to cement production. Therefore the shares and ranking of the top-10 cement producing countries in Table 2.7 somewhat different from the related CO_2 emissions. China accounted for 53% of CO_2 emissions from global total cement clinker production in 2014, followed by India (7%), the United States (3%) and Turkey (3%) (see Table 2.7). The EU accounts for 4.4% of the global total. According to EDGAR 4.3 FT2014, global cement clinker production emissions rose 2% in 2014, compared to an increase of 2% in 2013.

2.5.2 Iron and steel production

Steel production is related with non-combustion CO_2 emissions from blast furnaces used to produce pig iron and from conversion losses in coke manufacturing. China accounted for 49% of global crude steel production in 2014, followed by Japan (7%), the United States (5%), India (5%), the Russian Federation and South Korea (each 4%) (see Table 2.8). The EU accounted for 10% of the global total. According to WSA (2015), global crude steel production rose 1% in 2014, compared to 6.2% in 2013.

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.

2.5.3 Other industrial sources

Lime and ammonia production are other industrial sources of CO_2 emissions. In 2014, lime production increased globally by 1% and ammonia production remained the same (USGS, 2015).

2.6 Data quality and uncertainties

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 2.9). Also, most OECD-1990 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-1990 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 a 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

Table 2.9

Differences between EDGAR national total CO_2 emissions and official NIR/CRF submissions(excluding LULUCF emissions, IPCC sector 5) (in % of NIR/CRF data) (reported uncertainty estimate cf. IPCC definition: 95% confidence interval, CI)

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
EU-28	-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%								

Source: EDGAR 4.3: EC-JRC/PBL (2012); NIR/CRF data: UNFCCC (2014); for China and India: Second National Communications.

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 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.

However, 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). 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,

Box 2.4 Assessment of study by Liu et al. (2015)

Liu et al. (2015) re-evaluate China's carbon emissions which were calculated bottom-up with energy consumption and clinker production statistics and new CO_2 emission factors for Chinese coal based on measured carbon content and net heating value. They found that, with 10% higher energy consumption and 45% lower emissions from cement production and with coal-burning emission factors with a non-oxidation fraction of 8%, their revised estimate of China's CO_2 emissions from fossil-fuel combustion and cement production was 14% lower than the EDGAR estimate reported in Olivier et al. (2014) and 9% lower than the CDIAC estimate. An in-depth analysis of the study revealed the following points.

First, the study incorrectly mentions differences with EDGAR 4.2 FT2013 and CDIAC data (-14% and -9% for 2013), which should be -12% when we compared their estimate with the EDGAR 4.2 FT2013 (and -8% for CDIAC) according to the supplemental information. The difference with the EDGAR data is further exaggerated as the Liu study makes a comparison with EDGAR emissions that include many more sources than those used in the study. When correcting for the fugitive emissions (flaring, coke production) and emissions from non-energy use of fuels (e.g. for chemicals production) and other carbonate use (limestone), the real difference for 2013 is reduced to -6% (versus -14%/-12% in the study). This difference is well within the uncertainty range that is often estimated for China's CO_2 emissions.

Most of the actual difference of 6% can be attributed to the non-oxidation fraction of 8% (fuel carbon that remains in the ash) that was used in the study for coal burning, knowing that about four-fifths of fossil-fuel CO_2 is from coal and the EDGAR emissions assume a non-oxidation fraction of 0%. However, the values for coal non-oxidation fractions per sector reported in the study (2% and 5% for power plants and industrial combustion (NBS and NDRC T1/T3 data sets), that make up about 60% and 35% of total coal use) are not consistent with the very high average value of 8% used in the authors' revised estimate. That is also much higher than the present default value of 0% recommended by IPCC in the absence of representative national data (IPCC, 2006), which is also used for EDGAR CO_2 estimates and, as from this year, also by the IEA. We note that for all countries the EDGAR estimates assume – and in compliance with the IPCC default – that 0% of the carbon would remain in the ash, because this value is technology-dependent and not known for each country in the world. Moreover, this value reduces for power plants that have an energy efficiency (and therefore higher temperatures) that is similar to those in Europe (over the past 3 decades).

Second, extensive measurements made by the authors show that the average energy content (TJ/tonne coal) and average carbon content per tonne coal (tonne C/tonne coal) of domestic coal is much lower than the IPCC default values, which is primarily caused by the low quality and high ash content of Chinese coal. However, the average carbon content *per unit of energy* (e.g. tonne C/TJ) measured for Chinese coal is very similar to the IPCC default value for bituminous coal (IPCC, 2006), as it differs only by 2%. Moreover, the average net calorific value (e.g. TJ/kg) measured for Chinese coal is only 3% lower than the value that the IEA uses for bituminous Chinese coal, and these data are used in the EDGAR data set (IEA and EDGAR both use country-specific values for the energy content of coal). Also, the authors apply their country-specific factors to all years, also the non-oxidation fraction, whereas in practice these values may vary over time, as can be observed in IEA and UN data sets of the net calorific values per coal type, per main sector.

Third, Liu et al. suggest that the IPCC guidelines recommend using a default CO_2 emission factor expressed in tonne C per tonne coal, which is 40% too high in the case of China. However, the IPCC guidelines recommend to use an emission factor expressed in energy units, rather than in tonne of coal, if representative country-specific emission factors are not available. The authors suggest that the use of those emission factors in international data sets such as EDGAR is one of the main reasons why their revised estimate is much lower than that of EDGAR and CDIAC.

Fourth, noting the large differences between total coal consumption statistics at country level and the sum of provincial coal statistics, the authors claim that using so-called 'apparent consumption' (= production + imports – exports ± stock changes) as an estimate for domestic coal consumption is the most accurate method for China. Although this method is often quite accurate compared to consumption-based estimates from surveys held under coal users to estimate total sectoral coal consumption, in the specific case of China history has shown that coal production statistics are not very accurate either. Periodically, there have been major revisions, so this figure apparently is also not very accurate.

We conclude that Liu et al. do not provide good evidence to prove that present international CO_2 emissions inventories such as CDIAC, IEA and EDGAR are systematically and substantially too high.

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. 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 4.1 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. From these recent studies on the accuracy of the data on China's CO_2 emissions, and taking into account the uncertainty in the default coal emission factors, of the order of 5% or more, based on OECD-1990 countries (Olivier et al., 2010), and this year's major revision by NBS of the coal statistics going back to 2000, we concluded that the uncertainty in the present EDGAR 4.3 estimates for China is about ±10%. This conclusion was also based on subsequent revisions of CO_2 emission estimates made by the IEA. We refer to Box 2.4 for our assessment of the paper by Liu et al. (2015).

In conclusion, we estimate the uncertainty in our estimates of total national annual CO_2 emissions at 5% for the United States, European Union, other OECD countries and India, and at 10% for the Russian Federation, China and other countries with less-developed statistical systems. These uncertainties are primarily based on an uncertainty assessment of the emissions from fossil-fuel combustion, since these comprise the majority of total national emissions. The more uncertain CO_2 emissions from gas flaring and from non-combustion sources in industrial manufacturing do not substantially influence the uncertainty regarding total national emissions. The uncertainty in the emission trends, however, may be smaller than the uncertainty in annual emissions, as illustrated in the trend uncertainty assessments included in the national emission reports submitted to the UNFCCC (2014), which applied the methods described in the IPCC good practice guidance (IPCC, 2006).

Notes

1 If one had used the 2.9% decrease in coal consumption reported by NBS in February (NBS, 2015a), the calculation of China's CO_2 emissions would have decreased by 1.1%.

2 In 2007–2008 physical growth rates plummeted also in China due to the global economic recession caused by the credit crunch in OECD-1990 countries.

3 The category 'Other OECD-1990 countries' includes Australia, Canada, Iceland, New Zealand, Norway, Switzerland and Turkey. These are seven of the 24 countries that were members of the OECD in its composition of 1990, which furthermore consisted of the EU-15 countries, the United States and Japan. Another five countries (Mexico, Korea, Hungary, Estonia, and the Czech Republic) joined the OECD later in the 1990s, followed by another three countries (Slovenia, Israel and Chile) since 2010.

4 'Other large countries' include Brazil, Iran, Mexico, Saudi Arabia and South Africa.

5 'Remaining countries' include all non-OECD-1990 countries except eastern European countries, China, India, and the 'Other large countries'.

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, which we would need to start limiting, particularly by limiting the level of energy-intensive activities, such as related to power generation, manufacturing industry and road transport. In addition we should aim at an energy saving culture with a sparing use of energy not only in industry but also in households.
- 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 the significant support of some policies.

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.

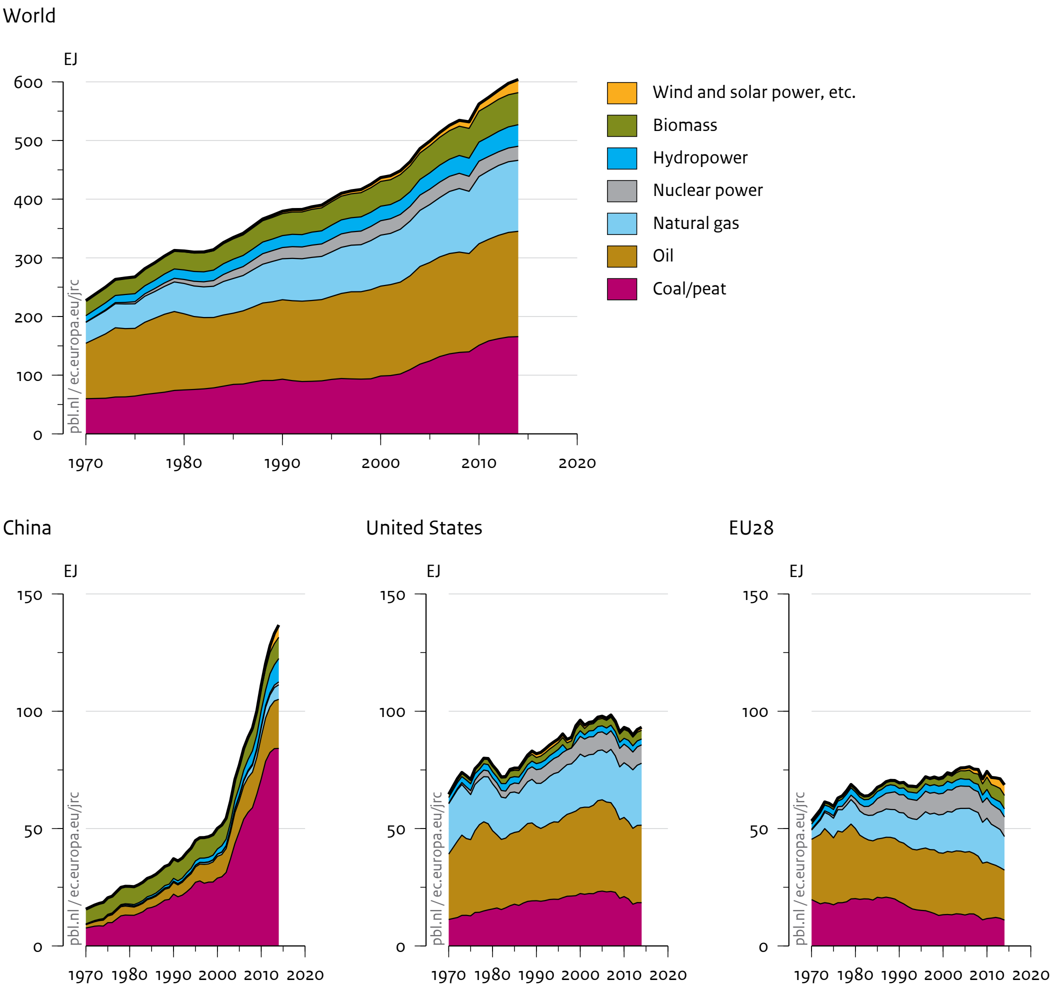
Analysis for a group of IEA countries showed that improved energy efficiency has been the main reason for decoupling total energy consumption from economic growth (IEA, 2008). The IEA has published many studies showing and analysing historical improvements in various economic sectors (e.g. IEA, 2008, 2015f,g).

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. 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, 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 2012 shows that coal combustion globally is responsible for 43% of CO_2 emissions from fossil-fuel combustion, with 28% emitted from coal-fired power plants, the remaining 15% emitted mainly from other industrial combustion (in cement, iron and steel, chemical industries in particular) but also from some smaller scale combustion in the residential sector. Industry, in particular iron and steel manufacturing, is the second largest source. The use of coal is country-specific: the share of coal in the energy mix of the top 25 countries varies from 33% in the United States to 43% in India, 47% in China and 49% in Poland. For more detailed information on the fuel mix and the available large tonnage of coal in comparison to shale gas and oil resources, we refer to last year's report (Olivier et al., 2014).

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.

Figure 3.1
Total primary energy supply, per type



Source: IEA 2014; BP 2015

Note: Figures were calculated using a substitution method for nuclear, hydro and other non-biomass renewables as in BP (2014) (i.e. assuming 38% conversion efficiency)

3.2 Trends in global fossil-fuel consumption and fuel mix

The historical trend in the global energy mix shown in Figure 3.1 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 United States and the European Union, as shown in Figure 3.1. The related CO_2 emissions in 2012 reported by the IEA are given in Table 3.1.

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; EC-JRC/PBL, 2015). Despite the fact that the global economy continued to grow (3.3%) in 2014 compared to 2013, the CO_2 emissions from global fuel combustion decreased by 0.17%, which is the first decline in the annual CO_2 growth over the past five years (BP, 2015). 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,

Table 3.1
CO_2 emissions from fossil fuel combustion in the top four countries in 2013, by main sector and fuel type (billion tonnes CO_2) (source: IEA, 2015b)

China (including SCA revision)	Total	Coal	Oil	Natural gas	Other
Total sectors	**9.0**	**7.5**	**1.1**	**0.3**	**0.0**
Power and heat production *	**4.4**	4.28	0.01	0.06	0.03
Other energy industry own use	**0.4**	0.26	0.06	0.05	
Manufacturing industry **	**2.8**	2.55	0.17	0.08	
Road transport	**0.6**		0.58	0.03	
Other transport ***	**0.1**		0.13	0.00	
Residential sector	**0.3**	0.19	0.07	0.06	
Other buildings ****	**0.3**	0.22	0.10	0.02	
United States	**Total**	**Coal**	**Oil**	**Natural gas**	**Other**
Total sectors	**5.1**	**1.7**	**2.0**	**1.4**	**0.0**
Power and heat production *	**2.1**	1.60	0.03	0.49	0.02
Other energy industry own use	**0.3**	0.01	0.11	0.16	
Manufacturing industry **	**0.4**	0.10	0.07	0.25	0.01
Road transport	**1.4**		1.44	0.00	
Other transport ***	**0.3**		0.21	0.05	
Residential sector	**0.3**	0.00	0.05	0.27	
Other buildings ****	**0.3**	0.00	0.08	0.18	0.00
European Union (EU28)	**Total**	**Coal**	**Oil**	**Natural gas**	**Other**
Total sectors	**3.3**	**1.1**	**1.3**	**0.9**	**0.1**
Power and heat production *	**1.3**	0.93	0.05	0.24	0.04
Auto producers/other energy industry own use	**0.2**	0.03	0.09	0.04	0.00
Manufacturing industry **	**0.4**	0.12	0.09	0.20	0.02
Road transport	**0.8**		0.82	0.00	
Other transport ***	**0.0**		0.04	0.00	
Residential sector	**0.4**	0.04	0.12	0.26	0.00
Other buildings ****	**0.2**	0.01	0.10	0.13	0.00
India	**Total**	**Coal**	**Oil**	**Natural gas**	**Other**
Total sectors	**1.9**	**1.3**	**0.4**	**0.1**	**0.0**
Power and heat production *	**0.9**	0.89	0.03	0.03	0.00
Other energy industry own use	**0.0**	0.00	0.03	0.01	0.00
Manufacturing industry **	**0.5**	0.41	0.07	0.02	
Road transport	**0.2**		0.20	0.00	
Other transport ***	**0.0**		0.02	0.00	
Residential sector	**0.1**	0.01	0.07	0.01	
Other buildings ****	**0.1**	0.04	0.04	0.00	

Notes:
** Includes auto producers power and heat production*
*** Excludes emissions from non-energy and feedstock uses of fuels*
**** Excludes international marine and aviation bunkers*
***** Service sector; includes agriculture and forestry*

which is the fifth decline in the past seven years, versus a 0.5% increase in non-OECD countries that is far below that of the average of the past decade (3.8%).

Coal consumption
Coal consumption increased globally by 0.4% in 2014, compared to 2013 (in energy units), according to BP (2015). China, with a share of 50.6% of global coal consumption, continued the increase throughout 2014 but only by 0.1%, confirming the slowdown in the increase in coal consumption in 2012 of 1.4% following the large increases in coal consumption in 2010 and 2011 (3.7% and 8.9%, respectively). The policies to accelerate the development of service industries (e.g. in 2013, the service sector's share of GDP surpassed that of the industry sector for the first time on record) (NBS, 2015c) and the new energy and environmental policies have slowed the growth of coal consumption in China (EIA, 2015a). 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, 2015j).

Section 2.6 provides more details on uncertainty.
Coal consumption in India keeps increasing at a high pace, at 11.1% in 2014, up from 7.3% in 2013; since coal consumption in India is outpacing domestic production, India has set a coal production target for 2020 and is expanding the transport infrastructure to facilitate additional coal production. Coal consumption in OECD countries decreased collectively by 1.5%, with large decreases in Europe, i.e. in Germany (5.3%), the United Kingdom (20.3%) and Italy (3.7%), as well as in Australia (2.5%), Japan (1.6%) and the United States (0.3%). This includes brown coal (lignite).

Natural gas consumption
Consumption of natural gas in 2014 increased globally by 0.4%, compared with 2013 (in energy units) (BP, 2015). Of the countries with more than a 2% share in the world's natural gas consumption, the largest increases took place in China (8.6%), Saudi Arabia (8.2%), Iran (6.8%), the United Arab Emirates (3.8%), the United States (2.9%), Mexico (1.4%), and Canada (0.3%). The European Union saw a large decline (10%) 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 1.5% in 2012, by 1.6% in 2013, and by the highest decline on record of 11.6% in 2014, mainly caused by declines in France (16.3%), Germany (14%), the Netherlands (13.3%), Italy (11.6%), Spain (9.3%) and the United Kingdom (9.2%).

Oil consumption
Global fossil oil consumption increased by about 0.8% in 2014 compared to 2013 (in energy units) (BP, 2015). The United States has the largest share (19.9%) of global oil consumption, followed by the European Union (14.1%) and China (12.4%). The United States oil consumption increased by 0.5% in 2014, down from 1.8% in 2013, China's oil consumption increased by 3.3%, which is below of the 10-year average growth (5.3%) and the European Union's oil consumption continued its decrease (2.2% average over the past decade), with a fall of 1.5% in 2014. According to BP (2015), in 2014 Europe had the greatest share of total oil imports (22.3%) followed by the United States (16.3%) and China (13.4%). The top net importers (imports minus exports) are: Europe, 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 30%.

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 fuelwood (REN21, 2015). Almost 60% of the electricity generating capacity added globally in 2014 consisted of renewable energy. At the end of 2014, the total in global power capacity generated from renewable energy had exceeded 1,712 GW, up 8.5% from 2013, supplying an estimated 22.8% of global electricity (16.6% in hydropower, 3.1% in wind power, 1.8% in biomass power and 1% solar PV)(REN21, 2015; IEA, 2015j). Today, about 145 countries have renewable energy support policies in place and at least 164 countries, 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. High levels of penetration of different forms of renewable energy, for example in the EU-28, meet 39.1% of electricity demand in Denmark and 27% in Portugal from wind power, and 7.9% in Italy, 7.6% in Greece and 7% in Germany from PV in 2014. 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 EU-28 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).

Table 3.2
Production of renewable energy and nuclear energy in 2014: capacity and production

Capacity (GWe)	Hydro	Wind	Solar PV	Biomass (bio-power)	Nuclear
Global total	**1055**	**370**	**177**	**93**	**377**
China	280	114.6	28.2	10	19
Germany		39.6	38.2	8.2	
Spain		23			
Italy			18.5		
United States	79	65.9	18.3	16.1	99.3
Brazil	89			12.3	
Canada	77				
Russia	48				24.7
Japan			23.3		42.6
India		22.5		5	
France					63.1
South Korea					20.7
Gross generation (TWh)	**Hydro**	**Wind**	**Solar PV**	**Biomass (bio-power)**	**Nuclear**
Global total	**3885**	**706.2**	**185.9**	**433**	**2410**
China	1060	158.4	29.1	41.6	123.8
Germany		56	34.9	49.1	
Spain		52.3			
Italy			23.7		
United States	260	183.6	18.5	69.1	798.6
Brazil	368			32.9	
Canada	377				
Russia	173				169
Japan			19.4	30.2	0
India		34.8			
France					418
South Korea					149.2

Note: Only the figures of the countries with the largest amounts per type are included.
Sources: REN21 (2015), BP (2015), IEA (2015j); Nuclear capacity change from WNA (2015).

In 2014, the investment in global new renewable power capacity was more than twice that of investment in net fossil fuel power capacity, which continue the trend of renewable outpacing fossil fuel in the last years. The investment in renewable was up 36% from the previous year in China and some other countries with emerging economy accounting for 63% of developing countries investment. 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 for the first time in four decades (REN21, 2015). 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% in 2014. Although in the same period hydropower increased globally by almost 40%, its share remained the same, at about 16%. Biomass and other forms of renewable energy, such as geothermal, increased their share slowly to more than 2% in 2014, up from 1% in 1990. The share of nuclear power decreased over this period by 5%, from about 16% to 11% (BP, 2015).

Hydropower

Hydropower output was 3,885 TWh in 2014, an increase by 2% compared to 2013 (down from 3.3 % in 2013) (BP, 2015). The top 5 hydropower countries when considering the capacity in 2014 were China (27% share), Brazil (8.5%), the United States (7.5%), Canada (7.3%), and the Russian Federation (4.5%) (REN21, 2015). Of the 46.9% increase in the hydropower output since 2002, China accounted for more than 62%, Brazil for 6.7% and Canada for 2.4% (BP, 2015). In terms of newly installed capacity in 2014 (37 GW), China led with 22 GW, followed by Brazil (3.3 GW), Canada (1.7 GW), Turkey (1.4 GW), India (1.2 GW) and the Russian Federation (1.1 GW), increasing the total

Table 3.2
(continued)

Capacity (annual change in 2014 in %)	**Hydro**	**Wind**	**Solar PV**	**Biomass (bio-power)**	**Nuclear**
Global total	**3.6**	**16**	**28.3**	**5.7**	**1.8**
China	8.5	25.4	60	17.6	19.2
Germany		16.7	5.2	*	
Spain		0			
Italy			2.1		
United States		7.9	51.3	1.9	-0.3
Brazil	3.9			13.8	
Canada	2.3				
Russia	2.3				4.2
Japan			71.3	23.7	
India	2.7	11.5		11.1	
France					0
South Korea					-0.6
Gross Generation (annual change in 2014 in %)	**Hydro**	**Wind**	**Solar PV**	**Biomass (bio-power)**	**Nuclear**
Global total	**2**	**10.2**	**38.2**	**9**	**1.8**
China	15.7	12.2	87.6	*	13.2
Germany		8.2	12.6	*	
Spain		-3.0			
Italy			9.7		
United States	-3.7	8.3	102.8	*	1.0
Brazil	-5.5			*	
Canada	-3.1				
Russia	-5				4.8
Japan			82.4	*	
India		10.5			
France					2.9
South Korea					12.7

global capacity to about 1055 GW (REN21, 2015). In 2014, hydropower generation/consumption declined in many countries due to droughts, but it increased significantly in China after a drop a year before (see Table 3.2) (BP, 2015).

Wind power
Total global wind power capacity was up nearly 8-fold from 48 GW in 2004 to 370 GW in 2014 (REN21, 2015) and increased 16% compared to 2013, lower than the average of about 23% over the last 10 years (GWEC, 2015). Wind power output was 706.2 TWh in 2014, an increase of 10.2% compared to 2013 (BP, 2015). In 2014, most new wind power capacity was installed in Asia (50.5%), Europe (25%) and North America (14.3%). Asia with 38% of the total in 2014 is the largest total wind power capacity in the world, followed by Europe (36%) and North America (21%). China, the world's largest wind power market, added 23196 MW in new wind capacity in 2014, resulting in a total of 114.6 GW installed by the end of 2014. Wind power represented 2.78% of the total electricity generated in China last year. During 2014, 11,829 MW of additional wind power was installed in the European Union, resulting in a total capacity of 128.8 GW. Germany installed 5,279 MW of additional capacity, the United Kingdom 1,736 MW, followed by Sweden (1,050 MW) and France (1,042 MW). The total wind power capacity installed in the European Union by the end of 2014 was enough to cover 10.2% of the EU's electricity generation and on average, produced 249.7 TWh of electricity; 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 4,854 MW wind capacity in 2014, a 7.9% increase, up from 1.8% in 2013, bringing its total wind capacity to 65.9 GW; by the end of 2013 wind provided 5.23% of total US installed generation capacity (GWEC, 2014). The top five countries in terms of cumulative capacity at the end of 2014 are listed in Table 3.2.

Solar energy
Total global *solar photovoltaic* (PV) capacity increased rapidly from 2004 (2.6 GW) to 2014 (177 GW). The increase in 2014 was 28.3% down from 37.5% in 2013 (REN21, 2015; IEA, 2015j). According to BP (2015), PV power output was 185.9 TWh in 2014, an increase of 38.2% compared to 2013. The global total PV installed in 2014 was 40.2 GW, up from 38.6 GW in 2013 and was dominated by growth in China (26.2% share in global total PV added) with 10.6 GW and Japan (24.1%) with 9.7 GW. By comparison, the United States (15.4%), United Kingdom (6.1%) and Germany (4.7%) installed 6.2, 2.4 and 1.9 GW, respectively. Regarding cumulative installed capacity, Europe is the world's leading region, with 88.4 GW, which represents 49% of the world's cumulative PV capacity in 2014, followed by Asia Pacific countries (61 GW) and North America (20 GW) (BP, 2015). In Europe, PV covers 3% of the electricity demand and 6% of the peak electricity demand (EPIA, 2014).

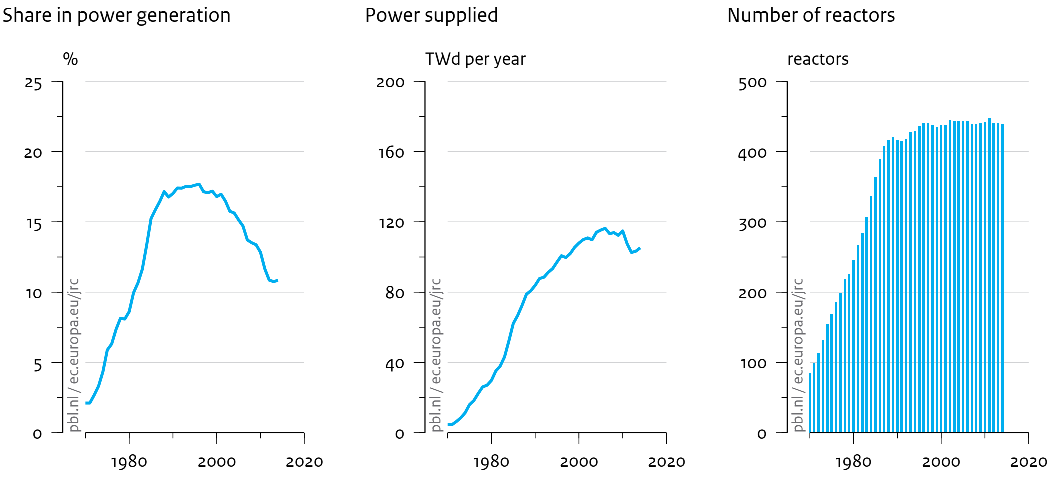
Total global *solar heat* (SH) capacity of water collectors increased in 2014 by 33 GWth to about 406 GWth (341 TWh). China was again the leading country with approximately 36.7 GWth newly installed capacity (including replacement of existing capacity) bringing the country total to about 289.5 GWth. In 2013 Europe's total operating capacity was 30.2 GWth but the growth continued to slowdown (a decline of 11%), Germany remained the largest installer in 2013 by adding 0.7 MWth for a total of 12.3 GWth. The solar water heating collectors global capacity shares of the top 10 countries in 2013 were: China 70.3%, the United States 4.5%, Germany 3.3%, Turkey 2.9%, Brazil 1.8%, Australia 1.5%, India 1.2%, Austria 0.9%, Japan and Greece 0.8% each (REN21, 2015). According to Mauthner and Weiss (2013), by the end of 2011, in China, the cumulative installed capacity, per type, was 93% in evacuated tubes and 7% in flat plate collectors, while in Europe 87% was in flat plate collectors, 8% in evacuated tubes and 5% in unglazed water collectors. By comparison, the United State had 89% in unglazed water collectors and 11% in flat plate collectors in cumulative installed capacity. Solar air collectors, which absorb solar radiation and use it to heat building ventilation air or to provide drying air for industrial applications, represented 1% (1.7 GWth) of global solar capacity in operation in 2013 (REN21, 2015).

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 than 60% to about 2.5 GW, the growth continued in the next period by an addition of 0.9 GW each year, up 36% and up 27% respectively, to about 4.4 GW total global capacity at the end of 2014 (REN21, 2015), most of which being concentrated in Spain and the United States (Jager-Waldau, 2013). Despite the fact that Spain added no new capacity in 2014 it remains the global leader reaching 2.3 GW of CSP. The United Stated added 752 MW to end the year increasing CSP to just over 1.6 GW. Newly installed capacity also included 175 MW in India increasing CSP to 225 MW. Other countries with existing CSP are United Arab Emirates (100 MW), Algeria (25 MW), Morocco (20MW), 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 of these technologies. From 2013 to 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. The best wind projects are delivering electricity for example for USD 0.05/kWh without financial support, whereas for biomass for power, geothermal and hydropower the levelised costs of electricity (LCOE) have been stable since 2010. Moreover, PV becomes increasingly competitive at the utility scale; the total installed costs of utility-scale PV systems have fallen by 29% to 65% (depending on the region) and LCOE of solar PV has halved between 2010 and 2014. The weighted average depends of the region and for installed capacities in the last two years varies from USD 0.11 to USD 0.12/kWh. Yet, for countries with good solar resources, projects could be built with LCOE of USD 0.08/kWh (IRENA, 2015). 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 2014, the investments in renewables increased in China by 31%, which is in line with the goal of producing 15% of total energy consumption from non-fossil by 2020 (RTCC, 2015).

Biofuels for transport
Global biofuel production has been growing steadily reaching 128 billion litters in 2014 (REN21, 2015). Consumption of biofuel in road transport has increased by 4.1% globally in 2014. The two leading countries are the United States with a share of 44.2% and Brazil with a share of 21.5% in global biofuel consumption. In 2014, the EU-28 as a whole had a share of 18.8% 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 (4% in 2012 and 11% in 2013) as the share of ethanol in petrol approached the 'blend wall', which is the practical limit of the fraction of ethanol in petrol that can be used in

Figure 3.2
Global power generation by nuclear energy



Source: IAEA 2015

most modern regular petrol-fuelled car engines, yet this growth slowed down in 2014 when the increase was only 0.3%. Continuing further this growth requires moving towards higher ethanol blends (Oil & Gas Journal, 2014). EPA's action to slash the biofuel targets for 2014, 2015 and 2016 shows the limited capability of the US fuel system to accommodate gasoline that contains more than 10 percent ethanol (BiofuelsDigest, 2015a). In the European Union, after an increase of 6% in 2012 and a decrease of 10% in 2013 the biofuel consumption increased by 5.8% in 2014, driven by large increases in 2014 in Germany (3.6%), the United Kingdom (13%) and Spain (8.2%). Significant increases have been seen also in Sweden (18%), Belgium (13.5%), and Denmark (14%) (see Table A1.1 in Annex A1.2).

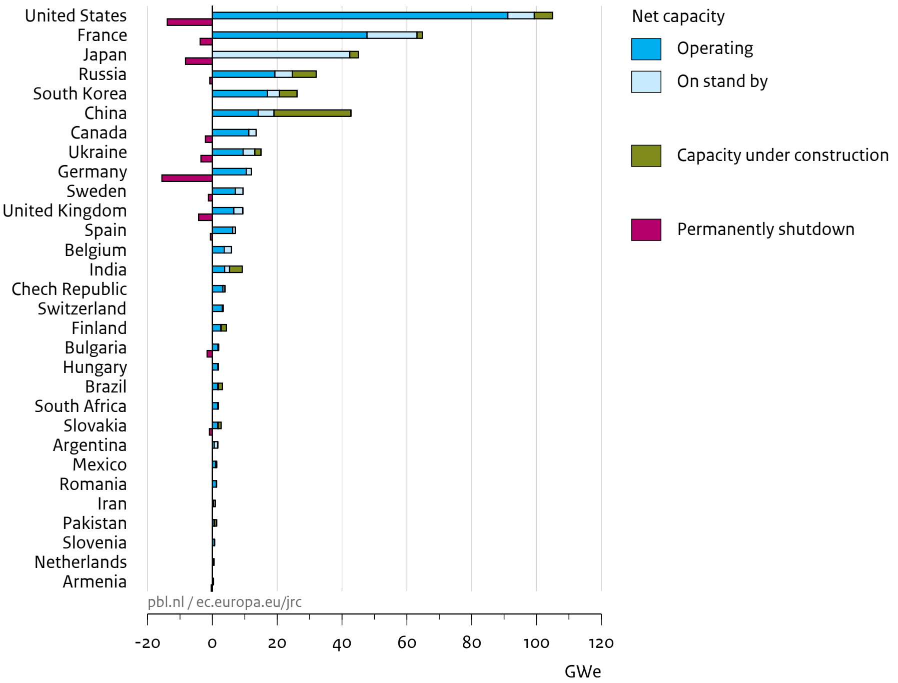
Current fuel ethanol and biodiesel use represents about 3% of global road transport fuels and could be expected to have reduced CO_2 emissions with a similar percentage if all biofuel had been produced sustainably. In practice, however, net reduction in total emissions in the biofuel production and consumption 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 (EC, 2009; Banja et al., 2015).

Recently, emission reductions in the transport sector through tax incentives and blending mandates act as a 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 2014, biofuels mandates were in place in the EU-28, 13 countries in North and South America, 12 in Asia and the Pacific and 11 in Africa and Indian Ocean (Biofuels digest, 2015b; GFRA, 2015), but only the United States and the European Union have policies targeting so-called advanced biofuels (IEA, 2014c). The total planned capacity in US, EU and other countries for advanced biofuels in 2014 estimated by Biofuel digest (2012) was 9.8 billion litres.

3.4 Trends in nuclear energy

In 2014, 438 nuclear power reactors generated 10.8% of the world's total electricity (BP, 2015). While the number of nuclear reactors worldwide has remained constant since the mid-1990s, nuclear power generation kept increasing slightly until 2007, and then dropped in 2011 and 2012 (after the Fukushima accident), leaving unused capacity, as shown in Figure 3.2. The slight increase

Figure 3.3
Global nuclear power capacity per country, 2014



Source: IAEA 2015

yielded from optimising plant operations did not fill the global need for more electricity, and the nuclear share in total electricity production decreased since the mid-1990s, from 17.6% to 10.7% in 2013. In 2014, nuclear power generation increased by 1.8 %, compared to 2013, thanks to seven additional reactors connected to the grid (5 in China, 1 in Argentina, 1 in India) and two that were shut down in Japan (ATW, 2015; WNA, 2014).

Even though this nuclear power increase of 5,250 MWe in China is of the same order of magnitude as the entire Belgian nuclear energy supply, and replaces about 16 GW from coal-fired power plants, its share in the total Chinese power generation remains barely 2.1%. However, China plans to double its nuclear power generation by 2020, according to WNA (2014), and, with the reactors currently under construction, it ranks among the top four nuclear power countries. The situation of 2014, represented in Figure 3.2, shows that, on the one hand, the nuclear reactor capacity was not exploited to its full extent (in particular in Japan), while, on the other hand, it is extending further (mainly in Asia), with a relatively large number of nuclear reactors (70 in total) being under construction. These constructions are mainly taking place in China (26), Russia (10), India (6), the United States (5) and South Korea (5).

Of the total global nuclear power of 105 terawatt days supplied in 2014, one third was generated by the 130 power plants in the 14 nuclear energy countries of the European Union, and another third by the 99 power plants in the United States. Half of the EU-28's nuclear power is generated by the 58 reactors in France, and another 17% by the 53 nuclear reactors in three non-EU neighbouring countries - Switzerland, Ukraine and Russia (see Table 3.2 for the top five countries).

France remains very active in the development of nuclear technology, and is finalising the construction of a new nuclear reactor (1,750 MWe) at Flamanville (Normandy), which is expected to join the grid in 2016. Finland is constructing its fifth nuclear reactor, which after a long delay is expected to be connected to the grid in 2018. Finland also plans to start constructing another nuclear plant. Hungary also plans to build two new nuclear reactors, as do Romania and Slovakia.

The European Commission is expected to adopt its vision for a European Energy Union, 'A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy', by the end of 2015, and to communicate this to the European Parliament. The EU's Energy Union strategy is based on five pillars: energy efficiency

(reducing the EU-28's energy use by 27% by 2030), supply security, a fully integrated internal energy market, emission reductions (40% by 2030 compared to 1990) and supporting low-carbon technologies (with renewable energy accounting for 40% of energy supply).
The electricity focus is on the real-time power market, long-term investment signals, and other energy services such as balancing demand and supply. The European Commission has noted that binding national targets for renewable energy does not fit well with a single EU market, and that cross-border effects of capacity mechanisms will create problems. Note that the EU's Energy Union strategy is promoting 40% of intermittent renewable energy, which implies the need for power plants that can easily run in load-following mode, which is not the case for nuclear power plants. However, nuclear power is starting to be considered as a significant contribution to mitigating climate change (Hansen, 2015).

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). Thus, the combustion of coal produces 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.

Future perspectives

The big question: when will global emissions start decreasing?
The big question remains: when and how quickly will these changes cause global CO_2 emissions to start decreasing in absolute figures? Future emission trends will be determined by the collective emissions of all countries, which are nowadays driven by different actors:
- National government policies and initiatives
- Initiatives of non-governmental organisations such as companies, industrial sectors (e.g. cement industry, aviation sector) and non-profit organisations
- Commitments of subnational governments
- More autonomous developments of economic and technological nature (by industry).

Although national governments have an important role in guiding their society towards a low-carbon structure of the economy, other government authorities and groups within society are also important actors, which collectively may steer the world towards lower greenhouse gas emissions. The largest momentum for swift reductions in global greenhouse gas emissions will be when climate and energy policies of governments and actions of other groups within society – companies, concerned citizens and associated organisations – become concerted actions and reinforce each other instead of just follow different tracks at different speeds.

The role of industry-policy interplay
The recent emission trend shows that an industry-policymakers interplay is present, in which national policies and other initiatives are taken up for implementation and for a collective mitigation of global CO_2 emissions. The slowdown in global emission growth over the past three years is due to structural changes in the economy, energy efficiency improvements and the energy mix (more renewable or nuclear energy and a shift from coal to gas) of key world players.

The changes and developments seen to date in China (over the past three years and in 2015) suggest that this might occur sooner than expected. After a decade of unprecedented growth rates, since 2012, China's economy is structurally changing its focus from export to more domestic services and consumption and with less energy-intensive but more high-value industries.

However, on a global level, the trends and changes in other major economies relevant for global CO_2 emissions and other greenhouse gas emissions also will determine when that will occur. Different assessments have been made of what the global trend might be if all INDCs and other pledges by national governments would be realised (e.g. Admiraal et al., 2015; Carbon Tracker, 2015; IEA, 2015e,i; UNEP 2015b). Earlier this year, Den Elzen et al. (2015) provided an overview of the estimated impact of current and planned policies on greenhouse gas emissions for seven major countries and the potential of selected enhanced mitigation policies.

Non-governmental initiatives
A private sector initiative is the Global Top-500 companies of the *Carbon Disclosure Project* (CDP), which stimulates large companies to set emission reduction targets and to report on their progress. An industrial sector initiative is the *Cement Sustainability Initiative* (CSI) of the *World Business Council for Sustainable Development* (WBCSD), an activity of 24 major cement producers with production plants in more than 100 countries, which measure and report their CO_2 emissions and have set individual targets to reduce their CO_2 intensity. Another sector initiative is the *Zero Routine Flaring* by 2030 initiative by the World Bank to bring together oil companies and national governments to stop CO_2 emissions from associated gas flaring by 2030. For a more detailed description of these and other international initiatives see Roelfsema et al. (2015), who also made an assessment of how much greenhouse emission reduction may be expected from these initiatives by 2020 and 2030. Other evaluations of the reduction potential have been made by Blok et al. (2012) and UNEP (2015a).

Multi-governance by initiatives of subnational governments
Over the past decade, the role of cities in altering the global climate has become a crucial issue for both science and policy (UNEP, 2014). In order to engage municipalities in combating climate change, subnational governments are encouraged to undertake specific actions. Urban areas account for about 69% of the total primary energy demand in the EU (EEA, 2015c). Under the International Energy Agency's reference scenario (IEA, 2009), urban energy consumption worldwide is projected to increase at twice the rate of that of the EU as a whole. Cities

and towns are therefore recognised to have enormous potential for driving sustainable energy use, with a positive impact on the local economy.

Several international initiatives have been undertaken over the past decade, bringing together sub-national and local actors. Examples are the *C40 Cities Climate Leadership Group* (C40), an association of megacities committing to sustainable climate-related policies. Another is the *US Conference of Mayors*, which is an organisation of US mayors who signed the 'US Mayors Climate Protection Agreement', representing almost 30% of the total US population. The *ICLEI-Local Governments for Sustainability* is an association of mainly large cities with sustainability projects, including resource efficiency and low-carbon energy. The *Compact of Mayors* is a new agreement of global city networks which has C40 Cities and ICLEI as partners. The European Union's *Covenant of Mayors* initiative is a mainstream European movement of local and regional authorities that voluntarily commit to reducing their greenhouse gas emissions by 20% or more.

To achieve the objective of the *Covenant of Mayors*, the local governments commit to act within their political mandates focusing mainly on more efficient energy use and on an increased exploitation of local renewable energy sources and establish not only an energy action plan but also a reference emission inventory. Kona et al. (2015) highlighted the effective penetration of the Covenant of Mayors initiative in Europe, particularly in the southern countries (mainly Spain and Italy) where supporting structures are present and well organised. However, in the northern countries, the Covenant is less popular. So far, the signatories that have submitted a monitoring report show a reduction of 23%, yielding a reduction of the 5.4 tonnes CO_2eq per capita in the reference inventory to 4.1 tonnes CO_2eq per capita in the 2015 monitoring inventory. This means that they are well on track to achieve their objective of 3.9 tonnes CO_2eq per capita in projected 2020 emissions (Kona et al., 2015). Recently, the *Covenant of Mayors* has been extended in time to 2030, in line with EU's 2030 Climate and Energy package with the 40% reduction target for 2030 for the greenhouse gases. It has also expanded in space, by also including cities of the EU's neighbourhood countries and countries in the Far East (China).

Pledges by all world governments

Further analysis may show whether the recent national and global CO_2 trends as estimated in this report fit into the total national greenhouse gas emission trends expected from the analyses of the countries' pledges. The United Nations Environment Programme's *Emissions Gap Report 2015* (UNEP, 2015b) presents the latest estimates of the gap in emissions likely to exist in 2020 between the emission levels consistent with the 2 °C limit and the levels expected if national pledges/commitments are being met. This report underlines the necessity of a new global climate agreement for curbing greenhouse gas emissions as soon as possible. In 2015, all countries report for the first time their national emission pledges as *Intended Nationally Determined Contributions* (INDCs). These are expected to become the basis of a new legal instrument to be approved at the 21st Conference of Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in December in Paris. This new legal instrument will supersede the Kyoto Protocol and provides the framework for global climate policy and action after 2020 under the UNFCCC.

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.

For a summary of the national greenhouse gas emission reduction pledges and INDCs of many countries and the impact on emissions by 2020 and 2030 see Admiraal et al. (2015) and PBL's updated interactive *Climate Pledge INDC* tool (PBL, 2015): http://infographics.pbl.nl/indc/. Other such assessments were made, for example, by Carbon Action Tracker (2015a) and UNEP (2015b).

Structural changes in global CO_2 emission trends still uncertain

The slowdown of the growth in China's CO_2 emissions since 2012 reflects structural changes in China's economy towards a less energy-intensive service sector and high value-added manufacturing industry that is more focussed on domestic consumption, with more energy efficiency and towards a low-carbon energy mix. On a global scale, the slowdown that has also lasted three years now, to a large extent, can be explained by the changes in China's economy and the associated energy consumption. However, it is uncertain whether these changes also reflect structural changes in the wider *global* economy, *global* energy efficiency improvements and in the energy mix of other key world players such the United States, European Union, India and Russia. What we do know is that it is very likely that the very high global annual emission growth rates of on average 3% per year, observed in the years 2003 to 2011, are definitely over for many years to come (even 4% per year when excluding the global recession years 2008 and 2009), whereas the average global growth rate in the 1980–2002 period was 1.2% per year.

Annex 1: Methodology, data sources, comparisons

A1.1 Methodology and data sources over the 2012–2014 period

The basis for the data time series here is the new EDGAR 4.3 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).
For the trend estimate for 2013 and 2014, 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 2012–2014 emissions:
(1) Fuel combustion (IPCC category 1A + international bunkers):
   - For energy, for 2012–2014, the BP Review of World Energy 2015 was used to calculate the trend in fuel consumption per main fossil fuel type: coal, oil and natural gas (BP, 2015). For CO_2 emissions from fossil-fuel combustion in China between 2000 and 2012, we initially used the data from the IEA (2014a), as we did for all countries and years up to 2012, but corrected the coal-related emissions based on very recent data from the National Bureau of Statistics of China (NBS, 2015b) because of the important coal statistics revisions that China made for this period (see Annex A1.4 for details).
   - 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, 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 in 2008 according to IEA statistics (covering about three-quarters and half of the total bunker fuel consumption, respectively).

(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 2012–2014 are assumed to be similar to the trend in crude steel production for 2012–2014 from USGS (2015) and for 2012–2014 from the Word Steel Association (WSA, 2015).
   - Fugitive emissions from oil and gas (1B2), which refers mainly to leakage, flaring and venting. For EDGAR version 4.3 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, 2012; Elvidge et al., 2009a,b), which are 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 2011 the updated NOAA dataset was used (NOAA, 2012). 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 (2015p) and UNFCCC (2014). For 2013 and 2014 we assumed constant emissions since updated NOAA

data are not yet available (see Section 2.4). For 2012, preliminary data for the top-20 flaring countries were used, as estimated by the GGFR (2015), except for the United States where we used GGFR data also for 2009 to 2011. For other countries, we used the trend reported by EIA (2015p). Due to a lack of information, we assumed for all countries that CO_2 emissions in 2013 and 2014 did not change compared to 2012.

(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 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 6 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 (2015) 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, 2015) for China over the 2002–2013 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 (2015) and Xu et al. (2014).

In addition, we extrapolated the 2012-2014 trend in the clinker production, using the trend in cement production based on USGS (2015), except for China, for which we used CCA (2015) for the clinker production trend in 2013, and NBS (2015a) for the cement trend in 2014. For all other sources in the minerals production category (2A), we used the trend in lime production data for 2012–2014 (USGS, 2015) as a proxy to estimate the trend in the other 2A emissions. All 2014 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 (2015) was used, except for urea production which data are from the *International Fertiliser Industry Association* IFA, (2015) (in which it is assumed that the fossil carbon in CO_2 from ammonia production is stored). . 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 2014. For simplicity, it was assumed that the small soil liming (4D4) emissions follow the gross ammonia production trend.

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

The 2010–2012 trend was extrapolated to 2014 for the relatively very small emissions of waste incineration (6C) and underground coal fires (mainly in China and India) and oil and gas fires (1992, in Kuwait) (7A).

CO_2 emissions from underground coal fires in China and elsewhere have been included in EDGAR 4.3 FT2010, 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 2014.

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) (see Table A1.1). 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 2000–2013 were compiled from the following data sources:
- OECD countries: For 2000–2013 we used for 29 OECD countries IEA statistics for Total Final Consumption (TFC) of bioethanol ('biogasoline'), biodiesel and other liquid biofuels from IEA(2015a). For 2014 we used per biofuel type the trend 2013-2014 of Total Primary Energy Supply (TPES) to estimate the consumption in 2014 (IEA, 2015a). For 2014 only TPES values are known in these IEA (2015a) statistics. In most countries this is equal to road consumption or TFC.
- Four OECD countries reported no biofuel consumption in IEA (2015a), three were supplemented by biofuel consumption reported by EIA (2013) for 2000–2011: Iceland, Israel and Mexico (Chili does not use biofuels according to IEA and EIA). Consumption in 2012 to 2014 was estimated by extrapolation. For Japan the USDA country report was used (USDA, 2014).
- Non-OECD countries: For 2000–2013 we used for 24 non-OECD countries IEA (2015a) for biogasoline and biodiesel consumption in road transport. For 2014 we used the trend 2013–2014 in USDA country reports (USDA, 2013, 2014, 2015) for the largest consuming countries: Argentina, Brazil, China, India, Indonesia, Malaysia, Peru, Philippines and Thailand.

The other 14 countries with reported biofuel consumption, for 2014 estimated between 20 TJ and 320 TJ, are in decreasing order: Singapore, Pakistan, Israel, South Africa, Ecuador, Ethiopia, Hong Kong, Malawi, Fiji, Guatemala, Macedonia, Honduras, Rwanda and Tanzania.

We used this dataset of all transport biofuel types (bioethanol, biodiesel, other liquid biofuels) as value to correct the oil consumption numbers of BP (2015), which include liquid biofuel consumption. Although data for 2005 onwards are presented in Table A1.1, only 2012-2014 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 (JRC/PBL, 2015) 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 CO_2 emissions from forest fires related to deforestation/ logging and peat fires and subsequent post-burn emissions from decay of remaining above ground biomass and from drained peat soils. Although they are also significant but highly uncertain, CO_2 emissions from the decay of organic materials of plants and trees that remain after forest burning and logging are also not included. Annual CO_2 emissions from peat fires in Indonesia estimated by Van der Werf et al. (2008) indicate that emissions from peat fires vary most around 0.1 to 0.2 billion tonnes per year, except for peak years due to an 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 to amount 1.3 billion tonnes CO_2, of which 0.5 billion tonnes from Indonesia. Also excluded are CO_2 *removals* from forest growth and afforestation.

A1.4 Revision of China's coal statistics for 2000-2013

In February 2015, the National Bureau of Statistics of China (NBS) published preliminary estimates in the 2015 *Statistical Communiqué* stating that coal consumption had declined by 2.9% in 2014 (NBS, 2015a). In addition, the communiqué reported that coal production in 2013 had been revised upwards by 7.9%, based on the results of the *Third National Economic Census* held in 2014. Next, in May 2015, in the *China Statistical* Abstract (CSA) 2015, NBS published a new preliminary estimate of total coal consumption in 2014 showing an increase of 0.05%, compared to 2013, and a major revision of fossil-fuel consumption, per main type of consumption, starting from 2000. This was done, implicitly, in a table showing total energy consumption in energy units (tonnes of *Standard Coal Equivalents* or SCE) and consumption of coal, oil products and natural gas as percentages of the total (NBS, 2015b). Then, in September/October 2015, final 2014 statistics were released in the *China Statistical Yearbook (SYB) 2015* (NBS, 2015d), which show coal consumption figures in SCE for 1990, 1995, 2000, 2005, 2010, 2012 and 2013 that were the same as those reported in the *China Statistical Abstract 2015*.

That statistics are revised from time to time is a general feature, as over time often more detailed data become available to make better estimates for total production or consumption and at sectoral level. The NBS publishes preliminary data each February and subsequently revises them in the following May, in its Statistical Abstract, again followed by new revisions in October in the Statistical Yearbook, based on some additional detailed data provided by the provinces. Yet another revision occurs after each *National Economic Census*, which are held every four years. The energy data on the previous year in the February Communiqué are based on the first eleven months of the previous year and a growth rate to estimate values for December, equal to the December growth rate of the year before. This is described in detail by Wang and Chandler (2011). Consolidation of monthly data into annual totals may also give rise to revisions (see e.g. Figure 3 in Eurostat, 2015b).

The fact that China's coal statistics saw a major revision is not surprising. Not only have many people pointed to the relatively large difference between national and (the sum of) the provincial statistics (most recently in Liu et al., 2015), but the statistical differences in the national coal balances (in mass units) also switched from negative to positive, and increased very fast from being a few per cent in the negative up to 2008 to about 7.8% in the positive for total coal consumption in 2012. In addition, annual stock changes also increased from about 1% in the negative up to 2008 to 3.5% in the negative in 2012, compared to total coal consumption (NBS 2015c). Often, when positive statistical differences grow rather large, statistical agencies try to improve their statistics by identifying mainly which sources are missing or have been underestimated. The resulting revisions often reduce these differences to a few per cent at the most. The latest NBS revisions were based on the *Third National Economic Census* in 2013 that exposed gaps in data collection, especially from small companies and factories. However, most of the revisions were made in data on consumption by heavy industry (e.g. cement production, coke ovens and chemical industry), with smaller revisions in power generation (Buckley, 2015).

A decrease in coal consumption of 2.9% (NBS, 2015a) in tonnes of mass may very well be consistent with a conversion into amounts in physical energy units (e.g. Joules or Standard Coal Equivalents) resulting in a 0.1% growth over 2014 (NBS, 2015b). An increase in the average heat content of the coal of about 2% in 2014, combined with a revision of coal consumption in mass units of about 1%, would explain the numbers NBS published in February and subsequently in May. The former was concluded by the U.S. Energy Information Administration (EIA), which made an assessment of information from several sources on the heat content of raw coal, coal washing rates and yields per coal type. The EIA concluded that, in 2014, the energy content per tonne of mass increased by about 2% (EIA, 2015j). Lower coal prices and stricter enforcement of tightened environmental regulations in 2014, compared to those of 2013, were strong incentives to use higher quality coal and for washing coal better before selling it. Average heating values implied in past Chinese Statistics have suggested that changes of 2% or higher can occur from one year to another, reflecting changes in coal washing ratios and in the use of low quality coals, such as subbituminous coal. China has a target of increasing the coal washing ratio to 65% in 2015, up from about 50% in 2012, and turning away from using poor quality coal (Jones, A., 2015, pers. comm.).

Because of the major changes in coal statistics, we have estimated and incorporated their effect on total CO_2 emissions from fossil-fuel combustion, both in China and worldwide, using the same method as was used by the EIA (2015j) to estimate the revisions in coal consumption. However, the new NBS coal statistics (in SCE) were not compared to those of the previous year, but to those reported in IEA (2014a), that was used for calculating CO_2 emissions in EDGAR 4.3. We used total primary coal consumption data from the IEA statistics, converted from toe into SCE (sum of coking coal, other bituminous coal and anthracite), neglecting the very small net import of coal products such as coke. First, for China, we calculated the percentage change in total coal consumption per year for the 2000–2012 period, compared to IEA statistics (IEA, 2014a). Next, we calculated the share of CO_2 emissions, per year, from coal and coal products in emissions from total fossil-fuel combustion, using data from IEA (2014b). These fractions vary between 82% and 84%. These numbers were used to calculate the percentage change per year of total fossil fuel CO2 emissions in China, as reported by the IEA (using the 1996 IPCC guidelines), due to the CSA 2015

Table A1.1

Biofuel consumption in road transport (bioethanol and biodiesel) per country, 2005–2014 (in TJ)

Country	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
OECD-1990	498,310	733,172	977,811	1,296,329	1,495,209	1,654,658	1,759,082	1,843,177	1,926,224	1,947,964
United States	347,566	482,340	604,448	822,734	931,441	1,019,686	1,085,568	1,130,257	1,256,102	1,259,447
Canada	7,129	7,298	30,069	32,614	36,941	48,837	67,342	72,595	76,718	78,449
Australia	777	2,176	4,644	6,952	9,822	8,539	10,250	9,319	9,058	9,592
Turkey	-	815	519	638	278	259	659	3,030	15,116	5,811
Norway	-	221	1,251	3,412	3,964	4,861	4,811	5,527	5,162	5,325
Japan	392	393	522	522	1,109	1,891	3,193	3,345	4,327	4,882
Switzerland	251	283	432	432	315	373	368	432	432	814
New Zealand	-	-	40	126	126	155	252	242	144	184
Monaco	4	7	15	28	26	24	21	21	21	21
Iceland	-	-	-	10	10	10	6	6	6	6
EU-28, of which:	142,191	239,640	335,871	428,566	510,330	568,624	585,471	617,190	558,181	582,476
Germany	80,736	145,342	164,214	132,600	121,924	131,816	125,225	129,228	117,296	121,555
France	27,939	33,688	60,354	96,799	103,906	101,727	101,829	111,817	113,279	112,416
Italy	7,400	8,251	7,474	30,517	47,918	59,427	58,656	57,273	52,359	46,964
United Kingdom	3,609	8,380	14,968	33,854	41,698	49,129	45,581	38,943	44,298	50,014
Spain	10,819	7,155	16,114	25,935	44,909	60,105	72,074	89,072	38,054	41,181
Poland	2,228	4,091	4,441	18,482	27,737	37,123	39,088	34,439	32,440	31,137
Sweden	5,650	7,850	11,912	14,392	15,098	15,923	18,222	22,660	26,799	31,716
Austria	2,342	11,822	14,735	17,825	22,407	21,852	21,955	21,679	21,581	19,370
Belgium	37	481	4,211	4,794	12,771	15,944	14,799	15,028	14,305	16,232
Denmark	-	160	240	289	439	1,197	5,473	9,814	9,588	10,942
Netherlands	446	2,800	15,156	13,413	16,942	10,180	13,488	14,017	13,378	15,806
Finland	-	28	55	3,173	6,521	7,070	9,598	8,822	9,537	13,899
Czech Republic	111	757	1,258	4,603	8,155	9,682	12,565	11,525	11,602	13,165
Portugal	-	2,997	5,660	5,771	9,434	13,689	12,875	12,020	11,583	12,435
Romania	-	-	1,693	4,490	6,805	4,827	8,166	9,126	8,514	8,514
Hungary	107	456	1,200	6,892	7,079	7,317	6,934	6,531	5,994	6,534
Greece	-	1,932	3,562	2,886	3,266	5,355	4,444	5,355	5,963	6,424
Slovak Republic	440	1,864	2,625	3,104	3,547	4,090	4,089	3,807	4,148	5,797
Ireland	37	101	942	2,307	3,228	3,918	2,397	2,497	3,030	3,781
Bulgaria	-	331	147	147	221	846	699	3,496	4,195	4,195
Lithuania	137	803	2,212	2,557	2,145	1,864	1,874	2,520	2,402	2,402
Slovenia	-	185	580	1,029	1,261	1,905	1,452	2,132	2,417	1,827
Luxembourg	40	40	1,897	1,897	1,783	1,743	1,908	2,037	2,315	2,956
Croatia	-	-	110	147	328	110	164	1,526	1,342	1,342
Belarus	-	-	-	294	846	1,398	1,141	1,214	957	957
Latvia	110	127	74	74	181	1,121	1,021	894	894	894
Cyprus	-	-	37	589	626	626	662	662	626	626
Malta	-	-	-	-	-	37	74	110	110	110
Estonia	-	-	-	-	-	-	161	161	134	241

Table A1.1
(continued)

Country	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Other countries	399,164	393,951	527,262	722,175	814,784	753,485	735,476	741,868	853,292	937,974
Brazil	330,433	323,732	451,698	613,262	675,078	575,248	522,738	484,071	562,278	613,000
China	29,176	37,216	42,808	53,384	64,496	67,712	66,712	72,536	71,000	75,602
Thailand	1,420	2,680	5,906	20,042	26,542	27,399	29,553	38,808	50,258	57,004
Argentina	662	662	662	662	1,987	22,866	33,617	38,758	44,211	51,339
Indonesia	-	147	790	763	2,031	7,213	11,702	21,933	34,298	35,172
Peru	-	-	-	-	2,907	3,958	5,970	14,423	15,478	15,621
India	4,261	4,261	4,261	5,950	3,111	2,765	9,722	8,767	6,352	14,373
Philippines	54	90	1,295	2,222	7,903	8,004	8,490	11,076	13,209	14,217
Korea	459	1,681	3,324	6,266	9,209	12,571	11,845	12,762	13,412	14,023
Malaysia	-	258	1,288	1,766	184	184	994	4,821	7,875	12,702
Cuba	31,758	21,976	11,980	11,417	10,372	10,398	11,256	10,479	10,157	10,157
Taiwan	-	-	196	1,215	2,091	4,051	4,024	4,754	4,775	4,775
Paraguay	724	750	643	1,233	2,278	3,028	3,189	3,350	3,966	3,966
Serbia	-	-	980	1,961	2,941	2,941	2,941	2,941	2,941	2,941
Jamaica	-	-	-	130	1,302	1,302	2,605	2,605	2,605	2,605
Trinidad and Tobago	-	-	-	-	-	0	2,605	2,605	2,605	2,605
Uruguay	59	78	118	98	248	321	874	1,162	1,737	1,737
Nigeria	-	-	391	651	-	-	1,302	1,302	1,302	1,302
Colombia	27	268	295	452	569	884	1,185	1,222	1,222	1,221
Vietnam	-	-	-	-	-	130	651	651	651	651
Mexico	-	-	196	196	200	587	587	587	587	587
Costa Rica	-	-	65	65	651	651	521	521	521	521
Other countries (14)	132	150	366	439	683	1,269	2,393	1,735	1,852	1,852
Global total	**897,474**	**1,127,123**	**1,505,073**	**2,018,503**	**2,309,993**	**2,408,143**	**2,494,558**	**2,585,046**	**2,779,516**	**2,885,937**

Notes: The table has been updated using data from IEA (2015a) until 2014 and supplemented with EIA (2013) for four OECD countries and 19 non-OECD countries and with USDA (2014, 2015) data for the last one or two years except for Israel, Japan, Mexico and some others for which the data were extrapolated for 2012 and 2013. The other 14 countries with reported biofuel consumption, for 2013 estimated between 200 TJ and 20 TJ, are in decreasing order: Israel, South Africa, Ecuador, Ethiopia, Malawi, Singapore, Fiji, Guatemala, Honduras, Rwanda and Tanzania.

(Sub)totals may not match precisely due to independent rounding.

Table A1.2

Revisions in CO_2 emissions from fossil-fuel combustion and from all sources for China and the global total

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
China													
Coal ratio CSA 2015/IEA 2014a	-1.9%	0.5%	4.2%	5.2%	6.5%	11.1%	10.6%	12.7%	11.2%	10.9%	9.2%	8.0%	6.9%
Fossil-fuel emissions CO_2:													
1A EDGAR 4.3 (cf. IEA 2014a; before CSA revis.) (Mt CO2)	**3,260**	**3,340**	**3,550**	**4,120**	**4,800**	**5,370**	**5,890**	**6,280**	**6,450**	**6,760**	**7,220**	**7,980**	**8,220**
Diff. last year(%)	7%	8%	7%	7%	6%	6%	5%	4%	-5%	-5%	-3%	-3%	-3%
Diff. last year (Mt)	200	240	240	280	260	300	270	240	-320	-350	-250	-220	-230
1A EDGAR 4.3 (incl. CSA revis.) (Mt CO_2)	**3,210**	**3,360**	**3,670**	**4,290**	**5,050**	**5,870**	**6,410**	**6,950**	**7,060**	**7,380**	**7,770**	**8,510**	**8,680**
1A EDGAR 4.2FT2013 (last year)	3,060	3,100	3,310	3,840	4,540	5,070	5,620	6,040	6,770	7,110	7,470	8,200	8,450
Diff. last year (%)	5%	8%	11%	12%	11%	16%	14%	15%	4%	4%	4.0%	4%	3%
Diff. last year (Mt CO_2)	150	260	360	450	510	800	790	910	290	270	300	310	230
Total CO_2 emissions:													
EDGAR 4.3 (before CSA revis.) (Mt CO2)	**3,840**	**3,940**	**4,180**	**4,840**	**5,570**	**6,200**	**6,840**	**7,340**	**7,550**	**7,920**	**8,500**	**9,390**	**9,710**
Diff. last year (%)	-1.3%	0.4%	2.9%	3.6%	4.6%	8.1%	7.6%	9.1%	8.0%	7.8%	6.4%	5.7%	4.8%
Diff. last year (Mt)	-50	20	120	180	260	500	520	660	600	620	550	530	470
EDGAR 4.3 (incl. CSA revis.) (Mt CO_2)	**3,790**	**3,960**	**4,300**	**5,020**	**5,830**	**6,700**	**7,360**	**8,000**	**8,150**	**8,540**	**9,050**	**9,920**	**10,180**
EDGAR 4.2FT2013 (last year) (Mt CO_2)	3,560	3,640	3,900	4,500	5,280	5,850	6,510	7,010	7,790	8,260	8,740	9,590	9,920
Diff. last year (%)	6%	9%	10%	12%	10%	14.5%	13%	14%	5%	3%	3.5%	3%	3%
Diff. last year (Mt CO_2)	230	320	400	520	550	850	850	990	360	280	310	330	260
Global total													
EDGAR 4.3 (incl. CSA revis.) (Gt CO_2)	**25.6**	**25.9**	**26.4**	**27.7**	**29.0**	**30.2**	**31.1**	**32.3**	**32.5**	**32.0**	**33.6**	**34.7**	**35.0**
EDGAR 4.2FT2013 (last year) (Gt CO_2)	25.4	25.5	26.1	27.2	28.6	29.4	30.4	31.4	32.0	31.6	33.0	34.0	34.6
Difference (%)	1%	2%	1%	2%	1%	3%	3%	3%	2%	1%	1.9%	2%	1%
Difference (Mt CO_2)	250	420	320	480	410	810	790	900	490	410	620	660	370

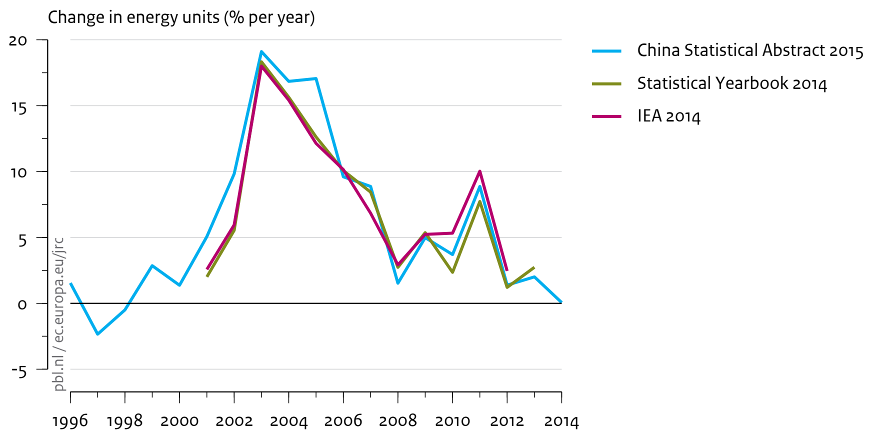
coal revision. Finally, these percentages were applied to the initially calculated EDGAR 4.3 CO_2 emissions from fossil-fuel combustion in China, the resulting figures of which are used in this study.

In Table A1.2 we show the main annual percentage changes calculated and the impact for 2000–2012 of (a) the ratio of total coal consumption in SCE and total primary coal consumption in IEA statistics, (b) the ratio between total corrected (i.e. CSA revised) fossil-fuel CO_2 emissions and the initial total CO_2 emissions based on IEA statistics, using default emission factors from the 1996 IPCC guidelines published in IEA (2014b), and (c) the difference between the new CSA updated emissions used and the figures from EDGAR 4.2 FT2013 used in last year's report.

In this table, we also show the total impact of the EDGAR CO_2 revisions from 4.2 to 4.3, for China and for the global total, by comparing total CO_2 emissions in this report to those in last year's report (Olivier et al., 2013). Initially, version 4.2 ran to 2005/2008, but it was extended using a Fast Track extrapolation method to 2010 and later to 2013 (4.2 FT2013). Therefore, some of the large changes in China's coal statistics appear to have a much smaller effect on total Chinese and global CO_2 emissions for the years 2008–2012, as it is for these years that full updates of statistics also have the largest impact on CO_2 emissions.

Table A1.2 shows that the largest change in China's coal consumption in CSA 2015, compared to IEA 2014a, is that of 13% in 2007. The largest change in China's total fossil-

Figure A1.1
Comparison of annual change in coal consumption in China



Source: NBS 2014, 2015; IEA 2014

Note: China Statistical Abstract (CSA) 2015 (NBS, 2015b), Statistical Yearbook (SYB) 2014 (NBS, 2014c), and primary coal consumption in IEA data set (IEA, 2014a). Unit: percentage change compared to the previous year.

fuel combustion emissions, compared to last year's report, is an increase of 900 Mt CO_2 or 15% in 2007. For total CO_2 emissions in China, the differences with last year's report are often somewhat smaller in percentages, because of updates of other sources, in particular downward revisions of CO_2 from cement clinker production due to improved clinker fractions used in the calculations, in particular for the years 2007–2012. For the year 2010, often used as a reference year, the total increase was 300 Mt CO_2 or 4%.

The difference in global total emissions from fossil-fuel use and industrial processes compared to last year's report was up to 3% in 2005–2007, with a maximum increase of 900 Mt CO_2 in 2007. For the year 2010, often used as a reference year, the total increase was 600 Mt CO_2 or 2%. This increase of 0.6 Gt CO_2 eq is an increase of 1.2% in global total greenhouse gas emissions, estimated by EDGAR 4.2FT2010 as 50.1 Gt (±5%) CO_2 eq in 2010. Compared to a total of 49.5 Gt CO_2 eq reported by IPCC's WGIII in its Fifth Assessment Report, this represents an increase of 1.2 Gt CO_2 eq. in 2010.

Furthermore, note that using updated *Global Warming Potentials* (GWPs) for the values reported in IPCC's Fourth Assessment Report (AR4) instead of those in the Second Assessment Report (AR2), will also impact global 2010 emissions in CO_2 eq. Mainly because the GWP of methane (CH_4) was updated from 21 to 25, global non-CO_2 emissions increase by about 1.5 Gt CO_2 eq. So, the impact of the change in GWPs is larger than of the revision of CO_2 emissions caused by the revisions in the fossil-fuel statistics on China and other countries.

In Figure A1.1 we compare the annual changes in coal consumption in energy units (SCE or toe) reported in the new CSA 2015, last year's SYB 2014 (NBS, 2014c) and in IEA 2014. This clearly shows that the changes in the IEA 2014 data set are very similar to those in China's SYB 2014, except for 2007, 2008 and 2009. In contrast, the revisions in the CSA 2015 show increases in annual changes, in particular in 2001 and 2002 and in 2005. Smaller decreases in the annual changes are visible, particularly in 2008 and 2010. The difference in total CO_2 emissions in China, before and after the revision, is shown in Figure 2.2 in Section 2.

A1.5 Comparison with other global greenhouse gas inventories

In the Fifth Assessment report of IPCC Working Group III (IPCC,2014a) the reported greenhouse gas emissions (e.g. Figure SPM.1) combines CO_2 emissions related to fossil fuel use from IEA (2012c) and other CO_2 emissions sources and non-CO_2 emissions from EDGAR 4.2 FT2010 (EC-JRC/PBL, 2012). Figures TS.2 and TS.4 from the Technical Summary of the Working Group III report provide insights on the growing uncertainty of the emissions and the range of per capita emissions, using definitions as given in Annex II of the WG III report (IPCC, 2014a).

Table A1.3 summarises the differences between six global CO_2 datasets in coverage, sources, methodology and key global CO_2 totals per source for 2005 and 2010 from the currently available datasets (as of 1 October 2015). The

Table A1.3

Comparison of six datasets for CO_2 emissions: data sources, methodology, level of detail in countries, fuels and sources, emissions from current datasets (as of 1 December 2014) (global emissions 2005/2010 in million tonnes CO_2)

Source	EDGAR 4.3	IEA	CDIAC	EIA	BP	UNFCCC	
Greenhouse gases	CO_2, CH_4, N_2O, F-gases	CO_2	CO_2	CO_2	CO_2	CO_2, CH_4, N_2O, F-gases	a
Update frequency	Annual/ Periodic	Annual	Annual	Annual	Annual	Annual	
Start year	1970	1971	1751	1980	1965	1990	b
Latest year	2012	2013	2010 (2012 for 67 + 5 other)	2011	2014	2012	
Countries in dataset	214	137+3 other	224	224	67+5 other	44 (yearly national inventory reports)	c
Fossil fuel combustion	**27,489** (2005) **30,450** (2010)	**27,048** (2005) **29,838** (2010)	**28,229** (2005) **31,646** (2010)	**27,880** (2005) **31,155** (2010)	**30,279** (2005) **33,471** (2010)		*
Fossil fuel types in energy database distinguished for CO_2 calculation	42 (as IEA)	42 (23 oils, natural gas, 16 coals + 2 non-renewable wastes)	4 (hard coal, brown coal, gas, liquid)	~40 (in CO_2 dataset)	3 (coal, oil, gas)	~40	
Fossil fuel types in CO_2 dataset	- (not in public dataset)	same	3 (solid, gas, liquid)	8	same	7 (solids, gas, liquid, other + petrol, diesel (road)	
Sectors in CO_2 dataset	20	46	-	-	-	20	
Energy data source	IEA energy statistics	IEA statistics *(from IEA questionnaire + UN questionnaire)*	UN energy statistics	open sources	open sources	CRF (national statistics)	
Emission factor source	2006 IPCC	2006 IPCC	US-based	see note	unknown	country-specific	d
Fraction of C oxidised	2006 IPCC	2006 IPCC	US-based for liquid and gas; also others for coal	see note	unknown	country-specific	d
Non-fuel use (feedstock)							
Countries in CO_2 dataset	214	137+3 other	included in global only	included in fossil fuel combustion	-	44 (yearly national inventory reports)	
Activity data type and data source	industrial production statistics (USGS, UN)	non-energy use of fuels (IEA)	non-energy use of fuels (UN)	unknown	-	country-specific (production and/or non-energy use)	d
Carbon content	2006 IPCC	2006 IPCC	US-based	see note	-	country-specific	d
Fraction of C stored	not applicable	1996 IPCC	US-based	see note	-	country-specific	d
International bunkers	**996** **1,123**	**1,003** **1,127**	**940** **1,080**				
Countries	global only	137+3 other	224	included above	included above	44	e
Sectors in CO_2 dataset	marine, aviation	marine, aviation	total	included in country totals	included in country totals	marine, aviation (memo items)	
Data source	IEA statistics	IEA statistics	UN energy statistics	-	-	country-specific	

Table A1.3 (continued)

Source	EDGAR	IEA	CDIAC	EIA	BP	UNFCCC	
Gas flaring	**493** **281**	**-**	**216** **238**	**227** **228**	**-**		*
Source of activity data	mainly NOAA/ NCDC for 54 countries (satellite derived)	-	mainly UN	open sources	-	country-specific	f
Sectors in CO_2 dataset	flaring only (venting separately)	-	includes venting	includes venting	-	country-specific (venting separately)	
Industrial processes	**958** **1,218**	**-**	**1,173** **1,632**	**-**	**-**		*
Sources	Cement (clinker), lime, other carbonate use, ethylene, etc.	-	cement	-	-	Cement (clinker), lime, other carbonate use, ethylene, etc.	
Activity for cement	cement production	-	cement production	-	-	cement clinker production	
Data source	USGS	-	USGS	-	-	country-specific	
Emission factor	2006 IPCC, corrected for clinker fraction		own global value, adopted by 1996 IPCC				g
Forests/ Landuse change	forest fires peat fires, post-burn	-	see note	-	-	-	h

Notes:

a UNFCCC: 44 countries report on a yearly basis national inventory reports for the time series 1990 till latest year of reporting.

b IEA: For OECD countries starting in 1960.

c IEA and EIA: other countries have been summed in a number of 'other countries' in a region.
UNFCCC: has annual, detailed data for Annex I countries. In addition, UNFCCC has also emissions from non-Annex I countries, but much less frequent, detailed and documented. Here we only specify the dataset of Annex I countries.

d IEA: As of 2015, the IEA applies the 2006 IPCC guidelines and does not calculate or include the CO_2 emissions related to non-energy/feedstock use of fossil fuels. Moreover, these amounts are now excluded from the calculation of CO_2 emissions using the Reference Approach.
EIA: Emission factors for petroleum, coal, and natural gas consumption and natural gas flaring are from EIA, Documentation for Emissions of Greenhouse Gases in the United States 2006 (October 2008), Tables 6.1 and 6.2. Storage fraction for non-fuel use of petroleum products are from the same report.
EDGAR uses a sector specific approach for industrial processes and therefore uses industrial production as activity data, rather than amounts of non-fuel use of fossil fuels, which are often not fully distinguished in energy statistics.

e EDGAR reports only global marine and aviation bunker emissions since most of the emissions from these bunker fuel sales occur outside the country of sale.

f EDGAR data rely mainly on independent observations of the amount flared vs. CDIAC and EIA estimate it from the amount of gas produced minus the amount of gas marketed and assumes the remainder is all flared, but does include gas vented.

g EDGAR corrects for the decreasing fraction of clinker in the cement produced since calcination emissions are actually related to clinker production not cement production.

h EDGAR estimates all actual emissions from forest and peat fires and post-burn and peat soil decomposition due to drainage, but does not include net carbon storage. CDIAC CO_2 emissions are part of the Global Carbon Project's dataset, that includes that net carbon storage from land use and land use change).

** Global total emissions (in million tonnes CO_2): top: 2005; bottom: 2010 (Unit: million tonnes CO_2). Fossil fuel combustion values include non-fuel use of fossil fuels (e.g. as chemical feedstock) and international bunkers. Industrial processes values in the table refer to cement production only. EDGAR total including lime production and other limestone use etc.: 1,226 and 1,547 million tonnes CO_2, respectively.*

Home pages of the datasets:

EDGAR: http://edgar.jrc.ec.europa.eu/

IEA: http://www.iea.org/statistics/topics/co2emissions/

CDIAC: http://cdiac.ornl.gov/trends/emis/meth_reg.html

EIA: http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=90&pid=44&aid=8

BP: http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy/statistical-review-downloads.html

UNFCCC: http://unfccc.int/ghg_data/items/3800.php level of detail for the fuel use calculations differs substantially, however at global level the differences are often relatively small. It should be noted that differences for individual countries can be much larger (Marland et al., 2009; Olivier and Peters, 2012; and Table 2.9 of Section 2.6).

As shown in Table A1.3 at global level the differences between CDIAC and EDGAR fossil-fuel related CO_2 emissions are very small. However, at global level the differences between IEA and EDGAR CO_2 emissions are around 4%, which can be explained largely by the difference in overall emission factors used (differences due to different default values for the emission factors and carbon oxidation factors in the 1996 and 2006 IPCC Guidelines for Greenhouse gas Inventories (IPCC, 1996, 2006). The latter changes results in 2%, 1% and 0.5% higher CO_2 emissions from respectively coal, oil and gas combustion, and increases overall fossil fuel emissions by about 1.3%. In addition, for recent years the latest IEA statistics for these years will show more updated values for fuel consumption than for years further in the past. For a more detailed analysis of the differences between EDGAR, IEA, CDIAC and EIA datasets see Andres et al. (2012) and between EDGAR/IEA and CDIAC/UN see Marland et al. (1999).

For flaring EDGAR reports values about twice as high as CDIAC and EIA (Table A1.2), which is remarkable since the CDIAC and EIA data also include venting. This difference can be explained by the different estimation method for the activity data, which is mainly based on reported energy statistics for CDIAC and EIA but mainly on satellite data for EDGAR.

For cement production the emission factors used in EDGAR include a correction for the fraction of clinker in the cement produced. As this fraction has be decreased significantly in most countries in the last decades, thereby proportionally decreasing the emission factor expressed in per tonne of cement produced, the EDGAR emissions are about 20% lower than the unadjusted values in the CDIAC dataset (Table A1.3).

A1.6 Global and regional temperature anomalies in 2013 and 2014

The weather in 2014 and 2013

This Annex summarises the regional winter and summer temperatures in 2014 and compares them with 2013, as this is relevant for inter-annual changes in de demand for energy for space heating and air-conditioning.

In **2014**, much of the warm weather in **Europe** can be attributed to the second warmest winter on record, followed by a record warm spring around the continent. According to a WMO report, 19 European countries were expected to observe their hottest year on record. **China** observed eight months of above-average temperatures, including its second warmest January, in 2014, but summer was cooler than average while autumn was warmer than average, and the year ended on a cool note. For **Australia**, following its warmest year on record in 2013, 2014 was the third warmest in the 105-year period of record.

In contrast to all other land areas around the world, much of **North America** had below-average temperatures for much 2014, particularly during the early part of the year, due to a series of cold Arctic outbreaks and a persistent dip in the jet stream that moved warm air northward into Alaska and northern Europe and cold air southward into North America and **central Russia**. The United States had its 33rd coolest winter in the 120-year period of record, with many States east of the Rockies having had their coldest winter since the 1970s. On the other side of the dip in the jet stream, however, California's winter was record-breaking warm and Alaska had its eighth warmest winter. The year 2014 was the warmest on record for Alaska and California, together with two other western states: Nevada and Arizona (NOAA, 2015).

In comparison, in **2013**, the Arctic Oscillation was a major driver of weather patterns during early 2013 across the Northern Hemisphere. Cooler-than-average spring temperatures were present across much of **Europe**, the south-eastern **United States**, north-western **Russia**, and parts of **Japan**, while in contrast the Arctic region was considerably warmer than average, along with much of central and northern Africa, the eastern **Mediterranean**, southern **Russia**, and much of **China**. This pattern is characteristic of the negative phase of the Arctic Oscillation.

It was warmer than average during winter for both **Canada** and the **United States**. However, the **United States** observed its coolest spring since 1996. **Canada** was warmer than average for the spring, and its summer was the eighth warmest on record. Many regions across **Europe** were warmer than average at the start of 2013. However, spring brought extremely cold conditions affecting a large swath of **Europe**. Summer was much warmer than average over many European countries and the beginning of autumn was also anomalously warm. Northern **East Asia** had a cold period during its 2012/13 winter season, associated with negative Arctic Oscillation conditions and blocking patterns around eastern Siberia. Summer was much warmer than average across many

Table A1.4
Heating Degree Days (HDD-15.5) for selected cities, United States and EU-28: 2014 compared to 2013

Country	City	HDD 2013	HDD 2014	Trend2014	Remark
China	Beijing	2492	2163	-13%	much warmer
	Shanghai	1145	998	-13%	much warmer
	Chengdu	770	840	9%	colder
	Guangzhou	200	246	23%	much colder
	Sum China-4:	**4607**	**4247**	**-8%**	**warmer**
United States	New York	2026	2212	9%	colder
	Washington, DC	1677	1764	5%	bit colder
	Atlanta	1122	1246	11%	colder
	Los Angeles	318	178	-44%	much warmer
	US (AGA,2015):	**4338**	**4620**	**7%**	**colder**
Italy	Rome	1092	868	-21%	much warmer
Germany	Berlin	2553	2016	-21%	much warmer
	Düsseldorf	2298	1655	-28%	much warmer
Netherlands	Amsterdam	2331	1679	-28%	much warmer
United Kingdom	London	2057	1511	-27%	much warmer
	EU-28 (EEA, 2015b):	**3535**	**3179**	**-10%**	**warmer**
India	New Delhi	269	304	13%	colder
	Mumbai	0	0		
Japan	Tokyo	1071	1076	0%	
	Osaka	1326	1297	-2%	
Russia	Moscow	3773	3826	1%	

Sources: http://www.degreedays.net, all except: total United States: AGA (2015) and total EU-28: EEA (2015b).

Note: For the EU-28, Heating Degree Days are based on daily observations using Eurostat's basic methodology for mean daily temperature: HDDs start to count for the number of degrees that the average daily temperature is below 18 °C with a threshold of 15 °C. For example, a day with an average temperature of 11 ˚C counts for the EU as 7 HDDs (18–11).

parts of **Asia**. A heatwave contributed to **China** observing its warmest August on record (NOAA, 2014, 2015).

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 °C, 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 A1.4 the number of *Heating Degree Days* in 2013 and 2014 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 most of Europe experienced a very warm winter in 2014, with HDDs about one quarter lower than in 2013, and that parts of China (Beijing, Shanghai) had a warmer winter than in 2013.

List of abbreviations and definitions

AGA	American Gas Association
IAI	International Aluminium Institute
AR5	Fifth Assessment Report of IPCC
BNEF	Bloomberg New Energy Finance
BP	BP plc (energy company; formerly British Petroleum Company plc)
DMSP-OLS	Defense Meteorological Satellite Program - Operational Linescan System
CCA	China Cement Association
CCS	Carbon Capture and Storage
CDD	Cooling Degree Days
CDIAC	Carbon Dioxide Information Analysis Centre (at ORNL)
CSA	China Statistical Abstract
CSI	Cement Sustainability Initiative (of WBCSD)
EC	European Commission
EDGAR	Emission Database for Global Atmospheric Research
EIA	U.S. Energy Information Administration
US EPA	U.S. Environmental Protection Agency
EPIA	European Photovoltaic Industry Association
EU ETS	EU Emissions Trading System
EU-28	European Union with 28 Member States
GCP	Global Carbon Project
GDP	Gross domestic product
GFED	Global Fire Emissions Database
GGFR	Global Gas Flaring Reduction Partnership (World Bank)
GHG	Greenhouse Gas
Gt	Gigatonnes (1,000 megatonnes = 10^9 metric tonnes)
GW	Gigawatt (1 billion W = 10^9 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
IEA	International Energy Agency (Paris)
IES	Institute for Environment and Sustainability of the Joint Research Centre JRC
IFA	International Fertiliser Industry Association
IMF	International Monetary Fund
INDC	Intended Nationally Determined Contribution (emission mitigation proposal for the Paris climate agreement)
IPCC	Intergovernmental Panel on Climate Change

JRC	Joint Research Centre of the European Commission
LCOE	Levelised costs of electricity
LPG	Liquefied Petroleum Gas
LNG	Liquefied Natural Gas
LSCE	Le Laboratoire des Sciences du Climat et de l'Environnement, part of Institut Pierre Simon Laplace (IPSL) in Paris
LULUCF	Land use, land-use change and forestry
MATS	Mercury and Air Toxics Standards
MODIS	Moderate Resolution Imaging Spectroradiometer (satellite instrument for remote sensing)
Mt	Megatonnes (1 million metric tonnes)
NBS	National Bureau of Statistics of China
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
OAO Gazprom	Open Joint Stock Company Gazprom
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)
OGCI	Oil and Gas Climate Initiative
OPEC	Organisation of Oil Exporting Countries
PBL	PBL Netherlands Environmental Assessment Agency
PPP	Purchasing Power Parity
PV	Photovoltaic
SNA	2008 UN System of National Accounts
SYB	Statistical Yearbook (China)
TFC	Total Final Consumption
TJ	Terajoule (= 10^{12}J)
TPES	Total primary energy supply
TW	Terawatt (1,000 GW = 10^{12} W) (unit of power, sometimes denoted as TWe)
TWd	Terawatt day
TWh	Terawatt hour (1000 billion W hour = 10^{12} Wh = 3.6 Petajoule, PJ)
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNEP	United Nations Environment Programme
UNPD	United Nations Population Division
USD	U.S. Dollar
USGS	United States Geological Survey
WBCSD	World Business Council on Sustainable Development
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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