# TRENDS IN GLOBAL $CO_2$ EMISSIONS

## 2013 REPORT

### BACKGROUND STUDIES

PBL Netherlands Environmental Assessment Agency


Joint Research Centre

# TRENDS IN GLOBAL $CO_2$ EMISSIONS: 2013 Report

**Trends in global CO2 emissions: 2013 Report**

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# Contents

# Summary

The increase in global emissions of carbon dioxide ($CO_2$) from fossil-fuel combustion and other smaller industrial sources – the main cause of human-induced global warming – slowed down in 2012, while the global average annual growth rate of 2.4 ppm in atmospheric $CO_2$ concentrations in 2012 was rather high.

Actual global emissions increased by 1.4% over 2011, reaching a total of 34.5 billion tonnes in 2012. After a correction for the leap year 2012, this increase was reduced to only 1.1%, compared with an average annual increase of 2.9% since 2000. The $CO_2$ emission trend mainly reflects energy-related human activities which, over the past decade, were determined by economic growth, particularly in emerging countries. In 2012, a 'decoupling' of the increase in $CO_2$ emissions from global economic growth (in GDP) took place, which points to a shift towards less fossil-fuel intensive activities, more use of renewable energy and increased energy saving.

Comparing regional $CO_2$ emission trends reveals large differences in underlying causes, which complicates the evaluation of the robustness of observed trends. For 2012, remarkable trends were seen in the top 3 emitting countries/regions, which accounted for 55% of total global $CO_2$ emissions. Of these three, China (29% share) increased its $CO_2$ emissions by 3%, which is low compared with annual increases of about 10% over the last decade. In the United States (16% share) and the European Union (11% share) $CO_2$ emissions decreased by 4% and 1.6%, respectively. In addition, in India and Japan, emissions increased by 7% and 6%, and the Russian Federation noted a 1% decrease. Although China's $CO_2$ emissions per capita are comparable to those in the EU and almost half of US emissions per capita, its $CO_2$ emissions per USD in Gross Domestic Product (GDP) are almost double those of the EU and United States and similar to those of the Russian Federation.

China's large economic stimulus package, intended to avoid a decrease in annual economic growth during the recent global recession, has come to an end. With electricity and energy increases at half the pace of GDP growth, the energy intensity per unit of GDP declined in 2012 by 3.6%, which is twice as fast as in 2011. This slower and structurally changed growth puts the country back on track, in combination with a national energy consumption target for 2015, to meet its 2015 target according to the 12th Five Year Plan, with an almost 17% cumulative reduction in energy intensity per unit of GDP, compared to 2010. China also increased its hydropower capacity and output by 23% in 2012, which had a significant mitigating effect of about 1.5 percentage points on its $CO_2$ emissions in 2012.

In that year, China's average carbon dioxide emissions of 7.1 tonnes $CO_2$ per capita resulted from a smoothing of their $CO_2$ increase by only 3% after the about 10% annual growth rates of the previous decade. This 2012 increase in fuel consumption was mainly driven by the increase in building construction and expansion of infrastructure, as indicated by the growth in cement and steel production. Although the United States, with 16.4 tonnes $CO_2$ per capita in 2012, showed a decrease in $CO_2$ emissions since

2005, they still ranks among the major industrialised countries with the highest emission levels. In 2012, with an economic growth of 2%, their $CO_2$ emissions decreased by 4%, mainly because of a further fuel shift from coal to gas in the power sector, due to the low gas price. In recent years, the United States expanded shale gas fracturing and has now become the largest natural gas producer in the world. Over the past 5 years, the share of shale gas increased to one third of the total US gross gas production and the share of shale oil in 2012 was almost one quarter of total US crude oil production. The European Union, as a whole, experienced an economic recession in 2012 with the EU27's GDP declining by 0.3%, compared to 2011, and actual $CO_2$ emissions declining by 1.3%, which is less than the 2011 decrease of 3.1%. The main reasons for this are a decrease in primary energy consumption of oil and gas, by 4% and 2% respectively , a decrease in road freight transport by 4%, and a decrease of 2% in total emissions from power generation and manufacturing installations participating in the EU Emissions Trading System (EU ETS). While the total $CO_2$ emissions from power generation in EU27 decreased by 2.3% in 2012, very different trends were noticed for the different EU Member States, in particular for coal. The use of coal in Europe's energy mix for electricity production became attractive again. In 2012, increased coal consumption was observed in the United Kingdom (+24%; the highest consumption since 2006), Spain (+24%; the second year with an increase after two years of decreasing consumption), Germany (+4%) and France (+20%), versus decreases in Poland and the Czech Republic of 4% and 8%, respectively.

On a global scale, energy carriers in primary energy supply all showed continuous increases over the past decade, except for nuclear energy, which decreased since 2012 in the aftermath of the Fukushima accident. Increases in fossil-fuel consumption in 2012 were 2.2% for natural gas, 0.9% for oil products, and 0.6% for coal. This has brought the share of coal combustion in global total $CO_2$ emissions to almost 40%, and the share of coal-fired power plants in $CO_2$ emissions from fossil fuels to 28%. Several measures have been implemented to level off coal use for power generation. Possible alternatives include a shift from coal to gas or renewable energy, converting coal-fired power plants to make them suitable for biomass, and making new coal-fired power plants ready for the use of carbon capture and storage (CCS) technology. However, such changes do not happen overnight.

Since 2002, however, the use of renewable energy has accelerated: the increase in the use of hydropower has accelerated and its output increased by 4.3%, between 2011 and 2012. The share of the 'new' renewable energy sources solar, wind and biofuel also increased with accelerating speed: it took 15 years since 1992 for the share to double from 0.5% to 1.1%, but only 6 more years to do so again, to 2.4% in 2012.

The small increase in emissions in 2012 of 1.1% may be the first sign of a slowdown in the increase in global $CO_2$ emissions, and ultimately of declining global emissions, if (a) China achieves its own target of a maximum level of energy consumption by 2015 and its shift to gas with a natural gas share of 10% by 2020; (b) the United States continues a shift its energy mix towards more gas and renewable energy; and (c) in the European Union, Member States agree on restoring the effectiveness of the EU Emissions Trading System to further reduce actual emissions.

Obviously, it is uncertain how the global society will develop over time and which economic and technological trends will continue; in particular, with respect to global and regional prices of different fossil fuels and the shares of nuclear power and renewable energy sources. However, there is additional uncertainty due to possible major changes in various areas that would have a large impact on global energy use.
For example:

- rising production of shale gas may affect natural gas prices worldwide;
- expansion of intercontinental trade in liquid natural gas (LNG) through increased transport and storage capacity may influence the natural gas markets;
- overcapacity and flexibility in the fuel mix for power generation may cause fast changes in the fuel mix used by utilities, in case of changes in relative prices of gas and coal (as observed in the United States and some European countries);
- the ability of China to smoothly transition towards a more service-based economy;
- a prolonged recession may hinder restoring the functioning of the carbon market of the EU ETS and thus the ability to set and meet more ambitious emission reduction targets.

These preliminary estimates have been made by PBL Netherlands Environmental Assessment Agency and the European Commission's Joint Research Centre (JRC), on the basis of energy consumption data on 2010 to 2012, as published by energy company BP, and coal consumption data on the 2011–2012 period, published by the National Bureau of Statistics of China (NBS). The estimates are also based on production data for cement, lime, ammonia and steel, as well as on emissions per country, from 1970 to 2010, from the Emission Database for Global Atmospheric Research (EDGAR) version 4.2 FT 2010, which is a joint project of JRC and PBL.

# Introduction

This report discusses the results of a trend assessment of global $CO_2$ emissions up to 2012 and updates last year's assessment (Olivier et al., 2012). This assessment focuses on the changes in annual $CO_2$ emissions from 2011 to 2012, and includes not only fossil-fuel combustion on which the BP 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. More details are provided in Annex 1 over the 2010–2012 period, including a discussion of the degree of uncertainty in national and global $CO_2$ emission estimates.

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. Specific attention is given to developments in shale gas and oil production and oil sands production and their impact on $CO_2$ emissions. To provide a broader context of global emissions trends, international greenhouse gas mitigation targets and agreements are also presented, including different perspectives of emission accounting per country. In particular, annual trends with respect to the Kyoto Protocol target and Cancùn agreements and cumulative global $CO_2$ emissions of the last decade are compared with scientific literature that analyses global emissions in relation to the target of 2 °C maximum global warming in the 21st century, which was adopted in the UN climate negotiations. In addition, we briefly discuss the rapid development and implementation of various emission trading schemes, because of their increasing importance as a cross-cutting policy instrument for mitigating greenhouse gas emissions.

Chapter 3 focuses on the energy trends and possible fuel shifts, as the special topic for this year's report. Compared to last year's report, global energy trends are described more fully, including an analysis of the main options for reducing emissions, being renewable energy, nuclear power, energy efficiency and carbon capture and storage. In addition, the extent to which structural changes have caused the observed slowdown in the increase in global $CO_2$ emissions is discussed. Finally, Chapter 4 summarises the main conclusions on trends, mitigation achievements and prospects.

This assessment excludes $CO_2$ emissions from deforestation and logging, forest and peat fires, from post-burn decay of remaining above-ground biomass, and from decomposition of organic carbon in drained peat soils. The latter mostly affects developing countries. These sources could add as much as a further 20% to global $CO_2$ emissions (Van der Werf et al., 2009) or perhaps as little as 10% (Harris et al., 2012). However, these percentages are highly uncertain and show a large annual variability. This variability is also a reason that

emissions and sinks from land use, land-use change and the forestry sector (LULUCF) are kept separate in reporting under the UN Climate Convention (UNFCCC) and the Kyoto Protocol. For the same reason, 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, which will publish later this year a comprehensive assessment of the global carbon budget including all sources and sinks (GCP, 2013).

Please note that national $CO_2$ emissions are accounted here in accordance with the official IPCC reporting guidelines approved and used by countries to report their national greenhouse gas emissions to the UN Climate Convention (UNFCCC) and Kyoto Protocol, based on domestic activities where greenhouse gas emissions occur ('actual' national emissions), such as fossil-fuel consumption and cement production (IPCC, 2006).

### Methodology and data sources used

For global $CO_2$ emissions from 1970 to 2008 we use the EDGAR 4.2 data set for greenhouse gases, the results from a joint project of the European Commission's Joint Research Centre (JRC) and the PBL Netherlands Environmental Assessment Agency, published in November 2011. This data set provides greenhouse gas emissions per country and on a 0.1 x 0.1 degree grid for all anthropogenic sources identified by the IPCC (JRC/PBL, 2011) for the period 1970-2008. Although the data set distinguishes about 25 sources categories, emissions are estimated for well over 100 detailed categories as identified in the Revised 1996 IPCC guidelines for compilation of emission inventories (IPCC, 1996). The core EDGAR 4.2 dataset was extended to 2010 using a fast-track approach based on IEA (2012) fuel-use trends for 2009-2010, for the greenhouse gas section in last year's $CO_2$ report of IEA (Olivier and Janssens-Maenhout, 2012) and it is this extended EDGAR 4.2 FT2010 data set that is used for this assessment.

EDGAR 4.2 includes $CO_2$ emission factors for cement production per tonne cement produced and taking into account the decreasing share of clinker in cement. In addition to cement production, EDGAR 4.2 includes other industrial non-combustion processes, such as the production of lime and soda ash (2A) and carbon used in metal production (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'sguidelines for national greenhouse gas inventories (IPCC, 2006). Collectively, the other carbonate sources added about 30% to global cement production emissions in 2008. More information on the data sources and methodologies used can be found in Olivier et al. (2012), which is part 3 of IEA (2012e).

Although not used in this study, the EDGAR 4.2 data set also includes annual $CO_2$ emissions from forest fires and peat fires as well as fires in other wooded land and savannahs estimated by Van der Werf et al. (2006). It also includes the significant, albeit highly uncertain, $CO_2$ emissions from the decay of organic materials of plants and trees, which remain after forest burning and logging, and from drained peat soils (JRC/PBL, 2011), while net carbon stock changes (resulting in $CO_2$ emissions or carbon storage) for forests, based on data from the FAO's Forest Resources Assessment (FAO, 2010) are included in the data set for completeness.

To estimate the trend for the 2008–2012 period, all $CO_2$ emissions have been aggregated into five main source sectors (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), and (5) waste incineration and fuel fires (6C+7A).

For each country, the trend from 2008 onwards has been estimated by either using the trend in the appropriate activity data or by approximating this trend using related statistics as the estimator. For the fuel combustion emissions (1A) that account for about 90% of total global $CO_2$ emissions, excluding forest fires, 2008 emissions were divided per country 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 2008–2010 trend was based on IEA $CO_2$ data (IEA, 2012e) and the 2010-2012 trend was based on BP data released in June 2013 (BP, 2013). A similar approach was used for the other source sectors. More details on the methodology and data sources are presented in Annex 1. Data quality and uncertainty in the data are also discussed in this Annex. 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 in Olivier and Peters (2002).

# Results

## 2.1 Slowdown in the historical increase in global $CO_2$ emissions

For global $CO_2$ emissions, 2012 was a remarkable year in which emissions increased by only 1.1% (including a downward correction of 0.3% for it being a leap year), which is less than half of the average annual increase of 2.9% seen over the last decade, reaching a new record of 34.5 billion tonnes (Figure 2.1). After a 1% decline in 2009, a 4.5% recovery in 2010, and a 3% increase in 2011, the actual 2012 increase in global $CO_2$ emissions of 1.4% (i.e. excluding leap-year effect) is less than would be expected, given that in 2012, the global economy grew by 3.5%, which is similar to 2011 and to the average annual growth rate over the last decade (IMF, 2013). With a leap-year correction of 0.3% (=-1/365), the 2012 increase in global $CO_2$ emissions was only 1.1%. However, within this global total, there are remarkable differences between countries.

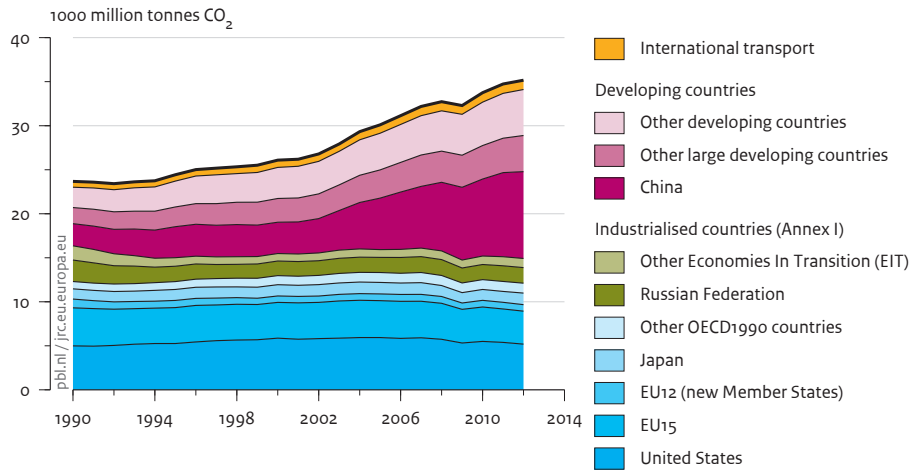
Please note that all 2012 percentages (increase/decline) for $CO_2$, as mentioned in this chapter, include a downward correction for the extra day in the leap year, unless labelled as 'actual', causing reported annual trends to be 0.3% lower than actual annual trends. Thus, uncorrected ('actual') 2012 trend percentages are about 0.3% higher. As an example, the above mentioned global $CO_2$ increase of 1.4% is only (1.4-0.3) %=1.1% (after leap-year correction).

Global coal consumption (responsible for about 40% in total $CO_2$ emissions), in 2012, grew by only 0.9% ('actual') in 2012, well below the decadal average of 4%. These figures were calculated using the actual coal consumption increase in China of 2.5% in 2012, as reported by the National Bureau of Statistics of China (NBS, 2013), rather than the 2012 figure provided by BP (2013) that implies a 6.4% increase in 2012 compared to 2011. The BP (2013) release contains updates for the coal consumption data for China over the last four years, with annual increases now very similar to the data reported by China's NBS. In BP's release of last year the increase in China's coal consumption for 2010 was still estimated to be 10.1%, while the NBS reported this to be 5.9%. However, in their current report, BP has now revised their estimation for 2011 to 6.4%. Global consumption of natural gas and oil products increased by 2.2% and 0.9%, respectively (leap-year corrected), somewhat below the historical trends of 2.7% and 1.2%, annually (BP, 2013).

The six largest emitting countries/regions (with their share in 2012 between brackets) were: China (29%), the United States (15%), the European Union (EU27[1]) (11%), India (6%), the Russian Federation (5%) and Japan (4%) (Figure 2.2). Remarkable trends were seen in the top three emitting countries/regions, which account for 55% of total global $CO_2$ emissions. In China emissions increased by 3.0%, while in the United States emissions decreased by 4.0% and the European Union as a whole also saw a decrease of 1.6% in 2012 compared to 2011. In the aftermath of the Fukushima nuclear accident, Japan's $CO_2$

Figure 2.1

**Global $CO_2$ emissions per region from fossil-fuel use and cement production**




Source: EDGAR 4.2FT2010 (JRC/PBL, 2012); BP, 2013; NBS China, 2013; USGS, 2013; WSA, 2013; NOAA, 2012

emissions showed a 6.2% increase in 2012 (leap-year corrected percentages). Within the European Union, decreases were seen in, for example, Italy, Poland, Spain and the Netherlands, whereas emissions increased in the United Kingdom and Germany. The increase in China was equivalent to two-thirds of the net global $CO_2$ increase in 2012; for India this was one quarter and for Japan almost one fifth, whereas the United States accounted for minus 40% and the European Union for minus 10%, with changes in 2012 compared to 2011 expressed as a fraction of the net emission increase in 2012.

China's $CO_2$ emission increase of 3% in 2012 was about 4 percentage points less than its historical average increase in emissions. This was primarily due to a decline in electricity and fuel demand by the basic materials industry, as economic growth slowed down when the stimulus package was terminated and the production of hydropower rebounded, aided by an increase in the use of renewable energy and by energy efficiency improvements (IEA, 2013).

In the United States, a shift from coal to natural gas in power generation that caused a 12% reduction in coal consumption, together with increased renewable energy production, in particular wind and bioenergy, were the main drivers of the 4% drop in $CO_2$ emissions. The rapid expansion of gas-fired power generation in 2012 was caused by the rapid increase in shale gas production. This, in turn, led to the lowest natural gas prices in the United States in a decade, and caused a 3% decrease in the share of coal in the national fossil-fuel mix.

The European Union's $CO_2$ emission reduction of 1.6% (1.3% 'actual') in 2012, was 1% less than the historical trend, and this was partly due to the continued weak economic condition post-2009, with a 0.3% decrease in total GDP in 2012 (in PPP units; IMF, 2013). The companies covered by the *EU Emissions Trading System* (EU ETS) – more than 12,000 installations covering more than 40% of the EU's $CO_2$ emissions (EC, 2013a) – reported 2% less in $CO_2$ emissions for 2012 than for 2011 (EC, 2013b). The EU saw a 1.6% decrease in natural gas consumption, despite a higher demand for space heating in parts of Europe due to the cold winter (BP, 2013). Europe's power industry took advantage of the drop in the US coal demand. The fact that the price of carbon credits in the EU ETS was too low to offset the price advantage of switching electricity production to more carbon-intensive coal, and that Europe started to import more coal, also from the United States, resulted in a 3.3% increase in EU-wide coal consumption.

The moderate 1.1% increase in global $CO_2$ emissions in 2012 seems remarkable in times where global economic growth was almost on a par with the average growth levels over the last decade. Within this percentage however, there are notable differences in the performance of various groups of countries. Economic growth in the industrialised OECD countries in 2012 was about two-thirds of the average over the past, while in eastern European countries ('Economies In Transition' or EIT) this was only half the level of the trend in recent history. In contrast, developing countries maintained their average growth of the previous decade (IMF, 2013; World Bank, 2013a). However, since a substantial part of a

country's economy is made up of its service and agricultural sectors, which are not energy-intensive activities, increases in energy consumption are not always closely related to overall economic growth.

It is obvious that energy-intensive activities are of the highest relevance and that fossil-fuel combustion accounts for 90% of the total $CO_2$ emissions (excluding deforestation and other land uses). Power generation remains the most import sector related to fossil-fuel consumption; therefore, the choice of fossil fuel by the power sector is of the utmost importance. More details on recent energy trends are given in Chapter 3. Contrary to the power industry, for which a relatively large variety of fuels can be selected (from fossil fuel to nuclear energy to renewable energy), other energy-intensive sectors, such as those of manufacturing and construction, are less flexible in the short term.

$CO_2$ emissions from cement clinker production (the largest source of non-combustion-related $CO_2$ emissions, contributing 4.5% to the global total) increased globally by 5% in 2012, mainly due to a 5% increase in the production in China, which accounts for more than half of total global production. The 2012 trend for $CO_2$ emissions from gas flaring (with a much smaller share in global emissions), generally contributing less than 1% to the global total, is not yet known, due to the absence of data updates from the NOAA satellite observation systems following changes in sensors.

The uncertainty in these figures varies between countries, ranging from 5% to 10% (95% confidence interval), with the largest uncertainties concerning data for countries with fast changing or emerging economies, such as the Russian Federation in the early 1990s and China since the late 1990s, and for the most recent statistics, based on Marland et al. (1999), Tu (2011), Andres et al. (2012) and Guan et al. (2012). Moreover, newly published statistics are often subject to subsequent revisions. Therefore, for China and the Russian Federation, we assumed 10% uncertainty, whereas for the European Union, the United States, Japan and India[2], a 5% uncertainty was assumed. Our preliminary estimate for total global $CO_2$ emissions in 2012 is believed to have an uncertainty of about 5% and the increase of 2.9% may be accurate to within 0.5%. For more details see Section A1.4 of Annex 1.

## 2.2 Different trends in the six largest emitting countries/regions

This section discusses each of the six largest emitting countries/regions in a descending order of importance.

The largest $CO_2$ emitting country by far was China, which share of 29% in 2012 was much larger than the second-largest, the United States, with 16% and the European Union with 11% (Figure 2.2).
A comparison between the shares of national GDP (on the basis of Purchasing Power-Parity (PPP)) in global GDP showed that China's share in the world economy in 2012 was 15%, while the United States and the European Union each had a share of 19%, followed by India (6%), the Russian Federation (3%) and Brazil (3%). However, when looking at their contributions to the global economic growth over the last decade, which was 44% since 2002, China contributed 31%, India 10%, United States 9%, EU 8%, Russian Federation 4% and Brazil 3% (World Bank, 2013; IMF, 2013). In 2012, the growth in the world economy was around 3.8%, about the same level as that in the last ten years, apart from the global credit crunch years 2008-2009, but with large differences between the largest countries/regions: China's annual economic growth in 2012 was only about three quarters of the decadal trend, so far the lowest this century. Economic growth rates of India (4.0%) and the Russian Federation (3.4%) were only half those of the recent past and that of Brazil (0.9%) only one quarter. The economy of the United States and Japan grew in 2012 by 2.2% and 2.0%, respectively, which closely represents their average historical growth rates, whereas the EU economy decreased by 0.3% (World Bank, 2013a; IMF, 2013).

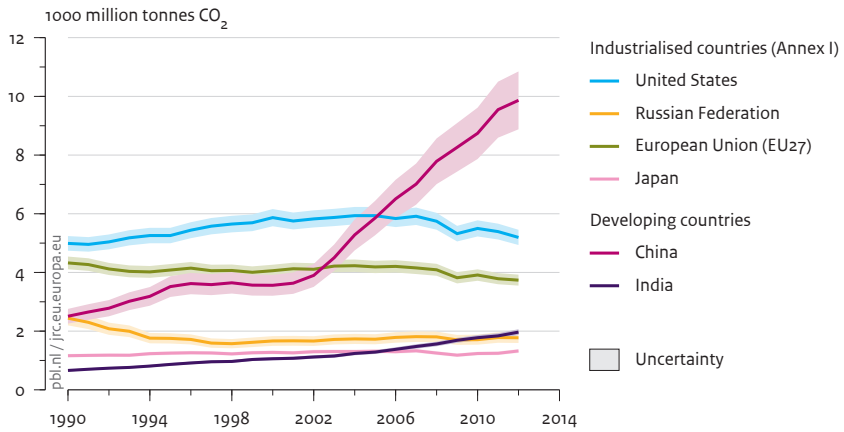
For most industrialised countries, the past decade has been characterised mainly by the 2008–2009 recession, which has since been slowly recovering. In 2012, most OECD countries outside Europe saw their historical economic growth rates continued. The United States, Canada and Japan showed a GDP growth of about 2%, whereas in many EU countries, economic growth was very small or even negative.

### China

In 2012, China's $CO_2$ emissions increased by 3.3% ('actual') to 9.9 billion tonnes, the slowest rate of increase in a decade. This mainly was caused by a relatively small increase of 2.5% in domestic coal consumption, as reported by NBS (2013), whereas in the receding decade, the annual growth rate was mostly around 10%. Coal consumption was responsible for three quarters of China's $CO_2$ emissions from fossil-fuel combustion. In contrast, natural gas consumption reached 10% in 2012, following annual increases of about 20%. If we had used BP's coal growth rate of 6.4% for China, the increase in $CO_2$ emissions would come to 6.1% (BP, 2013). Annex 1 provides a further analysis of the uncertainties in these values. The increase of about 3% was the lowest since 2001, the year after which the increase in Chinese emissions on average accelerated from about 3% to 10%,

Figure 2.2

**$CO_2$ emissions from fossil-fuel use and cement production in the top 6 emitting countries and the EU**




Source: EDGAR 4.2FT2010 (JRC/PBL, 2012); BP, 2013; NBS China, 2013; USGS, 2013; WSA, 2013; NOAA, 2012

annually. Even in the recent 'global recession' years, China's $CO_2$ emissions continued to increase by about 6% per year.

This relatively small increase in 2012 was consistent with the very small increase of 0.6% in thermal power generation (predominantly coal-fired power plants), 4.7% in steel production (also a large user of coal) and 5.3% in cement production, reported by the National Bureau of Statistics of China (NBS, 2013). The small increase in the kWhs generated by coal-fired power plants mainly was due to the large decline in the growth rate of electricity consumption to 4.8% in 2012, mainly from reduced industrial demand. In addition, power generation using hydropower increased by 23%, due to the expansion of installed capacity and recovery from the drop in 2011 due to drought. This large increase in hydropower production had a mitigating effect of around 1.5 percentage points on China's $CO_2$ emissions in 2012.

After years of double digit increases in GDP, China's increase in 2012 was only 7.8% (NBS, 2013; IMF, 2013). 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 (Houser, 2013). At the end of 2008, China implemented a large economic stimulus package that effectively helped avoid the recession suffered by many other countries during 2008 and 2009. This package was aimed at countering a decline in economic growth; it included investment in transport infrastructure and housing development, and was terminated in 2011. Together with restrictions on investments in construction activities (buildings, power plants, infrastructure) this termination resulted in a substantial slowdown in the growth rate of the demand for materials, halving the growth in this sector. Thus, not only the growth of the Chinese economy but also of other key energy trend indicators, such as production of cement, steel and electricity, decreased significantly in 2012, compared to the high annual growth rates over the 2002–2011 period. The growth rate in cement, steel and electricity production was around 5.3% in 2012, which was almost half of that observed in previous years (except for 2007-2008[3]) (see Table 2.1)). Nevertheless, China's 2012 GDP growth of 7.8% was only about 3% less than the decadal average of around 10%.

With energy and, in particular, electricity demand in China growing half as fast as GDP in 2012, the energy intensity per unit of GDP declined by 3.6%, twice as fast as in 2011. This was caused by a slower economic growth and a structural change in growth. In this way, the country is expected to be able to achieve its 2015 target of a 16% cumulative reduction by the end of the 12th Five Year Plan, compared to 2010 (Houser, 2013). The much smaller growth of 3.3% in total $CO_2$ emissions (3.1% of which related to energy) and the relatively large GDP growth of 7.8% meant a reduction in carbon intensity of 4.3% in 2012 (Houser, 2013).

To meet the intensity reduction target of close to 17% by 2015, relative to 2010, according to the 12th Five Year Plan (Fung, 2012), China's carbon intensity will need to continue to decrease but at a slightly higher rate (4.6%) for the three years following 2012. One strategy to reduce energy consumption would be to reorient the economy to the service sectors instead of manufacturing. In addition, more energy-intensive industries have begun to

Table 2.1
**Growth rates in 2012 of selected energy trend indicators in China, compared to average growth rates since 2002.**

| Indicator | Growth rate 2011 to 2012 | Average annual growth rate, 2002–2011 | Standard deviation |
|---|---|---|---|
| GDP | 7.8% | 10.6% | 1.7% |
| Cement | 5.3% | 12.2% | 4.7% |
| Crude steel | 4.7% [3.7%] | 16.5% | 7.5% |
| Electricity consumption | 5.5% | 12.3% | 3.4% |

Sources:
2002–2011: GDP (constant prices) (IMF), cement and crude steel (USGS), electricity (IEA, BP);
2012: NBS (2013); between brackets: WSA (2013).

shift from the eastern provinces to less-developed central and western regions, to improve their energy efficiency and promote low-carbon development, and this trend appears to be continuing (Fung, 2012). Moreover, the Chinese Government approved an energy consumption control target with the aim of bringing total energy consumption below 4 billion tonnes in standard coal equivalents by 2015 (Xinhua, 2013; Bloomberg, 2012).

A more detailed discussion on the uncertainty in Chinese fuel consumption data as reported by different sources is presented in Annex 1, Section A1.4. This discussion, which includes conclusions from recent literature on the accuracy of China's $CO_2$ emissions (Tu, 2011; Andres et al., 2012; Guan et al., 2012), yields an uncertainty for our estimates of about 5% for most industrialised countries, and in the range of 10% for China and the Russian Federation.

## United States

In the United States, in 2012, $CO_2$ emissions decreased by 4% to 5.2 billion tonnes, following a 2% decrease in 2011. This emissions level was the lowest since 1993 and occurred while the economy was growing, whereas, since 2005, $CO_2$ emissions had been increasing every year, with the exception of 2010.

The large decrease in 2012 was mainly due to a decrease in the use of coal (mostly used in power generation). The large increase in shale gas production (see Section 2.5) caused natural gas prices to decline in the first half of 2012, to the lowest level in a decade, leading to a switch to gas-fired power generation and less coal-fired power generation. Compared to coal, natural gas contains roughly about half the amount of carbon (C) per unit of energy; therefore, gas-fired electricity generation produces about half as much $CO_2$ as that from coal. In addition, since they operate at a higher temperature, gas-fired plants can achieve up to almost 15 percentage points higher energy efficiency than coal-fired power plants. Thus, this shift from coal to less carbon-intensive natural gas resulted in a decrease in $CO_2$ emissions. In addition, a 2.2% decrease in transport emissions (but no change in biofuel consumption) and mild winter temperatures reducing the demand for space heating also contributed to the decrease. In the United States, the demand for air conditioning in the summer months may also significantly influence annual trends in fuel consumption, but this was not the case in 2012 (EIA, 2013a,b). Although higher natural gas prices, later in the year, reduced the gas share in power generation below the record level of April 2012, the share of coal in power generation on average remained about 10 percentage points below the annual range of 48% to 51%, prior to 2009 (EIA, 2013d). MacMillan et al. (2013) and EIA (2013b,e) provide further insight into the fuel price incentives for coal- or gas-fired power plant operators and into the reasons for the natural gas price developments in 2012 and early 2013.

$CO_2$ emissions from fossil-fuel combustion decreased by 13% in 2012, thus falling below 2005 levels. Houser and Mohan (2013a,b) analysed the causes of the decrease for the United States, and concluded that the shift from coal to natural gas in power generation, from 20% in 2008 to 30% in 2012, contributed greatly to this change, but the increase in the share of renewable energy in power generation, from 7.9% in 2005 to about 11% in 2012, contributed as much. Houser and Mohan conclude that the total reduction in the carbon intensity of the US energy mix from 2005 to 2012 for about 40% was due to the shift towards natural gas, for 25% due to the shift towards wind energy, for 25% due to more use of biofuels and for the remaining 10% due to solar energy, hydropower and nuclear power. These changes contributed to about half the decrease in $CO_2$ emissions, the other half was due to a much slower economic growth; between 2005 and 2012, GDP grew on average by 1.1%, annually, compared to 3.1% between 1990 and 2005 (IMF, 2013). However, Shellenberger et al. (2013) claim that this analysis ignored the 10% decline in the energy intensity of the economy in 2012, compared with 2005, due to more efficient gas-fired power generation than the previous coal-fired plants, increases in energy efficiency in other sectors, and economy-wide sectoral shifts.

Moreover, they point out that renewable energy not only replaced coal-fired power, but rather several specific mixes of fuels, differing per region. In their response, Houser and Mohan (2013b) addressed these issues and concluded that regardless of how large the role of natural gas has been in $CO_2$ reductions to date, recent data and forecasts suggest that 'it will take new policy to extend those emission cuts forward as both the economy and the natural gas prices begin to recover'.

Natural gas prices in the United States are determined by the North American gas market. By 2012, the production of natural gas increased by 28.9%, relative to 2006. Shale gas production started in 2007 and, by 2013, it had already a one-third share in total US gas production. In comparison, production of shale oil started around 2005 and by 2012 had a share of almost one-quarter in total US crude oil production (EIA, 2013d). For a further discussion on gas flaring, we refer to Section 2.4, and a description of hydraulic fracturing is given in Section 2.5.

### European Union

The European Union, as a whole, remained in an economic recession in 2012; its GDP in that year declined by 0.3% compared to 2011 (in PPP units, IMF, 2013). However, $CO_2$ emissions declined by 1.3% ('actual') in 2012 compared with 2011 (1.6% with leap-year correction), less than the 3.1% decrease in 2011. The main causes of the decline are:

- Decreasing emissions in the EU's primary energy consumption of oil and gas by 4% and 2%, respectively. These decreases were mainly driven by a 1% reduction in electricity production and a reduction in emissions from the residential and services sectors, despite the colder winter (with 10% more heating degree days in 2012, compared to 2011) (Eurostat, 2013a and 2013c).
- Decreasing transport emissions in the EU, determined from a decrease in road freight of 4.1% and air freight of 18.4% between 2011 and 2012. Only rail and sea freight increased by 0.9% and 1.3%, respectively (International Transport Forum, 2013).
- A 2% decrease in emissions from the power plants and manufacturing industry installations in the EU27 participating in the EU Emissions Trading System (EC, 2013b). This includes a 4.5% emission reduction in the iron and steel industry between 2011 and 2012. All EU countries (except the United Kingdom and Slovakia) saw a decline in 2012; in particular, Bulgaria and Spain, with 24.2% and 12.6%, respectively. The chemical industry remained fairly constant, with only a slight increase of 0.8% in Germany (Eurostat, 2013b). Finally, a slight decrease in emissions from cement production; in particular, with a decrease between 2011 and 2012 in Spain with 10% and Italy with 3%. Only in Germany cement production increased by 1.5% (USGS, 2013).

Very different trends were noticed in EU Member States, between 2011 and 2012, for power generation, with a total $CO_2$ emissions reduction of 2.3% for the EU27 (Eurostat, 2013c).

For 2012, increased coal consumption was observed in the United Kingdom (+24%, the highest consumption level since 2006), Spain (+24%, the second year with an increase after two years of decreasing consumption), Germany (+4%) and France (+20%), versus decreases in Poland and the Czech Republic of 4% and 8%, respectively (BP, 2013). Almost all coal consumption in these countries was for power generation, except in France, where iron and steel production also had a substantial share (IEA, 2012d).

The German Government has been shifting away from nuclear energy, and over the past decade, has expanded its renewable energy sector, but no specific policy is in place for coal and lignite. Coal mining in Germany is subsidised until 2018; lignite production does not need subsidies and more than 90% is used for electricity and heat generation (Pöyry, 2013). In 2011 and 2012, old coal-fired power plants with a total capacity of 1,700 MW were permanently closed down. However, also 2 new coal-fired plants with a total capacity of 2,700 MW started production in 2012, 3 more plants have applied for a permit and 6 are currently (2013) under construction, which will provide a total additional capacity of 10,700 MW in the coming years (Sourcewatch, 2013a; Bundesnetzagentur, 2013).

New coal-fired plants also became operational in Italy (1,980 MW plant, operating since 2008) and Bulgaria (675 MW plant, operational since 2011). Relatively large construction activities for new coal-fired plants are still on-going (in 2013) within Europe: three in the Netherlands (with a total additional capacity of 3,500 MW), 2 in the Czech Republic (835 MW), 1 in Poland (910 MW) and 1 in Slovenia (600 MW). These plants will not replace closed down old power plants, but may be built in anticipation of the closure of some old plants, for which complying with the emission standards set in the Large Combustion Plants Directive (LCPD, 2001/80/EC) is expensive. For example, 85% of Poland's power generation is supplied by coal-fired plants, of which two thirds are over 30 years old (CCE Bankwatch, 2013). In most EU27 Member States, these new coal plants are said to be 'CCS ready', i.e. the infrastructure would allow for a carbon capture and storage (CCS) facility next to the power plant. More information on CCS is given in Section 3.6.

The United Kingdom has not constructed any new coal-fired power plants over the last decade (DECC, 2012). Moreover, it is phasing out these plants, having already

converted 3 plants to biomass with a total capacity of 5,160 MW, and has closed another 4 coal-fired plants with a total capacity of 14,670 MW (Sourcewatch, 2013b; Reuters, 2012d, Airlie, 2011).

Spain has also decreased the share of coal in its power generation, considerably, and continues to do so by quadrupling the tax rate on coal and not renewing the subsidies for such coal-fired plants. Since 2010, Spain has been delivering more than 20% of its electricity from renewable sources by widespread deployment of wind power and is investing further in wind and solar technologies (Pöyry, 2013). Recently, Spain has made a series of large legislative changes to its renewable energy policy, in order to control the country's growing electricity tariff deficit, turning renewable energy into a fully regulated business and bringing growth under control (Economist, 2013b; Ernst and Young, 2012).

### India

India, where domestic demand makes up three quarters of the national economy (Damodaran, 2011), has been relatively unaffected by the global financial recession because this recession in fact stimulated the already high share of domestic consumption in total national expenditure. Nevertheless, India's GDP growth of about 4% in 2012 was the lowest in a decade. India's $CO_2$ emissions in 2012 continued to increase by 6.8% to about 2.0 billion tonnes, making it the fourth largest $CO_2$ emitting country, following the European Union, and well ahead of the Russian Federation, which is the fifth largest emitting country (Figure 2.2). This high ranking is partly caused by the size of its population and economy. Per capita, India's $CO_2$ emissions were much lower than those of most developed countries and China (Figure 2.3). The increase in 2012 mainly was caused by a 10% increase in coal consumption, which accounted for two thirds of India's total emissions from fossil-fuel combustion and 55% of those from its electricity production. This growth rate was much higher than in the previous two years, but similar to those of 2008 and 2009. Coal-based power production, accounting for almost 70% of all of India's coal-related $CO_2$ emissions, grew by about 13% in 2012, the highest annual growth ever. Both the additional capacity and generation level were higher (Saikia, 2013). Although not as large as those of China and South Africa, which had a 75% share of coal in their fossil-fuel mix, India 's share was also large with 57%. Poland and Kazakhstan, other countries with large coal resources, had similar coal shares, whereas the global average share in 2012 was about 34%.

### Russian Federation

In 2012, the Russian Federation alone accounted for a share of 5.1% in global $CO_2$ and this represented half of the emissions from the so-called economies in transition (EIT countries). After the large decrease of 5.6% in emissions in 2009, due to the global recession, the Russian Federation in 2011 recorded an increase of 4.1% in emissions over the last twenty years, going back to the $CO_2$ emissions level of 2006. However, in 2012, $CO_2$ emissions in the Russian Federation decreased by 0.9%.

### Japan

The share of Japan in global $CO_2$ emissions decreased slowly, from 5.2% in the 1990s, to 4.5% in following decade, to 3.8% in 2012. However, economic recovery following the recession of 2009 and the closure of nuclear plants after the Fukushima accident led to the highest increases in $CO_2$ emissions of the past twenty years, with 6.2% in 2012. The increase in 2012 was partly due to a 5.4% increase in the use of coal, with consumption levels back at those of the years 2007 to 2010. Following the nuclear disaster in 2011, renewable energy in Japan is seen as an alternative for the future and could account for about one-fifth of Japan's energy mix by the 2020s. Renewable energy in 2012 accounted for about 10% of the energy supply, most of which from hydroelectric sources. At the end of 2012, Japan's total solar capacity reached 7.4 GW and this is expected to grow further (Guardian, 2013).

### Other OECD and EIT countries

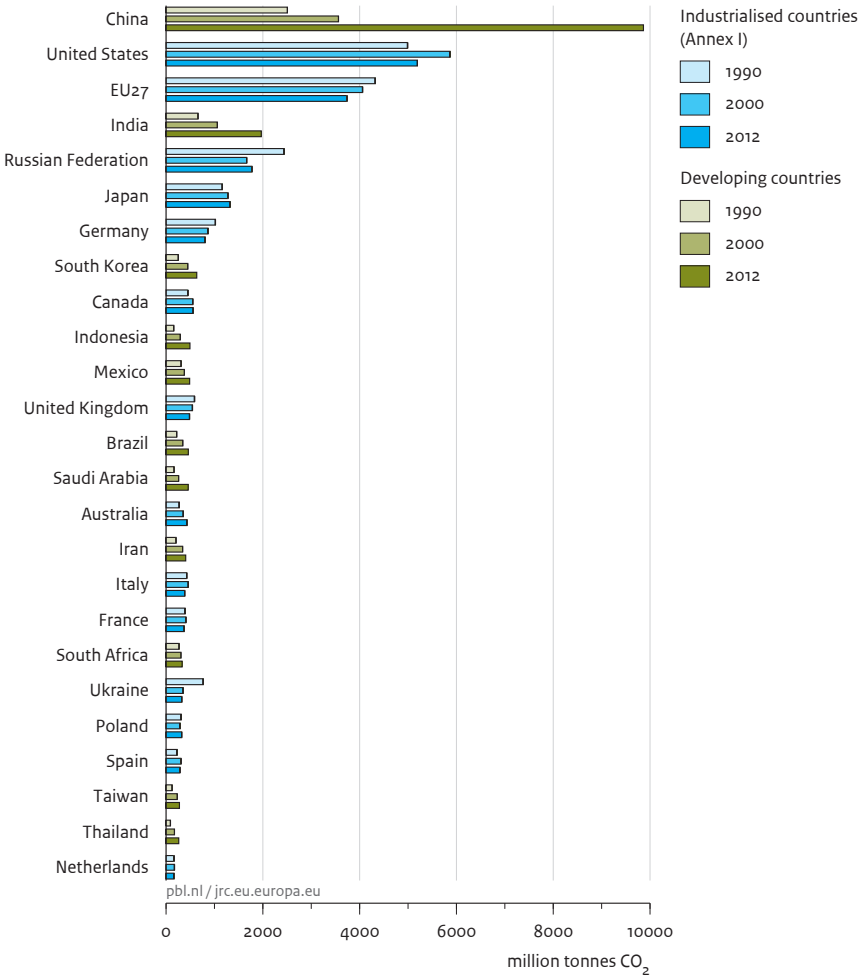
In 'other OECD-1990' countries[4], not included in the group of six largest emitting countries/regions, $CO_2$ emissions decreased by 1% in 2012. Their share in global $CO_2$ emissions was 4.2%, with the largest contributions from Canada, Australia and Turkey. Over the course of 2012, emissions dropped in Canada by 0.3%, in Turkey by 2.0% and in Australia by 2.5%.

The eastern European countries, excluding the Russian Federation and EU's 12 new Member States, recorded an increase of only 1% in 2012, following large increases in $CO_2$ emissions in 2010 and 2011 of about 8% and 6.6%, respectively. This group of countries accounted for a share of 3% in global $CO_2$, with the largest emitting country being the Ukraine (0.9%) with an emission increase of 0.9% in 2012.

### Other developing countries

In 2012, emissions from the category of 'other developing countries'[5] represented more than one fifth of the total in global $CO_2$ emissions, with South Korea having a share of 1.8%, and Indonesia and Mexico 1.4% each. After the economic recovery in most of these countries following the recession of 2009, large increases in $CO_2$ emissions were recorded for 2010. However, in the subsequent years, $CO_2$ emissions increased much less. Total $CO_2$ emissions in these 'other developing countries' increased by 2.9% in 2011 and 2.5% in 2012, down from the large

Figure 2.3
**$CO_2$ emissions per country from fossil-fuel use and cement production**




Source: EDGAR 4.2FT2010 (1990–2010); BP, 2013; NBS China, 2013; USGS, 2013; WSA, 2013; NOAA, 2012

jump of 5.5% in 2010, following the economic recovery in these countries after the global recession of 2009. Of the larger of these countries, $CO_2$ emission levels in South Korea and Indonesia did not change in 2012, compared to 2011, but increases were seen in Saudi Arabia (7%), Mexico (4%) and Brazil and Iran (both 2%).

## 2.3 Comparison between emissions in the various countries

Although emissions in China and other countries with emerging economies increased very rapidly in recent years (Table 2.2 and Figure 2.3), in both relative and absolute figures, the picture is different for $CO_2$ emissions per capita (see Table A1.2 and Figure 2.4) and per unit of GDP (Figure 2.5). Where, since 1990, in the EU27, $CO_2$ emissions decreased from 9.1 to 7.4 tonnes per capita, and in the United States from 19.6 to 16.4 tonnes per capita, they increased in China from 2.1 to 7.1. As such, Chinese citizens, together representing 20% of the world population, on average emitted about the same amount of $CO_2$ per capita in 2012 as the average European citizen.

The EU27 saw a decrease of 1.3% in total $CO_2$ emissions from fossil fuel and cement production between 2011 and 2012, which is a smaller decrease than in the United States (3.7%). China's total $CO_2$ emissions increased by 3.3%, and for India this was even more, with 7.1%. Japan, with 6.5%, showed one of the strongest increases in total $CO_2$ emissions, mainly due to the use of fossil fuel instead of nuclear energy in their power generation.

Table 2.2

**Trends in $CO_2$ emissions per region/country, 1990–2012 (unit: billion tonnes of $CO_2$)**

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| United States | 4.99 | 4.96 | 5.04 | 5.18 | 5.26 | 5.26 | 5.44 | 5.58 | 5.65 | 5.69 |
| EU27 | 4.32 | 4.27 | 4.12 | 4.04 | 4.02 | 4.08 | 4.15 | 4.06 | 4.07 | 4.01 |
| ***EU15*** | 3.33 | 3.36 | 3.29 | 3.22 | 3.23 | 3.27 | 3.34 | 3.28 | 3.32 | 3.29 |
| - France | 0.39 | 0.42 | 0.41 | 0.39 | 0.38 | 0.39 | 0.40 | 0.39 | 0.42 | 0.41 |
| - Germany | 1.02 | 0.99 | 0.94 | 0.93 | 0.92 | 0.92 | 0.94 | 0.91 | 0.90 | 0.87 |
| - Italy | 0.43 | 0.42 | 0.42 | 0.42 | 0.41 | 0.44 | 0.42 | 0.42 | 0.43 | 0.43 |
| - Spain | 0.23 | 0.24 | 0.25 | 0.23 | 0.24 | 0.25 | 0.24 | 0.26 | 0.27 | 0.29 |
| - United Kingdom | 0.59 | 0.60 | 0.58 | 0.56 | 0.56 | 0.56 | 0.57 | 0.55 | 0.55 | 0.54 |
| - Netherlands | 0.16 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.18 | 0.18 | 0.18 | 0.17 |
| ***EU12 (new Member States)*** | 1.00 | 0.91 | 0.83 | 0.81 | 0.79 | 0.81 | 0.80 | 0.78 | 0.75 | 0.71 |
| - Poland | 0.31 | 0.31 | 0.30 | 0.31 | 0.31 | 0.32 | 0.30 | 0.30 | 0.29 | 0.28 |
| Japan | 1.16 | 1.17 | 1.18 | 1.18 | 1.23 | 1.25 | 1.26 | 1.26 | 1.22 | 1.26 |
| Other Annex II | 0.83 | 0.83 | 0.85 | 0.85 | 0.87 | 0.89 | 0.92 | 0.96 | 0.99 | 1.01 |
| - Australia | 0.27 | 0.28 | 0.28 | 0.28 | 0.29 | 0.30 | 0.31 | 0.33 | 0.35 | 0.36 |
| - Canada | 0.45 | 0.44 | 0.45 | 0.45 | 0.47 | 0.48 | 0.49 | 0.51 | 0.52 | 0.53 |
| Russian Federation | 2.44 | 2.30 | 2.08 | 2.00 | 1.76 | 1.75 | 1.72 | 1.59 | 1.57 | 1.62 |
| Other Annex I-EIT* | 1.62 | 1.53 | 1.35 | 1.19 | 1.02 | 0.97 | 0.89 | 0.87 | 0.87 | 0.85 |
| - Ukraine | 0.77 | 0.71 | 0.63 | 0.55 | 0.45 | 0.45 | 0.39 | 0.38 | 0.36 | 0.36 |
| China | 2.51 | 2.65 | 2.78 | 3.02 | 3.19 | 3.52 | 3.62 | 3.59 | 3.65 | 3.57 |
| - cement production in China | 0.09 | 0.11 | 0.13 | 0.16 | 0.18 | 0.20 | 0.21 | 0.21 | 0.22 | 0.24 |
| Other large DC*** | 1.83 | 1.91 | 1.99 | 2.03 | 2.15 | 2.24 | 2.35 | 2.46 | 2.53 | 2.60 |
| - India | 0.66 | 0.70 | 0.74 | 0.76 | 0.81 | 0.87 | 0.92 | 0.96 | 0.97 | 1.03 |
| - Brazil | 0.22 | 0.23 | 0.23 | 0.24 | 0.25 | 0.27 | 0.29 | 0.31 | 0.32 | 0.33 |
| - Mexico | 0.31 | 0.32 | 0.32 | 0.32 | 0.34 | 0.33 | 0.34 | 0.35 | 0.38 | 0.37 |
| - Iran | 0.21 | 0.23 | 0.24 | 0.24 | 0.27 | 0.28 | 0.29 | 0.30 | 0.31 | 0.32 |
| - Saudi Arabia | 0.17 | 0.17 | 0.19 | 0.20 | 0.21 | 0.21 | 0.23 | 0.23 | 0.24 | 0.25 |
| - South Africa | 0.27 | 0.26 | 0.27 | 0.27 | 0.27 | 0.29 | 0.30 | 0.31 | 0.32 | 0.30 |
| Other non-Annex I **** | 2.31 | 2.42 | 2.51 | 2.65 | 2.76 | 2.94 | 3.13 | 3.27 | 3.26 | 3.38 |
| - Asian tigers** | 0.71 | 0.79 | 0.84 | 0.92 | 0.99 | 1.07 | 1.17 | 1.24 | 1.17 | 1.25 |
| - South Korea** | 0.25 | 0.28 | 0.30 | 0.33 | 0.37 | 0.40 | 0.43 | 0.45 | 0.39 | 0.42 |
| - Indonesia** | 0.16 | 0.17 | 0.18 | 0.19 | 0.20 | 0.21 | 0.23 | 0.26 | 0.26 | 0.28 |
| - Taiwan** | 0.13 | 0.14 | 0.14 | 0.16 | 0.16 | 0.17 | 0.18 | 0.19 | 0.21 | 0.22 |
| - Thailand** | 0.09 | 0.10 | 0.11 | 0.13 | 0.14 | 0.16 | 0.18 | 0.18 | 0.17 | 0.17 |
| International transport | 0.66 | 0.66 | 0.69 | 0.68 | 0.69 | 0.72 | 0.73 | 0.76 | 0.77 | 0.82 |
| Total | 22.7 | 22.7 | 22.6 | 22.8 | 22.9 | 23.6 | 24.2 | 24.4 | 24.6 | 24.8 |

** EIT = economies in transition. Including all other countries of the former Soviet Union (excl. the Russian Federation) and including Turkey.*

*** Asian tigers here are: Indonesia, Singapore, Malaysia, Thailand, South Korea and Taiwan.*

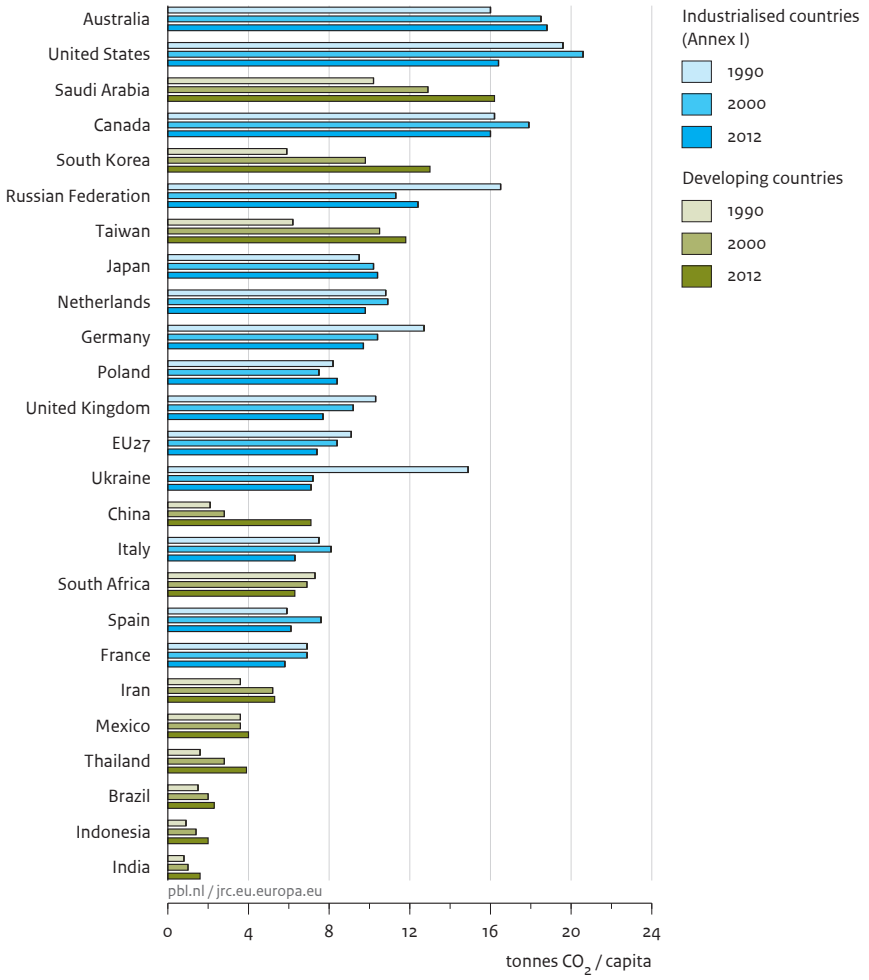
**** DCs = developing countries. Other large developing countries are: Brazil, Mexico, South Africa, Saudi Arabia, India and Iran.*

***** Remaining developing countries.*

OWT

| 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5.87 | 5.75 | 5.83 | 5.87 | 5.94 | 5.94 | 5.84 | 5.91 | 5.74 | 5.32 | 5.50 | 5.39 | 5.19 |
| 4.06 | 4.13 | 4.11 | 4.22 | 4.23 | 4.19 | 4.21 | 4.15 | 4.09 | 3.82 | 3.91 | 3.79 | 3.74 |
| 3.33 | 3.39 | 3.39 | 3.47 | 3.47 | 3.43 | 3.43 | 3.37 | 3.32 | 3.10 | 3.16 | 3.03 | 3.00 |
| 0.41 | 0.42 | 0.41 | 0.42 | 0.41 | 0.41 | 0.40 | 0.39 | 0.40 | 0.38 | 0.39 | 0.37 | 0.37 |
| 0.87 | 0.89 | 0.87 | 0.88 | 0.88 | 0.85 | 0.86 | 0.84 | 0.86 | 0.81 | 0.82 | 0.80 | 0.81 |
| 0.46 | 0.46 | 0.47 | 0.48 | 0.48 | 0.48 | 0.49 | 0.47 | 0.46 | 0.41 | 0.42 | 0.41 | 0.39 |
| 0.31 | 0.31 | 0.33 | 0.33 | 0.35 | 0.36 | 0.35 | 0.37 | 0.33 | 0.30 | 0.28 | 0.29 | 0.29 |
| 0.55 | 0.56 | 0.55 | 0.56 | 0.55 | 0.55 | 0.56 | 0.54 | 0.53 | 0.49 | 0.51 | 0.47 | 0.49 |
| 0.17 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.17 | 0.17 | 0.17 | 0.17 | 0.18 | 0.17 | 0.16 |
| 0.73 | 0.73 | 0.72 | 0.75 | 0.76 | 0.76 | 0.78 | 0.78 | 0.77 | 0.72 | 0.75 | 0.76 | 0.74 |
| 0.29 | 0.28 | 0.28 | 0.29 | 0.31 | 0.31 | 0.32 | 0.32 | 0.32 | 0.31 | 0.33 | 0.33 | 0.32 |
| 1.28 | 1.26 | 1.30 | 1.31 | 1.31 | 1.32 | 1.30 | 1.33 | 1.25 | 1.18 | 1.24 | 1.24 | 1.32 |
| 1.03 | 1.03 | 1.05 | 1.08 | 1.10 | 1.12 | 1.11 | 1.15 | 1.14 | 1.10 | 1.12 | 1.13 | 1.12 |
| 0.36 | 0.36 | 0.37 | 0.38 | 0.40 | 0.41 | 0.42 | 0.42 | 0.44 | 0.43 | 0.43 | 0.44 | 0.43 |
| 0.55 | 0.54 | 0.55 | 0.57 | 0.57 | 0.57 | 0.55 | 0.59 | 0.57 | 0.54 | 0.55 | 0.56 | 0.56 |
| 1.66 | 1.67 | 1.66 | 1.72 | 1.73 | 1.72 | 1.79 | 1.81 | 1.80 | 1.70 | 1.71 | 1.78 | 1.77 |
| 0.85 | 0.86 | 0.89 | 0.93 | 0.93 | 0.89 | 0.92 | 0.97 | 0.99 | 0.90 | 0.97 | 1.03 | 1.04 |
| 0.35 | 0.35 | 0.35 | 0.38 | 0.36 | 0.34 | 0.33 | 0.35 | 0.34 | 0.28 | 0.30 | 0.32 | 0.32 |
| 3.56 | 3.64 | 3.90 | 4.50 | 5.28 | 5.85 | 6.51 | 7.01 | 7.79 | 8.26 | 8.74 | 9.55 | 9.86 |
| 0.24 | 0.27 | 0.29 | 0.34 | 0.38 | 0.42 | 0.48 | 0.53 | 0.54 | 0.64 | 0.73 | 0.85 | 0.89 |
| 2.69 | 2.72 | 2.81 | 2.91 | 3.09 | 3.20 | 3.37 | 3.56 | 3.54 | 3.65 | 3.81 | 3.91 | 4.11 |
| 1.06 | 1.08 | 1.12 | 1.15 | 1.24 | 1.29 | 1.38 | 1.48 | 1.56 | 1.69 | 1.78 | 1.84 | 1.97 |
| 0.35 | 0.35 | 0.35 | 0.34 | 0.36 | 0.37 | 0.37 | 0.39 | 0.41 | 0.38 | 0.44 | 0.45 | 0.46 |
| 0.38 | 0.38 | 0.38 | 0.39 | 0.40 | 0.42 | 0.44 | 0.45 | 0.45 | 0.44 | 0.46 | 0.47 | 0.49 |
| 0.34 | 0.35 | 0.37 | 0.40 | 0.43 | 0.45 | 0.48 | 0.51 | 0.37 | 0.38 | 0.39 | 0.40 | 0.41 |
| 0.26 | 0.27 | 0.28 | 0.30 | 0.31 | 0.32 | 0.34 | 0.36 | 0.38 | 0.41 | 0.43 | 0.43 | 0.46 |
| 0.31 | 0.29 | 0.31 | 0.34 | 0.36 | 0.36 | 0.36 | 0.37 | 0.37 | 0.35 | 0.33 | 0.33 | 0.33 |
| 3.53 | 3.60 | 3.69 | 3.81 | 4.03 | 4.17 | 4.31 | 4.47 | 4.58 | 4.64 | 4.93 | 5.09 | 5.22 |
| 1.31 | 1.36 | 1.41 | 1.46 | 1.53 | 1.57 | 1.61 | 1.65 | 1.68 | 1.67 | 1.80 | 1.89 | 1.91 |
| 0.45 | 0.46 | 0.48 | 0.49 | 0.51 | 0.50 | 0.51 | 0.52 | 0.54 | 0.55 | 0.59 | 0.63 | 0.64 |
| 0.29 | 0.32 | 0.32 | 0.33 | 0.35 | 0.36 | 0.38 | 0.40 | 0.41 | 0.42 | 0.45 | 0.49 | 0.49 |
| 0.23 | 0.24 | 0.25 | 0.25 | 0.26 | 0.27 | 0.28 | 0.28 | 0.27 | 0.25 | 0.27 | 0.28 | 0.28 |
| 0.17 | 0.18 | 0.19 | 0.20 | 0.22 | 0.23 | 0.23 | 0.22 | 0.23 | 0.22 | 0.24 | 0.25 | 0.26 |
| 0.83 | 0.80 | 0.84 | 0.85 | 0.93 | 0.95 | 1.00 | 1.05 | 1.04 | 1.00 | 1.07 | 1.07 | 1.06 |
| 25.4 | 25.4 | 26.1 | 27.2 | 28.5 | 29.3 | 30.3 | 31.4 | 32.0 | 31.6 | 33.0 | 34.0 | 34.5 |

Figure 2.4
**$CO_2$ emissions per capita from fossil-fuel use and cement production**



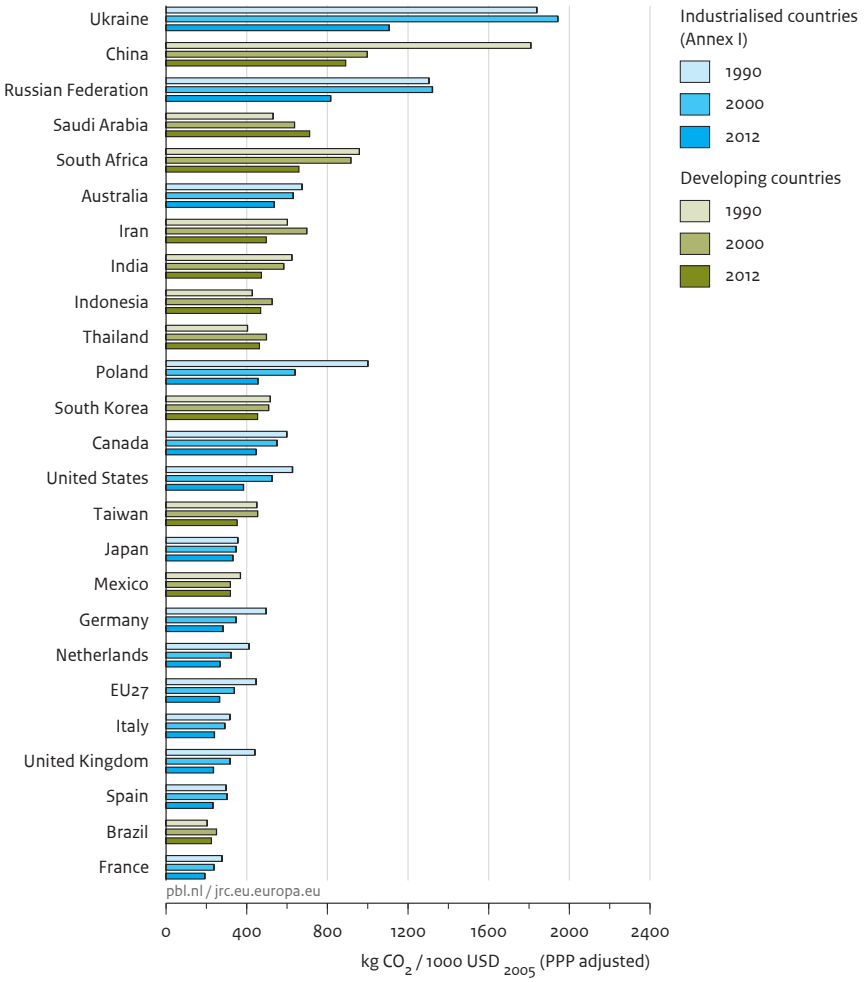

Source: EDGAR 4.2FT2010 (1990–2010); UNDP, 2013 (WPP Rev. 2012); BP, 2013; NBS China, 2013; USGS, 2013; WSA, 2013; NOAA, 2012

The trends in $CO_2$ emissions per capita in the top 6 emitting countries are shown in Figure 2.6a. 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 in the Russian Federation in the early 1990s and in the United States in 2008, 2009 and 2011, and in Europe in 2009 (for the whole of the EU27) and 2011 and 2012 (mainly in some EU15 countries). Factors that also contributed to the emission decrease in the United States between 2007 and 2012, were high oil prices with a relatively large impact on retail prices due to low fuel taxes and an increased share of 3% natural gas in total national fossil-fuel consumption (EIA, 2012a,b). The EU saw a smaller decrease in emissions during the recession years, among other things, because of high fuel taxes, which dampened the impact of strong international variations in oil prices on retail prices.

The two dashed lines in Figure 2.6a represent the range of $CO_2$ emissions per capita (minimum and maximum) for the major industrialised countries (the Annex I countries listed in Figure 2.2), the lowest levels of $CO_2$ per capita being those in France (5.8 tonnes $CO_2$/cap because of the amount of nuclear power used in that country) and the highest levels were seen in Australia (18.8 tonnes $CO_2$/cap because of natural resource depletion). The per-capita $CO_2$ emissions in the United States decreased in 2012 down to 16.4 tonnes $CO_2$/cap, and in Kazakhstan emissions increased with precisely that amount, due to its intensive mining. When comparing $CO_2$ trends between countries over a decade or more, trends in population numbers also should be taken into account, as

Figure 2.5

**$CO_2$ emissions per unit of GDP from fossil-fuel use and cement production**



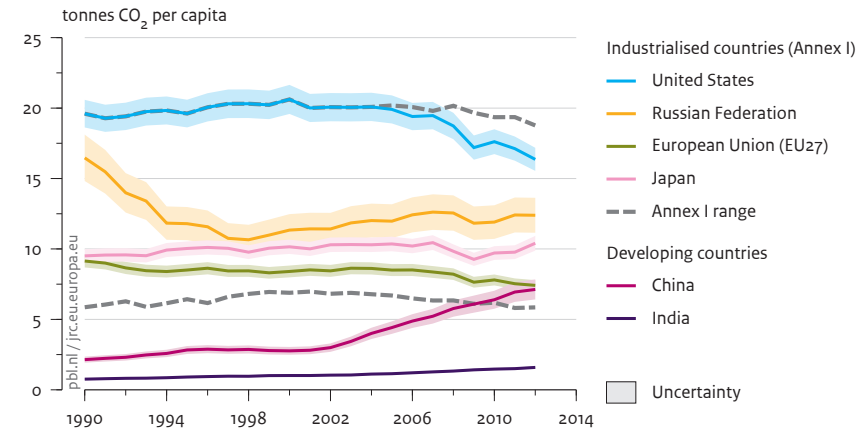

Source: EDGAR 4.2FT2010 (1990–2010); World Bank, 2013; IMF, 2013; BP, 2013;NBS China, 2013; USGS, 2013; WSA, 2013; NOAA, 2012

population growth differs considerably, also between Annex I countries, with the highest growth rate since 1990 seen in Australia (+32% between 1990 and 2011) and in the United States and Canada (both +24%). The populations of the EU and Japan, however, increased much less (by 7% and 3%, respectively), and the Russian Federation even saw a decline of 4% (see Table A1.2).

Over the past decade, all countries experienced a declining trend for $CO_2$ in terms of GDP[6], but the ranking order of countries more or less remains the same: with a lower emission level in the European Union; Japan emitting less $CO_2$ per invested USD in GDP than all the other countries of the world[7]; 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. In 2012, the emission intensity of the EU was about three quarters that of the United States and about one third that of China. The higher levels for the Russian Federation and China indicated either 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 also applied to the Ukraine, which is depicted in Figure 2.6b by the upper dashed line.

Figure 2.6a

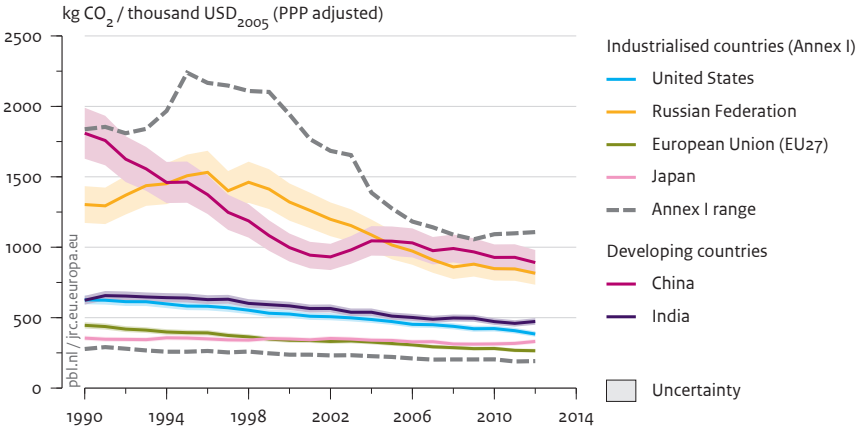
**$CO_2$ emissions per capita from fossil-fuel use and cement production in the top 6 emitting countries and the EU**




Source: EDGAR 4.2FT2010 (1990–2010); UNDP (WPP, Rev. 2013), 2013

Figure 2.6b

**$CO_2$ emissions per unit of GDP from fossil-fuel use and cement production in the top 6 emitting countries and the EU**




Source: EDGAR 4.2FT2010 (1990–2010); World Bank, 2013; IMF, 2013

## 2.4 Gas flaring emissions

When natural gas is co-produced during conventional or unconventional oil production and cannot be marketed, this 'associated' 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 the emissions of greenhouse gases: methane from venting and $CO_2$ from flaring.

The global $CO_2$ emissions of about 250 million tonnes from 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 2011, after a steady decrease by about a quarter since 2003. These estimates on natural gas flaring were derived from DMSP-OLS and MODIS satellite measurements, analysed by the US National Oceanic and Atmospheric Administration (NOAA) and supported by the Global Gas Flaring Reduction Partnership (GGFR), a public-private partnership which is led by the World Bank. The night-time lights from gas flares observed by the satellites provide an estimate of the amounts of gas flared, when related to reported flaring volumes available from the GGFR Partnership (Elvidge et al., 2009a). Countries with the largest satellite observed flaring emissions are the Russian Federation and Nigeria, with shares of global flaring emissions of

about one quarter and one tenth, respectively. These two countries contributed also most to the global emission decrease over the last decade, followed by Iran, Iraq and the United States (NOAA, 2012, pers. comm.; World Bank, 2012).

However, in 2012 NOAA has changed to a new sensor, for which cloud corrections and calibration to the flared gas volume needs to be done. Earlier, satellite information shows that flaring emissions in the United States are on the rise, with a steep increase of 50% in 2011, making the country the fifth largest gas flaring country. 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, EIA, 2012j), in particular, in North Dakota and Texas. We tentatively assumed that gas flaring in the United States increased in 2012 by 35%, which is less than the increase in crude oil production in North Dakota in 2012, to account for the expansion of gas processing capacity and gas gathering infrastructure that reduces flaring. Due to lack of information, we assumed that in other countries the flaring level did not change in 2012 over 2011. Recently, the governments of these countries announced policy measures aimed at reducing $CO_2$ emissions from gas flaring. The US Environmental Protection Agency announced that drillers that use fracking to extract natural gas and oil, from January 2015 onwards, will be required to use equipment to capture the emissions, a process known as 'green completion' (US EPA, 2012a). Until that time, they may burn off or flare the gas (Reuters, 2012a).

The Russian Ministry for Natural Resources and Ecology has announced that oil companies, on average, utilise 76% of the associated gas they produce. A target of 95% utilization of produced gas was set in 2012, and companies will be fined if they flare more than 5%. The ministry expects that the 95% target will be met by 2014-2015 (Reuters, 2012b; Moscow Times, 2012). Gazprom increased the utilization efficiency of associated gas production from 59% in 2010 to 70% in 2012 (Gazprom, 2013).

In Nigeria, the Associated Gas Re-injection Act 1979 (AGRA) required the oil companies to cease gas flaring by 1 January 1984. However, this cease date has been moved several times (2005) and also some of the oil companies are allowed to continue to flare the gas under special conditions and paying a nominal fine. Furthermore, the Petroleum Industry Bill (PIB) set the cease date to 2013 (PLC, 2013). The revised PIB that is expected to be put before Parliament at the end of 2013 includes more severe exception rules. Even if the regulatory authority considers that gas flaring has reduced considerably, about 50% of the total gas produced in Nigeria is still flared and the lack of funds to invest in additional gas gathering facilities is seen by the oil companies as a future challenge (Nigerian Tribune, 2013).

According to the official reporting by industrialised countries to the UN Climate Convention, the fraction of methane in total greenhouse gas emissions from venting and flaring varies largely between countries; for example, in the Russian Federation and the EU as a whole this is about a quarter, in Canada it is about half, and in the Ukraine this is about 90% (UNFCCC, 2013).

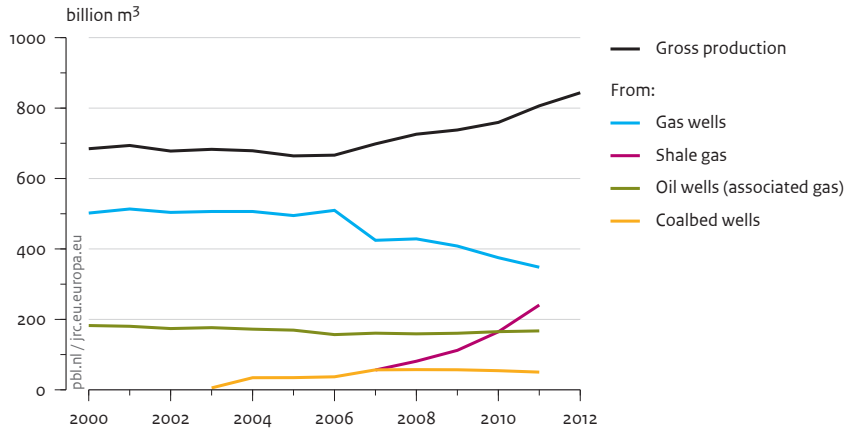
## 2.5 Shale gas and oil production through hydraulic fracturing and oil sands exploitation

A survey by the EIA (2013f) estimates that, globally, 32% of the total estimated technically recoverable natural gas resources (proven and unproven reserves) are located within shale formations and 10% of estimated global crude oil resources are in shale formations or tight gas reservoirs. Economic recoverability depends on the costs of drilling and well completion, the size and quality of the oil or natural gas well. Recent experience with shale gas suggests that economic recoverability is significantly influenced by location and geology. The variation across the world's shale formations makes it difficult to estimate the extent to which these shale resources will prove to be economically recoverable. According to EIA (2013f) most of the 220 trillion $m^3$ technically recoverable shale gas has been found in the United States (33 trillion $m^3$), China (32) , Argentina (23), Algeria (20), Canada (16), Mexico (15) and the EU (13), and most of the 335 billion barrels (bbl) of technically recoverable shale oil is found in the Russian Federation (75 billion bbl), the United States (48), China (32), Argentina (27), Libya (26) and the EU (14). The United States and Canada already produce shale gas and shale oil on an industrial scale. Exploration activities in shale formations have also begun in a number of other countries, including Algeria, Argentina, Australia, China, India, Mexico, Poland, Romania, the Russian Federation, Saudi Arabia, Turkey, the Ukraine and the United Kingdom. However, there is considerable uncertainty about all estimates, as is illustrated by the large downward adjustments for some oil and gas basins after two years of exploitation (EIA, 2013f).

### United States

Already in the 1820s, natural gas was extracted, on a small scale, from shale formations in New York State. It then took until the 1970s for a breakthrough, initiated by

Figure 2.7
**Gross natural gas production in the United States**




Source: EIA, 2013

the engineers of Energy Research & Development Administration (later the US Department of Energy) who on the basis of a directional drilling demonstrated the commercial potential of massive hydraulic fracturing; in particular, with multifracture horizontal wells. Public-private partnerships helped to push hydraulic fracturing for shale gas into full commercial competitiveness, and in 1991 the first commercial shale gas extraction was achieved (Trembath et al., 2012). Also, a petrochemical industry with experience in other types of unconventional gas production (i.e. tight gas and coalbed methane) and favourable regulation furthered this development (Wang and Krupnick, 2013).

In recent years, the United States expanded its production of shale gas by fracking to such a degree that in 2011 they became the largest gas producer in the world. Figure 2.7 shows that, in 2006, shale gas production began to contribute to total gas production and to compensate the decline in production of other gas wells. By 2011, shale gas had a share of about one third in total US gross gas production. A similar trend was seen for shale oil (tight oil) production, which share was only 1% in 2007 but increased to 11% in 2011 and to 23% in 2012, reversing the slow decrease over time in 2008 into an increase in total production with the 2012 production level being highest since 1995 (EIA, 2013a,b).

In 2012, the US EPA announced that drillers that use fracking to extract natural gas and oil, from January 2015 onwards, will be required to use equipment to capture the emissions, a process known as 'green completion'. Until that time, they may burn off or flare the gas (US EPA, 2012a).

In 2013, in its 2013 report for the UN Climate Convention, the US EPA revised its official reported methane emissions for 2010 from both conventional and unconventional production in the oil and gas sector downward by 29% or 75 million tonnes of $CO_2$ eq (US EPA, 2013). This decrease in methane emissions corresponds to about 1% of total national greenhouse gas emissions of the United States. The size of this revision is an illustration of the uncertainty in emission estimates for this sector. The largest change in emissions was presented in an update related to the methodology for gas well deliquification(removal of water or condensates that have accumulated at the bottom of producing gas wells) for 2010: 85.6 million tonnes $CO_2$ eq in the previous inventory versus 5.4 million tonnes $CO_2$ eq in the current inventory. Data from a survey on gas well deliquification from over 50,000 wells showed that wells with and without hydraulic fracturing use such gas well deliquification, and control technologies are more commonly used than was assumed previously. In addition, methodological changes made to well completions with hydraulic fracturing and workovers with hydraulic fracturing (i.e. refracturing) resulted in a four-fold increase in estimated methane emissions, to 16.7 million tonnes $CO_2$ eq versus 3.8 million tonnes in the previous inventory. Emissions from wells with hydraulic fracturing were recalculated with updated activity data for completed wells with hydraulic fracturing, with a revised refracturing rate, and with a revised estimate of state regulatory reductions (US EPA, 2012b).

## Canada

Commercial production of oil from the Athabasca *oil sands* in the Canadian province of Alberta began in 1967, with the first surface mine producing 4,800 $m^3$ per day in

synthetic crude oil. Presently, Canada is the largest supplier of oil that is imported by the United States, supplying nearly 150,000 $m^3$ per day from oil sand sources (Swart and Weaver, 2012). The amount of oil contained in Alberta's oil sands is about the same as in Canada's conventional proven oil reserves (BP, 2013). Canada's total crude oil production has increased by about 30% since 2002, which is completely due to oil sands products (crude bitumen and synthetic crude oil), while conventional oil production has decreased by 13%. In 2011, the ten-year decline in conventional crude oil production (i.e. non-oil sands) was reversed due to the increased use of hydraulic fracturing.

Over time, the energy intensity of conventional oil production has increased due to a shift towards the production of more difficult to obtain oils, such as heavy oil, and oil extraction using enhanced oil recovery (EOR) techniques.

Analysis showed that the greenhouse gas emission intensity of the production of bitumen and synthetic crude oil from oil sands (mining, in-situ bitumen recovery, upgrading) is about three times that of conventional light oil production, but similar to that of conventional heavy oil production. To put these high energy-intensity activities into perspective: the increase of 40 million tonnes of $CO_2$ eq from expanding oil sands production since 1990 is similar to the increase in total transport emissions in Canada since 1990. However, the main source of greenhouse gas emissions from oil sands operations is $CO_2$ from fuel combustion, whereas the main source in heavy oil production it is from gas venting. The construction of the TransCanada 'Keystone XL' pipeline would likely encourage further expansion of oil sands production as this would increase the capacity to export Canadian oil to the United States.

Technological improvements caused the greenhouse gas emissions intensity of oil sands production to decrease by about 25%, since 1990, whereas that of heavy oil increased by 25%. Moreover, increasingly often, bitumen instead of synthetic crude oil is shipped to the United States, thereby increasing the amount of emissions occurring outside the country that are associated with upgrading and refining (Environment Canada, 2013).

In Canada, the share of unconventional gas production in 2011 was about 40% of total gas production, twice as high as in 2002: 6% from shale gas, 32% tight gas and a few per cent coalbed methane. Despite this increase, total gas production decreased by 16% from 2002 to 2011 (Environment Canada, 2013).

### Europe

In Europe, some exploratory drilling using hydraulic fracturing has taken place in Sweden, Poland, France, Germany and the United Kingdom. According to Philippe & Partners (2011), the Swedish Mining Inspectorate has granted one exploitation concession, but so far without any exploitation activities. In France, exploration authorisation for hydraulic fracturing was abrogated twice, on the basis of the Prohibition Act, due to concerns over the environmental impact of shale gas activities. Hydraulic fracturing is currently taking place in Poland and has been tested at one location in Germany. In Sweden, the existing Minerals Act is under review, in terms of transparency and the participatory process of authorising shale gas projects. Poland, highly dependent on the Russian Federation for its oil and gas resources, has granted most permit requests, and has the most developed exploration activities on its territory, but the geology appears to be more difficult than anticipated.

Developments and the potential of unconventional gas (shale gas, tight gas and coal-bed methane) in Europe have been assessed by Pearson et al. (2012). They conclude that there are many and substantial uncertainties in estimating the recoverable amount of shale gas on regional and global levels. For example, for the United States, the uncertainty range around the best estimate is between +130% and -36%. A significant source of uncertainty is the fraction of shale gas in place that is assumed to be recoverable, which varies substantially (15% to 45%) for shale gas. However, in a special report on unconventional gas, the IEA also refers to the high population density in many of the prospective areas, and to the state ownership of oil and gas rights; things that are likely to impede a rapid growth in shale gas production (IEA, 2012d).

For Europe, the impact from decreasing natural gas prices is also seen in the fast increase in the global trade in liquid natural gas (LNG). The EU's liquefaction and regasification capacity is expected to double by 2020 (Pearson et al., 2012).

### China

For China, which wants to boost natural gas consumption from 4% to 8% of the energy mix by 2015 and 10% by 2020, much of the gas will be imported. However, the government also wants to increase shale gas production to 60 billion $m^3$ by 2020. By comparison, the United States produced about 150 billion $m^3$ shale gas in 2010. Some have doubts about whether China will be able to increase its gas production so quickly, as it has taken the United States a number of decades to produce significant amounts of gas. In addition, China's geology is different from that of the United States, with shale formations

lying deeper and containing more clay, making them less suitable to be fractured. It is expected that shale gas would first be used as feedstock for chemicals and fertiliser production, thereby reducing the demand for gasified coal (Tollefson, 2013).

### Environmental concerns related to fracking

In recent years, considerable concern has been expressed over the environmental impact of hydraulic fracking, in general (direct local impacts, such as aerial footprint, air pollution, noise, night lights, traffic, earthquakes, local water depletion, waste water, possible groundwater contamination by additives in the fracturing fluids and substances in waste water), and also regarding the impact of greenhouse gas emissions related to shale gas production, compared with those from conventional natural gas production. In the United States there are concerns regarding air pollution, about meeting ambient air quality standards with increases in ozone levels in general, and particularly in remote areas in the wintertime. Stevens (2012) and AEA (2012b) mention that concerns about fracking operations and subsequent shale oil and gas production are generally based on past experience with fracking operations in the United States, which have developed very rapidly and have sometimes involved improper practices that pose health and environmental risks. AEA (2012b) reviewed the current EU environmental legislation relevant to shale gas exploration and production, but did not analyse individual Member State legislation and standards. However, Stevens (2012) concludes that many environmental problems in the United States have come from poor well completion and limited environmental regulation – not by the fracking and production technologies themselves – and that large differences exist between environmental regulations related to fracking and shale oil and gas production in the United States and in the European Union.

The concern over the impact from fracking and shale gas and oil production on greenhouse gas emissions refers to the higher energy intensity of the fracking and production process and to the possibly larger amounts of methane emissions, the second most important greenhouse gas. Methane has a global warming impact ('GWP') that is, per kilogram, more than 20 times larger than $CO_2$, or additional emissions of $CO_2$ from flaring, when gas is produced that cannot be economically utilised due to a lack of infrastructure or local demand, as was the case in parts of the United States (see Section 2.4). The high energy intensity is mainly due to the large amounts of water and other materials (sand and chemicals) that are transported to and from the sites, to the high pressure required for the fracturing process, and the infrastructure used for transporting the gas and oil produced at the many locations (Wood et al., 2011; AEA, 2012a).

Although natural gas emits less $CO_2$ per unit of energy than coal and oil when combusted, there are concerns from life-cycle analyses that methane emissions from fracking could largely offset this benefit if escaping gas is not captured but flared or used, in particular during the well completion stage (Howarth et al., 2011; Hultman et al., 2011; Jiang et al., 2011; Tollefson, 2012). However, other studies criticise these conclusions (e.g. Cathles et al., 2012). The uncertainties in these assessments are large, as all recent methane emission estimates for unconventional gas production are based on sparse and poorly documented data (Howarth et al., 2011, 2012), with the exception of the emission rate reported by Petron et al. (2012), which is based on measured fluxes at one site during the course of a year. However, results from the NOAA study by Petron et al. (2012) cannot easily be extrapolated to other sites, as geological circumstances and actual operating practices may be very different from those at study's measurement location (Sgamma, 2012; O'Sullivan and Paltsev (2012). New regulation that US EPA has announced, as mentioned above, requires that the natural gas that currently escapes to the air is captured and either used or sold (US EPA, 2012a). The regulation also applies to methane emissions that are currently vented as a result of shale gas fracking.

O'Sullivan and Paltsev (2012) refer to the recent US EPA's upward revisions of their greenhouse gas emissions from natural gas systems, and conclude that methane emissions associated with the flowback in the drilling phase are proportional to the duration and rate of gas produced during that stage. Potential fugitive methane emissions as a percentage of total gas production over the lifetime of the well is 0.4% to 0.5%, except for the well at Haynesville with 0.8% to 1.0%, with the lower percentage being based on a 30-year lifetime of the well and the higher on a 15-year lifetime. O'Sullivan and Paltsev also conclude that most previous estimates assume that all gas will be vented, while data shows that, in actual practice, only about a quarter is vented and the remainder is flared or captured and sold. They assume that, on average, 70% of fugitive emissions will be captured, 15% vented and 15% flared.

Referring to US EPA (2013), more accurate and complete emission estimates are now reported for the United States, leading to lower total greenhouse gas emission estimates for the oil and gas sector. 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, remains highly uncertain. This has been

reaffirmed by a recent measurement study by Allen et al. (2013).

Life-cycle greenhouse gas emissions from shale gas production and use also depend on the methane emissions from the gas transport and distribution system, for which, in the United States, the estimates also vary by a factor of two or more (Howarth et al., 2012). Gas transport and distribution emissions could be equally or more important than pre-production- and production-related emissions; in particular, in the case of long pipelines (e.g. when transporting Russian gas to Europe). A life-cycle analysis made by AEA (2012a) for shale gas produced in Europe showed total greenhouse gas emissions to be about 4% to 8% higher than conventional pipeline gas from within Europe, with most additional emissions from well completion, when the fracturing fluid is brought back to the surface together with released methane. If emissions from well completion are mitigated through flaring or capture, then this difference is about 1% to 5%, which is broadly in line with results from US studies that found life-cycle emissions from shale gas to be about 2% to 3% higher than conventional pipeline gas, and with results from Wood et al. (2011). In a comparison with emissions from electricity generated by using conventional pipeline gas imported from outside Europe (the Russian Federation and Algeria), life-cycle greenhouse gas emissions from shale gas were found to be 2% to 10%. In comparison with coal, life-cycle emissions from shale gas used in electricity generation are significantly lower (about 40% to 50%, including differences in power generation efficiency) than emissions from using coal (using a GWP value for methane of 25) (AEA, 2012a). Even when the significant uncertainties involved in this analysis are taken into account, from these numbers may be concluded that, if venting and flaring is limited and with best operational practice in well completion and during production, the greenhouse gas emissions from shale gas production and use are comparable with those from imported conventional gas and substantially lower than life-cycle emissions from coal.

The IEA states that vast resources of shale gas could be produced if this would be done in a socially and environmentally acceptable manner (IEA, 2012d). However, several social and environmental concerns associated with its extraction need to be overcome, as shale gas production is an intensive industrial process, generally imposing a larger environmental footprint than conventional gas development, and may have major implications for local communities, land use and water resources. The IEA concludes that the technologies and know-how exist for unconventional gas to be produced in a way that satisfactorily meets these challenges, but that 'a continuous drive from governments and industry to improve performance is required if public confidence is to be maintained or earned'.

## 2.6 Industrial non-combustion sources

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. $CO_2$ 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 about 4.5% to total global emissions. Fuel combustion emissions of $CO_2$ related to cement production are of approximately the same level, so, in total, cement production accounts for roughly 9% 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).

### Cement production

The world's cement production remains heavily dominated by China, with an estimated share of 58.5% in global emissions from cement production, followed by India with a more than 6.6% share. The cement producers next in row have shares between 1.5% and 2% and are: the United States, Turkey, the Russian Federation, Brazil, Iran and Vietnam. With a continuing trend in China, global cement production increased by 5% in 2012. China increased cement production by 5% and was responsible for 59% of the world's cement produced in 2012 (NBSC, 2012). According to preliminary estimates by USGS (2013), cement production increased in 2012 in most countries among which Vietnam, Brazil, the United States, the Russian Federation and Iran by 7% to 10% and decreased in Saudi Arabia, Spain and Thailand by 10% and in Turkey and Italy by several per cent. 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 World Business Council on Sustainable Development (WBCSD, 2009) has shown that the share of blended cement that has been produced in recent years in most countries has considerably increased relative to that of traditional Portland cement. Consequently, average clinker fractions in global cement production have decreased to between 70% 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 in the 1980s. At that time, it was not common practice to blend cement clinker with much other mixing material, such as fly ash from coal-fired power plants or blast furnace slag. According to EDGAR 4.2 data, this yielded an annual decrease of 250 million tonnes in $CO_2$ emissions, compared to the reference case of Portland cement production. Moreover, a similar amount has been reduced in fuel combustion for cement production and related $CO_2$ emissions.

### Iron and steel production

When looking at steel production, with related non-combustion $CO_2$ emissions from blast furnaces used to produce pig iron and from conversion losses in coke manufacturing, China accounted for 46% of crude steel production in 2012, followed by Japan (7%), the United States (6%), India (5%), the Russian Federation and South Korea (each 5%). According to WSA (2013), global crude steel production rose 2.2% in 2012, compared to 5.6% in 2011. The 3.7% increase in China accounted for three quarters of the global increase in production in 2012. Production plummeted in Spain (-13%), Ukraine (-7%), Italy (-5%) and Germany (-4%) and production strongly increased in Australia and Austria (each +76%), Iran (+11%) and South Africa (+7%) and India (+6%).

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 (WSA, 2013). Lime and ammonia production are other industrial sources of $CO_2$ emissions. In 2012, lime production increased globally by 6% and ammonia decreased by 10% (USGS, 2013).

## 2.7 Climate change mitigation in the 21st century

In 1990, the industrialised countries, with a total greenhouse gas mitigation target under the Kyoto protocol (including the United States, which did not ratify the protocol, and Canada that withdrew in 2012), had a share in global $CO_2$ emissions of 63% versus 34% for developing countries. In 2012, the shares were almost reversed: 39% for mature industrialised countries and 58% for developing countries. The remaining 3% is attributed to international air and sea transport.

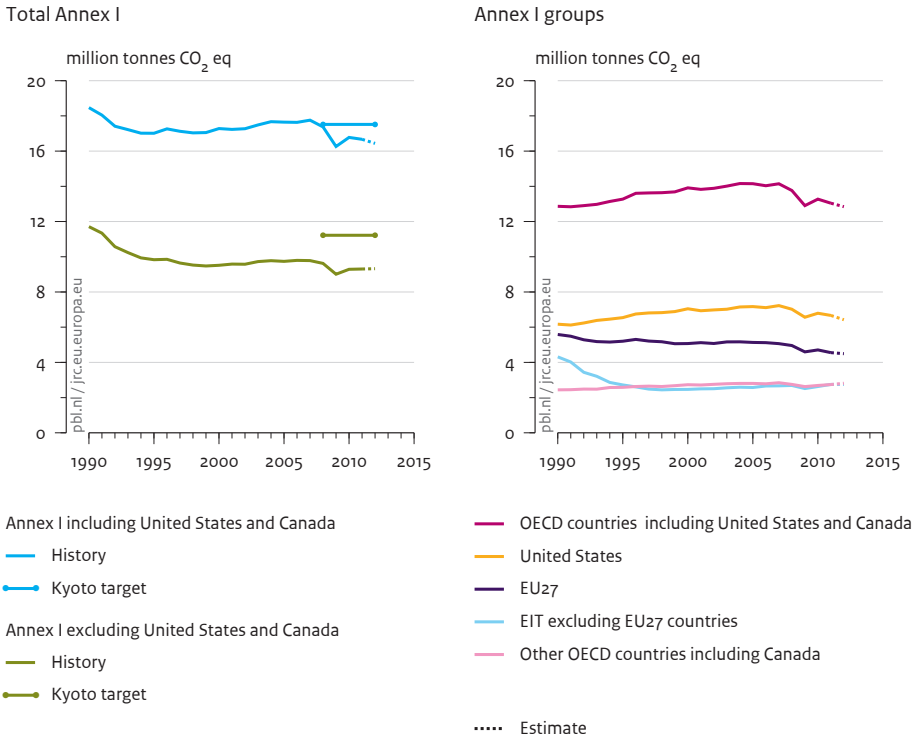
In April 2013, the industrialised countries of Annex I to the UN Climate Convention published their updated national greenhouse gas emission inventories up to and including 2011, which were officially submitted to the UN Climate Secretariat (UNFCCC, 2013). We summarised the trend in historical greenhouse gas emissions for the 1990–2011 period for the group of countries with an emission target under the Kyoto Protocol, for the average over the years from 2008 to 2012 (Figure 2.8). These countries are called Annex B countries in the protocol (these are essentially the Annex I countries of the Climate Convention, but excluding Belarus and Turkey). Trends including those in the United States and Canada (who have not committed to an emissions target) are also presented to show the achievements of the Annex B countries, with targets as intended by the protocol over the last two decades. We also included our estimates of 2012 greenhouse gas emissions, which are based on the trend estimates for $CO_2$ presented in this study, to provide a comparison of total Annex B emissions against the actual Kyoto reduction target for the average of the years from 2008 to 2012. This is a fair assumption since non-$CO_2$ greenhouse gases accounted for only about 25% of total greenhouse gas emissions from the industrialised countries, although the trend in these emissions is somewhat lower than for $CO_2$. Note that neither net 'sinks' (carbon storage in forests and soils) or emissions from Land Use Land Use Change and Forestry (so-called LULUCF) nor possible (but usually limited) corrections in response to the 2013 expert reviews of these national emissions inventories are included here.

### Industrialised countries meet collective Kyoto target of -4.2%

Collectively the group of industrialised countries presently committed to a Kyoto target, i.e. all Annex B countries excluding the United States and Canada, have a target of reducing their greenhouse gas emissions by 4.2 % on average for the period 2008-2012 relative to the base year, which in most cases is 1990 but 1995 for the F-gases. The collective target is met even without accounting for emission credits purchased from certified emission reduction projects under the UN's Clean Development Mechanism (CDM). With an estimated average emission reduction of 20.5% over the 2008–2012 period, excluding the United States and Canada (and by 9.5% if including them), industrialised countries are certain to achieve their targets quite comfortably (Figure 2.8). The United States and Canada are treated differently from other Annex B countries, because the United States never ratified the protocol and Canada withdrew from it in 2012. The EU15, with an 8% reduction target, reduced

Figure 2.8

**Greenhouse gas emissions in Kyoto Protocol countries and their targets (excl. LULUCF)**




Source: 1990–2011: UNFCCC (2013); 2011–2012: PBL/JRC, 2013

its greenhouse gas emissions by 12% (for EU27 the total reduction was about 16% with the same 8% reduction target). The Russian Federation and the Ukraine, with 0% reduction targets, saw their emissions decrease by one-third and more than half, respectively. In contrast, Australia and New Zealand saw their emissions increase by 23%, although their respective targets were 8% and 0% increase, and Japan's emissions increased since 2009 to a five-year average of 2% above its base year level, whereas its reduction target is 6%.

Although some individual countries will not achieve their national targets without emission trading, the group as a whole is certain to comply, with trading, with its collective target quite comfortably. Their collective target will be met even without accounting for emission credits purchased from certified emission reduction projects under the UN's Clean Development Mechanism (CDM). These projects aim to generate emission reductions in developing countries and fast growing economies and by purchasing the credits that fund the projects, the resulting emission reduction may be counted towards the purchaser's nation's national Kyoto target. Emission reductions by Annex B counties, excluding the United States and Canada, were largely due to the 40% reduction in emissions between 1990 and 1999 in the Economies In Transition (EIT) (Russian Federation, Ukraine and other eastern European countries). The remaining Annex B counties (OECD countries, including the EU15) experienced a limited increase in emissions between 1990 and 2006, followed by stabilisation and a more marked decrease from 2007 onwards. The recession of 2008-2009, together with high fuel prices in 2008, drove 2008 and 2009 emission levels down by several per cent. In the EIT countries, greenhouse gas emissions started to increase again after 2001 (at an average group rate of about 1% per year) due to their economic recovery, while the Kyoto target of the largest EIT countries is +1% and for the smaller EIT countries -8%. The large emission reductions by the EIT countries that are currently EU Member States, aids the present EU27 in more than achieving its collective Kyoto target.

Australia, New Zealand and Spain do not meet their national target without emissions trading and need to purchase emission credits from other countries. These may be either CDM credits from developing countries or credits from other industrialised countries that have a large surplus compared to their target (Den Elzen et al., 2011). However, for Spain, the EU Emissions Trading System applies, which is described in the next subsection.

Greenhouse gas emissions by the United States, which did not ratify the Kyoto Protocol, have increased by 8.5% since 1990. In part this is due population growth of almost 25% between 1990 and 2012, much higher than other industrialised countries except for Australia and Canada. With emissions slowly increasing until they peaked in 2005, and decreasing in 2008-2012 to a level that was about 8.5% higher than in 1990, the United States will not meet the intended reduction target of 6% included in the protocol.

If the United States had joined the other industrialised countries in ratifying the Kyoto protocol and accepting their 6% target, and Canada would not have withdrawn, the average percentage reduction in greenhouse gas emissions for the group total would have been 5.2% as intended by all Parties when they adopted the protocol in 1997, including the targets (Figure 2.8).

Thus the group of Annex I countries that have ratified the protocol, and have a collective mitigation target under the Kyoto Protocol of -4.2%, are on course to achieve a 20% reduction relative to the base year. Including the United States and Canada, the Annex B countries are still expected to achieve an almost 10% reduction which is also lower than the intended group target of 5.2%. These figures exclude expected purchased emissions credits.

## Emission Trading Systems

Carbon pricing mechanisms are important policy instruments for mitigating greenhouse gas emissions that are increasingly implemented in countries or subnational regions because of their flexibility and cost-effectiveness. Two main types can be distinguished: ( a) emission trading schemes (ETS) ('cap and trade') for large businesses and (b) a carbon tax on the purchase of fossil fuels (coal, oil, gas). Countries with carbon pricing mechanisms emit roughly 20% of total global greenhouse gas emissions. If China, Brazil, South Korea, Chile, and the other emerging economies considering these mechanisms would be included, the countries with carbon pricing mechanisms would emit almost half of the total global emissions. This shows the potential importance of these policy instruments for a global mitigation of climate change (World Bank, 2013b). For this reason, we summarised the present status of emission trading systems in the world and, in particular, the development of the ETS of the EU, which is the world's first and biggest international cap-and-trade system for greenhouse gas emission allowances.

The European Union was the world's pioneer by launching their Emissions Trading System (ETS) in 2005, to reduce $CO_2$ emissions in a cost-effective and economically efficient way. Several others followed: in 2007 initiatives for an ETS were taken in seven US States, four Canadian provinces, in Australia and, one year later, also in New Zealand. In addition, carbon taxes exist in Australia (fixed price scheme), British Columbia, Denmark, Finland, Ireland, Japan, Norway, Sweden and Switzerland. Plans to introduce a carbon tax exist in the United Kingdom (in 2013) and in South Africa (in 2015) (World Bank, 2013b). The European Commission is also founding member of the *International Carbon Action Partnership*, which brings together countries and regions that are actively pursuing the development of carbon markets and provides a forum for sharing experience and knowledge (ICAP, 2013).

Table 2.3 provides a summary of existing and planned ETS systems and their scope (national or subnational) and types of offsetting. In addition, Mexico and Costa Rica are working on a national ETS (World Bank, 2013b). New schemes have benefited from lessons learned under the EU ETS. Most implemented and planned systems involve a phased approach, allowing for gradual introduction with consecutive compliance periods or using pilot approaches. Many ETS systems start with the distribution of free permits which are subsequently reduced over time. Schemes that allow learning can also adjust better to unforeseen changes in the economy and national priorities.

In the first phase of the EU ETS (2005–2007), mechanisms were introduced to establish a price for carbon on the market, allocation of allowances to operators of large point sources (businesses), registering trade in emission allowances across the EU, and the necessary infrastructure for monitoring, reporting and verifying actual emissions from the businesses and organisations covered (Gilbertson and Reyes, 2009). This first phase of the EU ETS covered $CO_2$ emissions from power generation and the manufacturing industry (e.g. iron and steel, cement) in all Member States (EC, 2013a).

The second phase (2008–2012) coincided with the period during which industrialised countries had to achieve their Kyoto Protocol emission targets. The scope of the EU ETS was extended with three countries of the European Free Trade Area (Iceland, Norway, and Liechtenstein) and an optional subsector of the chemical industry emitting $N_2O$. In 2012, $CO_2$ emissions from aviation were also included. The coverage of aircrafts entering and leaving the EU was temporarily put on hold in November 2012, while waiting for developments involving the International Civic Aviation Organisation (ICAO) for a more global approach. Most operators were allocated free allowances by their national governments and only a small number of allowances were auctioned. Businesses participating in the EU ETS were also allowed to buy credits from the flexible mechanisms under the Kyoto Protocol for parts of

Table 2.3
**Overview of existing, emerging and potential emission trading schemes.**

| ETS | Status | Scope | Offsetting | |
|---|---|---|---|---|
| EU27 | Implemented | National | CDM and JI credits | |
| Australia | Implemented | National | CDM and JI credits | Domestic offsets |
| New Zealand | Implemented | National | CDM and JI credits | |
| Switzerland | Implemented | National | CDM and JI credits | |
| Kazakhstan | Implemented | National | | Domestic offsets |
| California | Implemented | Sub-national | Bilateral offsets | Domestic offsets |
| RGGI* | Implemented | | Sub-national | Domestic offsets |
| Quebec | Implemented | | Sub-national | Domestic offsets |
| Tokyo | Implemented | | Sub-national | Domestic offsets |
| South Korea | Scheduled | National | | Domestic offsets |
| Japan | Under consideration | National | | |
| Ukraine | Under consideration | National | | |
| Turkey | Under consideration | National | | |
| China | Under consideration | National | | Domestic offsets |
| Brazil | Under consideration | National | | |
| Chile | Under consideration | National | | |
| WCI** | Under consideration | | Sub-national | |
| China | Scheduled | | Sub-national | |

Source: World Bank, 2013b.

** RGGI: Regional Greenhouse Gas Initiative. Participating US States are Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont.*

*** WCI: Western Climate Initiative. Participating jurisdictions are California (US) and the Canadian provinces of British Columbia, Manitoba, Ontario and Québec.*

their compliance commitments: credits from Clean Development Mechanism (CDM) projects in developing countries and Joint Implementation (JI) projects in EIT countries. The EU ETS became the main driver of the international carbon market, providing clean energy investments in developing countries and economies in transition (Gilbertson and Reyes, 2009; EC, 2012).

In the third phase (2013–2020), the EU ETS scope was further extended to include other industrial sectors (aluminium, ammonia, bulk organic chemicals production) and other greenhouse gases ($N_2O$ and perfluorocarbons, PFCs), and rules for the allocation of allowances were harmonised across Member States. Auctioning was introduced as the main method of allocating allowances. For sectors possibly exposed to a significant risk of 'carbon leakage' (i.e. increase in production and related $CO_2$ emissions in other countries as a result of higher production costs due to emission reductions in countries with stricter climate policy), free allocation was based on European $CO_2$ performance benchmarks (i.e. emissions of the 10% best performers in the sector). Also, Member States were allowed to compensate their industries for indirect costs from higher electricity bills. About 50% of the allowances available up to 2020 will be auctioned during this phase. Installations continue to have access to international credits with limits per installation guided by the EU regulation on international credit entitlements. Presently, the EU ETS covers about 45% of EU-wide greenhouse gas emissions in the EU. The cap for stationary installations will be reduced annually by 1.74% of the average allowances issued annually in the 2008–2012 period (an annual reduction of 38 million tonnes $CO_2$ eq) (EC, 2013a; World Bank, 2013b).

Current carbon prices in the EU ETS are low, at about 5 euros. This situation on the ETS market illustrates the weakness of the EU ETS design, as it is not flexible enough to adapt to unforeseen turns of events, such as an economic crisis. The cap on emissions in phase two was about 6.5% lower than in phase one, which was considered ambitious at the time. However, since the start of the economic crisis in 2008, EU ETS emissions

have come down by more than 10%, and the economic crisis is likely to be the major cause of these emission reductions. Since 2009, the emissions of greenhouse gases from installations participating in the EU ETS are below the cap and decreased further in 2012, by 2%, compared to 2011. Also the large inflow of international credits from Clean Development Mechanism (CDM) and Joint Implementation projects (JI) have lowered the carbon price, as have the national subsidy schemes for renewable energy. This resulted in a cumulative surplus of almost two billion allowances by the end of 2012 (CLIMA, 2013). Without action, it is expected that a structural surplus of about 2 billion allowances will persist for most of phase three. Apart from the risk of undermining the functioning of the carbon market, these imbalances will seriously affect the ability of the EU ETS to achieve more ambitious emission reduction targets in a cost-effective manner in future phases, as a proper price signal without much volatility is required for investment in low-carbon technologies (EC, 2012; Verdonk et al., 2013).

Therefore, the European Commission proposed two actions (EC, 2013a). The first of which was to postpone the auctioning of 900 million allowances ('backloading') from the 2013–2015 period until 2019/2020, when demand is expected to have picked up. However, such backloading would not affect the structural surplus of around 2 billion allowances over the 2013–2020 period. Therefore, the second action by the Commission was to launch a debate on structural changes to the EU ETS that could provide a sustainable solution in the longer term to the growing imbalance between supply and demand. In its first report on the state of the European carbon market, the Commission identified six options, any of which could potentially correct the surplus (EC, 2012). An assessment of these and other options for structural reform of the EU ETS, such as an EU-wide carbon tax on all energy use, was made by Verdonk et al. (2013).

## Cancún agreements

We observe a growth of 52% in global anthropogenic $CO_2$ emissions in the 20 years since 1992, when the UN Earth Summit was held in Rio de Janeiro. This growth in emissions caused an increase of 10.8% in the $CO_2$ concentration in the atmosphere, from 356 to 394 ppm (annual average) and it tipped the 400 ppm mark in May 2013. Since 2000, an estimated total of 450 ± 50 billion tonnes of $CO_2$ was cumulatively emitted during human activities (including emissions from deforestation). In the scientific literature, one criterion discussed for achieving the 2 °C maximum global warming target with a reasonable probability, is that the cumulative emissions over the five decades from 2000 to 2050 should not exceed 1,000 to 1,500 billion tonnes of $CO_2$ (Meinshausen et al., 2009). The agreements reached at the UNFCCC climate negotiations, in Copenhagen in 2009, Cancún in 2010 and Durban in 2011, all indicate that countries should take urgent action to reduce global greenhouse gas emissions, in order to limit the increase in global average temperature to less than 2 °C relative to pre-industrial levels. Our data show that the cumulative emissions in the 12 years of this century are already make up a substantial share of the maximum cumulative emissions not to be exceeded to achieve the 2 °C target. If the global $CO_2$ emission growth rate until 2011 would continue at the historic annual increase of 2.7%, cumulative emissions would exceed this criterion within the next two decades. However, the low emissions growth in 2012 of 1.1% (after correction for the leap year) may have been the first sign of a slowdown in the increase in global emissions. A further slowdown will mainly depend on the realisation of China's own target of not exceeding a certain level of coal consumption by 2015, on the further increase in the natural gas share in the US energy supply, from about 4% to 10% by 2020, and on re-establishing the effectiveness of the Emissions Trading System for businesses in the European Union.

However, it is uncertain how global society will develop, over time. and which economic and technological trends will continue; in particular, regarding the shares of nuclear power and renewable energy. Without the use of modern renewable energy (e.g. wind, solar, biofuel, hydropower), present annual global $CO_2$ emissions could potentially have been about 5% higher (see Section 3.3 for more details). Various technological developments for renewable energy and shale gas hydraulic fracturing have matured enough for a sustained global growth and market penetration. Moreover, the expansion of the intercontinental trade in liquefied natural gas (LNG) through increased transport and storage capacity is changing global gas markets.

As part of the Cancún Agreements (2010), 42 developed countries submitted quantified economy-wide emission reduction targets for 2020, and 45 developing countries, including the seven major emitting countries, pledged mitigation action plans. Hof et al. (2013) analysed the emission levels that would be expected to result from these pledged actions. They concluded that the emission gap between the emission levels resulting from the pledges (52.7 to 56.5 billion tonnes $CO_2$ equivalent) and those consistent with achieving the 2 °C target ranges from 6.7 to 10.6 billion tonnes $CO_2$ equivalent, for a medium chance of achieving the 2 °C climate goal. These updated estimates are in line with other studies, such as by UNEP (2012). Blok et al. (2012) estimate the impact of 21 major (potential) initiatives and claim that together these could stimulate sufficient reductions by 2020 to bridge this global greenhouse gas emission gap. Olivier (2013)

shows that the mitigation potential of existing international initiatives varies between 2 and 5 billion tonnes of $CO_2$.

All these policies assume emissions are accounted for in accordance with the official IPCC reporting guidelines, as approved and used by countries to report their greenhouse gas emissions that are related to domestic activities (territorial emissions) to the UN Climate Convention (UNFCCC) and Kyoto Protocol. Examples of such emissions are those from fossil-fuel consumption domestic cement production (IPCC, 2006). For completeness, we note that in the scientific literature, alternative perspectives and accounting schemes for national emissions and equity in target setting for individual countries are also discussed, such as cumulative emissions (i.e. including historical emissions from the beginning of the industrial revolution) (Höhne et al., 2011; Wei et al., 2012; Den Elzen et al., 2013b) and emissions based on final consumption of goods and foods (including 'embodied carbon' in traded products) (Peters et al., 2011, 2012; Davis and Caldeira, 2010; Steinberger et al., 2012). This last perspective is sometimes also referred to as 'consumption-based' accounting as opposed to 'production-based' accounting, which then refers to the official IPCC/UNFCCC accounting of national greenhouse gas emissions based on domestic fossil-fuel combustion and other economic activities with actual greenhouse gas emissions associated with them.

The IEA concludes in a recent study (2013c) that the 2 °C global temperature goal could still be achieved with the urgent implementation of four energy policies that rely on existing technologies that have been adopted successfully by several countries:

- Targeted energy efficiency measures in the end-use sectors of building, industry and transport, will account for nearly half the emission reductions in 2020, with the additionally required investments being more than offset by reduced spending on fuel bills;
- Limiting the construction and use of the least-efficient coal-fired power plants delivers more than 20% reduction in emissions and helps curb local air pollution.
- Actions to halve expected release of methane into the atmosphere from the upstream oil and gas industry by 2020 would provide an 18% emission reduction.
- Implementing a partial phasing out of fossil-fuel consumption subsidies would account for 12% emission reduction and would support efficiency efforts.

## Notes

1 In this report, 'European Union' without further specification refers to the 27 Member States in the composition of 2012 ('EU27'). In some cases, trends in 'EU15' and 'EU12' are discussed, referring to the composition of the 15 Member States when the EU ratified the Kyoto Protocol, and to the 12 new Member States that joined at a later stage. Note that on 1 July 2013 Croatia became the 28th EU Member State. However, it is a relatively small country and in 2012 its $CO_2$ emissions represented only 0.6% of the total in EU27 emissions.

2 India uses an elaborate statistical accounting system, based on the British system introduced in the past. Therefore a 5% uncertainty is assumed for statistical data from India (Marland et al., 1999; IPCC, 2006).

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

4 The category 'other OECD-1990 countries' include Australia, Canada, Iceland, New Zealand, Norway, Switzerland and Turkey. These are seven of the countries that were members of the OECD in its composition of 1990 (which furthermore consisted of the EU15 countries, the United States and Japan).

5 The category 'other developing countries' consist of the so-called non-Annex I countries, excluding China and India, but including countries such as Brazil, Indonesia, Mexico, South Africa, and South Korea.

6 Only the $CO_2$/GDP from Iceland and Saudi Arabia, two countries with extreme climate conditions, did not show a declining trend.

7 Except for Singapore, which also emitted less.

# Trends in energy supply and consumption

## 3.1 Introduction

$CO_2$ emissions originate for 90% from fossil-fuel combustion and therefore are determined by the following three main factors:

- Energy demand or the level of energy-intensive activity; in particular, related to power generation, basic materials industry and road transport;
- changes in energy efficiency;
- shifts in fuel mix, such as from carbon-intensive coal to low-carbon gas, or from fossil fuels to nuclear or renewable energy.

Important drivers of specific fossil-fuel consumption are the *fuel price,* in general, and relative price differences between coal, oil products and natural gas. Of course, *energy policies* also are aimed to manage fossil-fuel use. In addition, *energy consumption is* affected by certain preconditions, such as *weather:* 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 and climate of a country affect activities such as distances travelled and the potential for renewable energy such as hydropower, wind, solar and tidal energy).
Section 3.2 presents general trends in the fuel mix, Section 3.3 shows changes in energy-efficiency, and Section 3.4 looks more specifically at renewable energy.

For $CO_2$ emissions it is important to 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. Therefore, recent trends in the fossil-fuel mix with shifts from coal to gas, or vice versa, in the United States, China and Europe, are very relevant for the overall trend in $CO_2$ emissions. Table 3.1 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. 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. Swart and Weaver (2012) also point to the large tonnage of coal available and its high carbon content in comparison to other fossil-fuel resources. The known reserves of global coal resources would cause 5 times more $CO_2$ eq emissions, if all would be consumed, compared to the $CO_2$ eq emitted from the consumption of all global shale gas and oil resources. Shale gas and oil, in turn, would cause 10 times more $CO_2$ eq emissions, if all would be consumed, compared to the total in conventional global gas and oil resources.

The historical trend in 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 has not been due to an absolute decrease in gas consumption, but trend breaks in the

Table 3.1.

**$CO_2$ emissions from fossil-fuel combustion in 2010, per sector**

| | Total | Coal | Oil | Natural gas | Other |
|---|---|---|---|---|---|
| **Sector total (billion tonnes $CO_2$)** | **30.3** | **13.0** | **10.9** | **6.2** | **0.2** |
| Main activity power generation * | **11.4** | 8.4 | 0.7 | 2.2 | 0.1 |
| Fuel production and transformation | **2.8** | 0.8 | 0.9 | 1.0 | 0.1 |
| Manufacturing industry ** | **6.1** | 3.3 | 1.5 | 1.3 | 0 |
| Road transport | 5.0 | | 4.9 | 0.1 | |
| Other transport *** | **1.7** | | 1.6 | 0.1 | |
| Residential sector | **1.9** | 0.3 | 0.6 | 1.0 | |
| Other sectors **** | **1.4** | 0.2 | 0.7 | 0.5 | |
| | | | | | |
| **Sector total (% of global total)** | **100%** | **43%** | **36%** | **21%** | **1%** |
| Main activity power generation * | **38%** | 28% | 2% | 7% | 0% |
| Fuel production and transformation | **9%** | 3% | 3% | 3% | 0% |
| Manufacturing industry ** | **20%** | 11% | 5% | 4% | |
| Road transport | **16%** | | 16% | 0% | |
| Other transport *** | **6%** | | 5% | 0% | |
| Residential sector | **6%** | 1% | 2% | 3% | |
| Other sectors **** | **5%** | 1% | 2% | 2% | |

Source: IEA, 2012e

** Includes heat production*

*** Includes emissions from non-energy and feedstock uses of fuels*

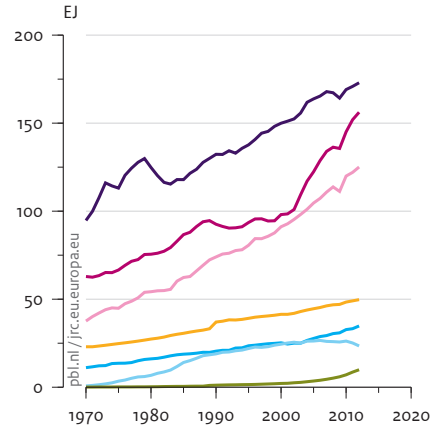
**** Includes international marine and aviation bunkers*

***** Service sector; includes agriculture and forestry*

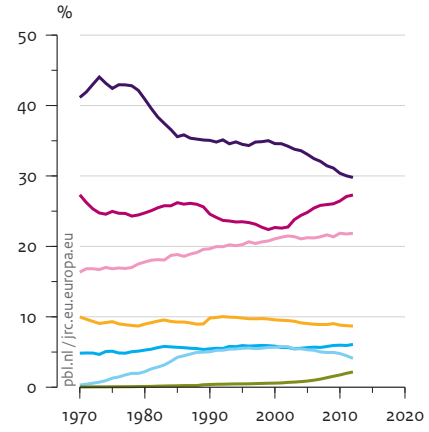
Figure 3.1

**Global total primary energy supply by type**

Energy supply in exajoule




Shares in energy supply mix




Oil
Coal
Natural gas
Wood fuel
Hydropower
Nuclear energy
Wind, solar, biofuels

Source: BP, 2013; IEA, 2012 (for wood fuel)

relative growth rate of natural gas and oil shares were due to the much higher growth rate of coal consumption since 2002. This strong increase in coal consumption mainly was caused by the fast developing economy of China.

## 3.2 Trends in fossil-fuel consumption and fuel mix

Fossil fuel combustion accounts for about 90% of total global $CO_2$ emissions, excluding those from forest fires and the use of wood fuel (EDGAR 4.2, JRC/PBL, 2011). As the global economy continued to grow (3.5%) in most countries in 2012, global energy consumption saw an actual growth of 1.5% (1.2% after leap year correction), which represents half the average growth over the last decade (BP, 2013; NBSC, 2013). The $CO_2$ emission trends in OECD and non-OECD countries are diverging, with a 1.4% decline in OECD countries, the fifth decrease in the past seven years, versus a 2.7% increase in non-OECD countries.

Global fossil oil consumption increased by about 0.9% in 2012. China's oil consumption increased by 5.3%, below their 10-year average, and accounted for more than half of the increase in oil trade in 2012, with oil import increasing by 7.2%.

Natural gas consumption increased globally by 2.2% in 2012 (BP, 2013). Among countries with more than a 2% share in the world's natural gas consumption, the largest increase took place in Saudi Arabia (+11%), Japan and China (each +10%), Mexico (+8.9%) and the United States (+4.1%). After the largest decline on record (-11%) in 2011, due to warm weather, a weak economy, high gas prices and increase in renewable electricity production, consumption in the European Union did not take off again, but continued to decrease by -2.3% in 2012 mainly caused by declines in the United Kingdom (by 5.7%) and Italy (by 4%).

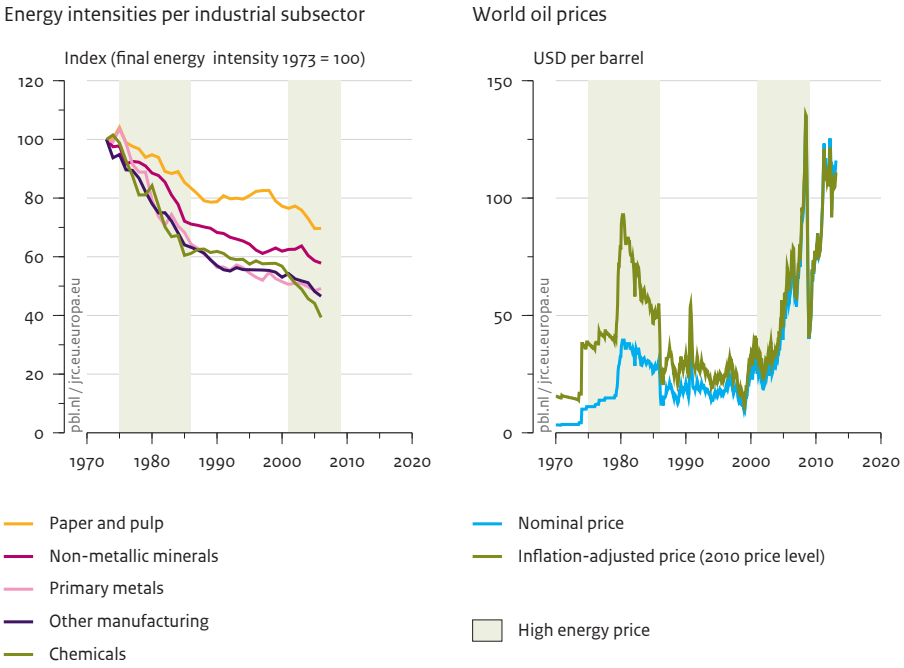
Coal consumption, which accounts for almost one third of global energy consumption, increased globally by 0.6% in 2012 (using NBSC data for China and with leap year correction). China, with a share of 50% in global coal consumption, after a large increase in coal consumption in 2010 and 2011 (9.5% in both years) increased only by 2.5% in 2012. This increase in 2012 was mainly driven by the increase in building construction and expansion of infrastructure, as indicated by the growth in the cement and steel production. China, the world's largest coal importer, increased coal imports from 2011 to 2012 by 58%, mainly to support its economic development (Platts, 2013; Chinadaily, 2013). The coal import volume is determined, to a large extent, by the domestic and international coal price difference. In addition, domestic use of coal produced in China faces a transportation bottleneck, due to transport capacity limitations of the road and rail infrastructure used for transporting the coal from the mines to the consumption areas (Tu, 2011). Coal imported from overseas may help to ensure a stable supply of coal, especially during the peak demand season. Please note that the accuracy of China's coal consumption data is commonly estimated by at about 5% to 15%, with higher uncertainties expected regarding the data on the last 15 years. Annex A1.4 provides more details in a discussion on uncertainty. Coal consumption in India increased by 10%. Consumption in OECD countries decreased by 4%, with a large decline of 12% in the United States and smaller declines of 5% in Australia and 2% in Canada. In contrast, increases are observed in the EU (3%), caused by Spain (24%), the United Kingdom (24%), France (20%) and Germany (4%).

The United States, over the past five years, saw a significant fuel shift from coal to gas. The exploration of shale gas increased such that the United States no longer depends as much on fossil-fuel imports. The large decrease in $CO_2$ emissions in 2012 was mainly caused by the drop in coal consumption, in particular in the power sector. This also shows that in countries with sufficient reserves in power generation capacity, changes in the fuel mix can occur relatively fast. The United States has overtaken the Russian Federation to become the world's largest gas producer (IEA, 2013a). As a consequence, the United States since 2008 has relatively low natural gas prices compared to Europe and Japan, and larger reserves of fossil fuel.
In 2012, the price of thermal coal exported by the United States dropped, due to a decrease in domestic demand. In addition, world coal prices were relative low due to slowing Chinese demand. The lower coal prices and large disparity with natural gas prices made European utilities (mainly in Germany, the Netherlands, Italy and Spain) willing coal buyers and European purchases of US coal rose by a third in the first six months of 2012 (Economist, 2013a).

## 3.3 Trends in energy efficiency improvements

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

Figure 3.2
**Industrial energy intensities and energy prices**




Source: Intensities: IEA, 2004, 2008 (IEA-11 for 1973–1998; IEA-21 for 1999–2006)
Oil prices: EIA, 2013 (with Brent [North Sea] from 1988 onwards and West Texas Intermediate for 1970–1978)

various economic sectors (e.g. IEA 2004; 2007; 2008). 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.

This is shown most clearly in the manufacturing sector: intensity (corrected for changes in structure) fell by 41% from 1973 to 1998, but had already declined 36% by 1986. Figure 3.2 illustrates the effects of energy prices on the evolution of energy intensities. In periods of high fuel prices, shown in Figure 3.2 by the shaded periods (1975–1986 and 2001–2009), the rate of improvement is much higher than in times of relatively low energy prices (period in between). Although changes in energy intensity (energy consumption per unit of activity) can be due to changes in the product mix within the industry subsector itself, more energy-efficient industrial processes were responsible for most of the decreases.

Without the energy-efficiency improvements that occurred between 1973 and 2005 in those countries, energy use would have been 58% higher in 2005 than it actually was. However, since 1990, the rate of energy-efficiency improvement slowed down because of less economic interest due to relatively low fuel prices (IEA, 2008). Many studies have shown the large potential of energy-efficiency improvements for reducing fossil-fuel and electricity consumption, in all sectors, in end-use and in power generation.

In Europe, a more efficient way of using energy was observed especially in the residential sector, mainly due to more efficient appliances and equipment, more efficient heating systems and better insulated buildings, in general (Bertoldi et al., 2012). Differences in regional heating demand reflect the energy efficiency of the heating appliances used: this demand in northern countries generally is larger than in southern European countries. Between 2004 and 2009, final energy consumption in the EU27 in the residential sector fell by 2%, in 2007 reaching the lowest consumption level of the last 20 years, but in 2010 consumption increased again to a total energy consumption share of 27%. The tertiary sector, accounting for 13% of total energy consumption in the EU27 in 2010, showed an increasing trend of only 17% from 2005 to 2010. Energy-efficiency proposals have been evaluated for the industry, accounting for 25% of the EU27's total energy consumption in 2010. Effective activities include a gradual replacement of coal-fired power plants at the end of their lifetime by the best available technology (Morbee, 2012), a decrease in the clinker-to-cement ratio (Moya et al., 2010) and smart

electricity grids (Giordano et al., 2013). A report by Energy Efficiency Watch (EEW, 2013) provides an overview of energy-efficiency improvement policies in the 27 EU Member States, for the 2010–2012 period, as described in their National Energy Efficiency Action Plans (NEEAPs) under the EU Energy Efficiency Directive. It showed an enormous diversity between Member States in their levels of ambition.

## 3.4 Trends in renewable energy sources

Together, renewable energy sources have increased to supply 19% of global final energy consumption, including traditional biofuels, such as fuel wood (UNEP, 2013). Half of the electricity generating capacity added globally in 2020 consisted of renewable energy. . By the end of 2012, the total in global power capacity generated from renewable energy exceeded 1,470 GW, up 8.5% from 2011, and supplied an estimated 22% of global electricity (16.5% in hydropower and 5.2% in other renewable energy). By early 2013, at least 138 countries, more than half of which are developing countries, had renewable energy targets in place, up from 118 countries one year before, although some slackening of policy support was seen in developed countries. In the United States, renewable energy provided 12% of net electricity generation in 2012. Wind accounted for 45% of new renewable power capacity. In Germany, renewable energy sources met 13% of total final energy consumption and accounted for 23% of electricity consumption, up from 20.5% in 2011 (UNEP, 2013).

Hydropower output was 3,700 TWh in 2012, an increase by 4.3% compared to 2011 (up from 1.6% in 2011) (BP, 2013). China accounted for all the net growth, leading a hydropower output to 6.7% in global energy consumption, the largest share on record. The top 5 hydropower producers in 2012 were China (23% share), Brazil (11%), Canada (10%), the United States (8%) and the Russian Federation (4.5%). Of the 39% increase in the hydropower output since 2002, China accounted for more than half and Brazil for almost one eighth (BP, 2013). In terms of newly installed capacity in 2012 (30 GW), China led with 15.5 GW, followed by Turkey (2 GW), Brazil (1.9 GW), Vietnam (1.8 GW) and the Russian Federation (0.9 GW) (UNEP, 2013).

Total global wind power capacity was 282.5 GW at the end of 2012, an increase of more than 10% compared to 2011, lower than the average of about 28% over the last 10 years (GWEC, 2013). Wind power output was 520 TWh in 2012, an increase of 18% compared to 2011 (BP, 2013). In 2012, most wind power capacity was installed in Asia (35%), North America (33%) and Europe (28%). However, Europe still had the largest wind power capacity in the world, with 39% of the total in 2012. China, the world's largest wind power market, added 12,960 MW in new wind capacity in 2012, resulting in a total of 75.3 GW installed by the end of 2012. Wind represented 2% of the total power generated in China last year. According to GWEC (2013), the grid itself poses the most serious challenge to wind development in China. One of the problems in the past was that the local grid infrastructure did not expand quickly enough, causing connection delays. India added 2,336 MW of new capacity to reach a total of 18.4 GW, accounting for about 8.7% of electricity generation, up from 2% in 1995. During 2012, 11,900 MW of additional wind power was installed in the European Union, more than in 2011, resulting in a total capacity of 106 GW. Germany installed 2,400 MW of additional capacity, the United Kingdom 1,900 MW, followed by Italy (1,300 MW), Spain (1,100 MW), Romania (900 MW), Poland (900 MW), Sweden (850 MW) and France (750 MW). The total wind power capacity installed in the EU by the end of 2012, on average, produced 231 TWh of electricity, equivalent to 7% of total EU electricity consumption (up from 6.3% in 2011). The United States added 13,10 MW wind capacity in 31 States in 2012, a 28% increase from 2011, bringing its total wind capacity to 60 GW.

Total global solar photovoltaic (PV) capacity increased in 2012 by 47% to about 102 GW, and could produce, on average, 110 terawatt hours (TWh) of electricity every year (EPIA, 2013). According to BP (2013), PV power output was 90 TWh in 2012, an increase of 58% compared to 2011. The global total of 31 GW installed in 2012 was almost the same as the capacity installed in 2011 (29.7 GW) and was still dominated by growth in the EU, led by Germany (7.5 GW) and Italy (3.4 GW). By comparison, the United States and Japan installed 3.3 and 2 GW, respectively, and Australia and India were close to 1 GW. Regarding cumulative installed capacity, Europe is the world's leading region, with 70 GW in 2012, followed by China (8.3 GW), the United States (7.8 GW) and Japan (6.9 GW).

According to Mauthner and Weiss (2013), total global solar heat capacity increased in 2012 by 14% to about 268 GWth (225 TWh). Austria, Brazil, China, Germany and India accounted for 89% of additionally installed capacity in 2011. Solar heat, after hydropower and wind power, is currently the third most important renewable energy in terms of globally installed capacity. Worldwide solar heat (SH) capacity, by the end of 2011, was 234.6 GWth, with China (152.2 GWth) and Europe (39.3 GWth) accounting for 81.6% of the total installed capacity. The additionally

installed capacity (48.1 GWth) led to an increase of 14.3%, compared to the year 2010. China (40.3 GWth) and Europe (3.9 GWth) accounted for 92% of new collector installations in 2011. In China, the cumulative installed capacity, per type, was 93% in evacuated tubes and 7% in flat plate collectors, while in Europe 86% 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.

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. In 2012, total global CSP capacity increased by more than 60% to about 2.5 GW (UNEP, 2013) and could reach 4.7 GW by the end of 2013, most of which is concentrated in the United States and Spain (Jäger-Waldau, 2013). The United Arab Emirates, China, India, Italy, Algeria, Morocco and Australia also are investing in CSP.

The competitiveness of solar and wind power is improving, considering the price evolution of these technologies. The prices of PV modules have decreased by 80% since 2008, and by 20% in 2012 alone, and wind turbine prices have decreased by 29% since 2008 (Clean Technica, 2013).

Global biofuel production decreased by just 0.4%, the first recorded decline since 2000, mainly due to a decline in the United States (-4.3%) (BP, 2013). In the United States, growth in consumption (+0.2%) slowed down as the share of ethanol in petrol approached the 'blend wall', the practical limit of the fraction of ethanol in petrol that can be used in most modern regular petrol-fuelled car engines. After the largest decline (-13%) in 2011 due to a poor sugar harvest, Brazil's biofuel consumption decreased also in 2012 by 0.7%. In the EU, biofuel consumption increased by 3.1% in 2012, driven by large increases from 2011-2012 in Spain (17%), Italy (14%) and Poland (20%) , although partly offset by decreases in Germany, France, the United Kingdom, Portugal and Romania (see Table 3.2). Current fuel ethanol and biodiesel use represent about 3% of global road transport fuels and could be expected to have reduced $CO_2$ emissions of 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. 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 EU, the United States, China, Brazil and India. In 2012, biofuels mandates were in place in the EU, 13 countries in North and South America, 12 in Asia and the Pacific, and 8 in Africa (Biofuelsdigest, 2013; GFRA, 2013).

## 3.5 Trends in nuclear energy

In 2011, nuclear energy was used to produce 12.3% of the world's electricity. The highest share of nuclear generated electricity was 25.7% in western Europe, followed by 18.9 in North America and 18.8 in eastern Europe. For the Far East, the share was 6.9% and for other regions, such as the Middle East, South Asia and Southeast Asia, shares were no higher than 2.2%.

In 2012, nuclear power plants produced only 267 GW electricity worldwide (corresponding to 2476 TWh), a minimal amount since 1999, and 6.8% less compared to 2011 (in which 2653 TWh were produced) (Schneider and Froggatt, 2013; BP, 2013). This was mainly caused by the continuing and substantial decrease in generation in Japan (–50% in 2012 compared to 2011). But also in all top five nuclear generating countries production decreased in 2012, compared to 2011: in the United States by 2.5%, France by 4%, Germany by 10%, South Korea by 5% and in the Russian Federation by 0.5%.

However, in 2013, the power supply capacity is back to 372 GWe, according to the IAEA PRIS database (IAEA, 2013), generated by 437 nuclear reactors in 31 countries, after having dropped in 2011 to 368 GWe. In 2011, 13 reactors were permanently shut down, globally, 12 of which directly due to the Fukushima Daiichi accident (5 in Japan and 7 in Germany). However, since then, 9 new reactors have been put into operation: in 2011 7 new reactors were connected to the grid, and in 2012 another 2. In 2012, all power plants, except those in Japan, were used with an average availability of 87% (WANO, 2013; NEI, 2013). Japan reduced its nuclear power down to zero, in the first half of 2012, but restarted 2 of its 50 nuclear reactors in July 2012.

The number of new reactors being constructed was reduced by 14 in 2011, but by January 2012 was up again by the same number, bringing the number of new reactors worldwide to 67. Of these new reactors, 31 are hosted by China; they had already been approved by the State

Table 3.2

**Biofuel consumption in road transport (bioethanol and biodiesel), 2005–2012 (in TJ)**

| Country | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|
| **Annex I** | **476,913** | **714,250** | **920,093** | **1,259,334** | **1,472,531** | **1,640,328** | **1,741,481** | **1,761,360** |
| **United States** | 337,941 | 473,793 | 601,146 | 819,755 | 928,090 | 1,012,973 | 1,068,621 | **1,070,660** |
| Canada | 7,129 | 5,789 | 27,721 | 29,306 | 32,966 | 51,560 | 68,520 | 68,520 |
| Australia | 777 | 2,177 | 4,644 | 6,952 | 9,821 | 12,049 | 14,323 | 14,323 |
| Norway | 0 | 221 | 1,251 | 3,412 | 3,965 | 4,888 | 4,812 | 4,812 |
| Japan | 400 | 400 | 500 | 500 | 1,100 | 1,800 | 1,800 | 1,800 |
| Belarus | 0 | 0 | 0 | 294 | 810 | 1,251 | 1,568 | 1,568 |
| Turkey | 0 | 815 | 519 | 638 | 278 | 259 | 659 | 659 |
| Switzerland | 251 | 283 | 432 | 432 | 315 | 373 | 368 | 368 |
| New Zealand | 0 | 0 | 40 | 127 | 98 | 155 | 252 | 252 |
| Monaco | 0 | 10 | 10 | 30 | 30 | 20 | 20 | 20 |
| Iceland | 0 | 0 | 0 | 10 | 10 | 10 | 6 | 6 |
| EU27, of which: | 130,415 | 230,762 | 283,830 | 397,878 | 495,048 | 554,991 | 580,531 | 598,371 |
| **Germany** | 81,259 | 144,818 | 117,543 | 107,561 | 112,919 | 123,947 | 123,217 | **120,873** |
| **France** | 16,733 | 30,460 | 60,574 | 95,076 | 103,260 | 101,336 | 102,024 | **100,429** |
| **Spain** | 10,819 | 7,155 | 16,114 | 25,934 | 44,909 | 60,105 | 72,059 | **84,029** |
| **Italy** | 7,480 | 6,732 | 5,909 | 31,588 | 49,410 | 61,389 | 59,224 | **67,600** |
| **Poland** | 2,228 | 4,090 | 4,441 | 18,482 | 27,737 | 37,122 | 39,088 | **46,875** |
| **United Kingdom** | 3,345 | 8,029 | 14,467 | 33,072 | 40,599 | 47,202 | 43,757 | **37,051** |
| **Austria** | 1,884 | 10,245 | 12,882 | 16,088 | 20,118 | 19,830 | 19,899 | **20,955** |
| Sweden | 5,650 | 7,850 | 11,912 | 14,392 | 15,098 | 15,923 | 17,509 | 17,509 |
| Belgium | 0 | 0 | 3,767 | 4,239 | 11,958 | 15,167 | 14,572 | 14,572 |
| Netherlands | 0 | 1,734 | 13,834 | 12,026 | 15,625 | 9,575 | 13,452 | 13,452 |
| **Czech Republic** | 111 | 759 | 1,261 | 4,612 | 8,170 | 9,702 | 12,592 | **12,826** |
| **Portugal** | 0 | 2,923 | 5,550 | 5,365 | 9,250 | 13,468 | 12,691 | **11,715** |
| **Romania** | 0 | 0 | 1,693 | 4,490 | 6,804 | 4,827 | 8,895 | **8,485** |
| Finland | 0 | 28 | 55 | 2,926 | 5,059 | 5,041 | 7,513 | 7,513 |
| Hungary | 107 | 456 | 1,200 | 6,892 | 7,080 | 7,317 | 6,935 | 6,935 |
| Denmark | 0 | 160 | 240 | 214 | 364 | 1,121 | 5,553 | 5,553 |
| Greece | 0 | 1,932 | 3,562 | 2,886 | 3,266 | 5,355 | 4,444 | 4,444 |
| Ireland | 37 | 101 | 941 | 2,307 | 3,227 | 3,918 | 4,131 | 4,131 |
| Slovakia | 439 | 1,864 | 2,626 | 3,104 | 3,547 | 4,090 | 4,088 | 4,088 |
| **Lithuania** | 137 | 803 | 2,212 | 2,557 | 2,145 | 1,864 | 1,878 | **2,290** |
| Latvia | 110 | 101 | 74 | 74 | 181 | 1,121 | 1,959 | 1,959 |
| Luxembourg | 40 | 40 | 1,897 | 1,897 | 1,783 | 1,743 | 1,828 | 1,828 |
| Slovenia | 0 | 74 | 580 | 1,030 | 1,261 | 1,904 | 1,452 | 1,452 |
| Bulgaria | 0 | 331 | 147 | 148 | 221 | 846 | 720 | 720 |
| **Cyprus** | 0 | 0 | 37 | 589 | 626 | 626 | 648 | **684** |
| Croatia | 0 | 0 | 220 | 111 | 327 | 110 | 196 | 196 |
| Estonia | 6 | 47 | 22 | 178 | 74 | 322 | 187 | 187 |
| Malta | 30 | 30 | 70 | 40 | 30 | 20 | 20 | 20 |

Table 3.2 (continued)

| Country | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|
| **Non-Annex I** | **300,691** | **325,104** | **434,613** | **595,770** | **670,552** | **737,176** | **741,202** | **737,511** |
| **Brazil** | 291,533 | 270,201 | 373,039 | 502,514 | 550,826 | 588,900 | 521,186 | **517,495** |
| China | 0 | 42,200 | 39,056 | 49,188 | 51,742 | 50,696 | 63,217 | 63,217 |
| Argentina | 662 | 662 | 662 | 662 | 1,987 | 22,130 | 32,630 | 32,630 |
| Thailand | 1,420 | 2,680 | 5,906 | 20,042 | 26,543 | 27,399 | 29,115 | 29,115 |
| Colombia | 27 | 268 | 295 | 415 | 532 | 800 | 25,460 | 25,460 |
| South Korea | 459 | 1,681 | 3,324 | 6,266 | 9,209 | 12,571 | 11,845 | 11,845 |
| India | 4,556 | 5,038 | 5,601 | 6,191 | 6,861 | 7,611 | 11,736 | 11,736 |
| Philippines | 59 | 98 | 1,390 | 2,386 | 8,574 | 7,522 | 10,111 | 10,111 |
| Indonesia | 0 | 368 | 790 | 321 | 853 | 1,435 | 9,803 | 9,803 |
| Peru | 0 | 0 | 0 | 0 | 2,907 | 3,517 | 9,079 | 9,079 |
| Taiwan | 0 | 0 | 196 | 1,215 | 2,091 | 4,051 | 3,004 | 3,004 |
| Serbia | 0 | 0 | 980 | 1,961 | 2,941 | 2,941 | 2,941 | 2,941 |
| Trinidad  Tobago | 0 | 0 | 0 | 0 | 0 | 0 | 2605 | 2605 |
| Jamaica | 0 | 0 | 0 | 130 | 1,302 | 1,302 | 2,605 | 2,605 |
| Nigeria | 0 | 0 | 391 | 651 | 0 | 0 | 1302 | 1302 |
| Uruguay | 59 | 78 | 118 | 98 | 248 | 522 | 653 | 653 |
| Vietnam | 0 | 0 | 0 | 0 | 0 | 130 | 651 | 651 |
| Mexico | 0 | 0 | 196 | 196 | 200 | 587 | 587 | 587 |
| Costa Rica | 0 | 0 | 65 | 65 | 651 | 651 | 521 | 521 |
| Cuba | 1,302 | 912 | 521 | 391 | 391 | 391 | 391 | 391 |
| Paraguay | 482 | 509 | 429 | 858 | 1,635 | 2,171 | 260 | 260 |
| Pakistan | 0 | 0 | 0 | 0 | 0 | 260 | 260 | 260 |
| 14 Other countries | 132 | 408 | 1,654 | 2,219 | 1,059 | 1,587 | 1,238 | 1,238 |
| **Global total** | **777,605** | **1,039,354** | **1,354,706** | **1,855,104** | **2,143,083** | **2,377,504** | **2,482,683** | **2,498,870** |

*Notes: Data for 2012 were extrapolated using total global production data, except for Germany, the United Kingdom, the United States, Brazil and some other countries (shown in bold). The other 14 countries with reported biofuel consumption, which for 2012 were estimated at between 250 TJ and 20 TJ, are in decreasing order: Hong Kong, Israel, South Africa, Ecuador, Malawi, Malaysia, Singapore, Ethiopia, Fiji, Honduras, Guatemala, Macedonia, Rwanda, and Tanzania.*

Council before the Fukushima accident and, therefore, their construction was not affected by that disaster (Vivoda, 2013). In India, the construction of 7 new reactors also remained unaffected, and the Russian Federation increased its number of new reactors to be constructed to 11. Only South Korea, Taiwan and Japan have partially halted the construction of new reactors (Vivoda, 2013). Europe continues the planned construction of new reactors in France and Finland, and finalises construction of 2 reactors in Slovakia after safety upgrades, so that they can go on grid by 2014. Similarly, in the United States, plans for the construction of one new reactor have remained unchanged (NEI, 2013).

## 3.6 Carbon capture and storage

Carbon capture and storage (CCS) is a method for long-term isolation of the $CO_2$ generated in combustion facilities that otherwise would have been emitted into the atmosphere. The method involves capturing and storing $CO_2$ in suitable geological formations. The CCS process has three stages:

- Capture: separation of $CO_2$ from the other gases produced when fossil fuels or biofuels are combusted to generate electricity, or when $CO_2$ is produced in other industrial processes;
- Transport: once separated, the $CO_2$ is compressed and transported to a suitable geological storage site ;
- Storage: $CO_2$ is injected into deep underground rock formations, such as deep saline aquifers or depleted

Table 3.3.
**Present carbon capture and storage (CCS) facilities and capacities**

| Country | Location | Capacity (Mt $CO_2$/yr) | Start year | Storage type |
|---|---|---|---|---|
| United States | Val Verde | 1.3 | 1972 | Enhanced oil recovery |
| United States | Enid | 0.7 | 1982 | Enhanced oil recovery |
| United States | Shute Creek | 7 | 1986 | Enhanced oil recovery |
| Norway | Sleipner | 1 | 1996 | Long-term geological storage |
| United States | Great Plains | 3 | 2000 | Enhanced oil recovery |
| Algeria | In Saliah | 1 | 2004 | Long-term geological storage |
| Norway | Snohvit | 0.7 | 2008 | Long-term geological storage |
| United States | Century | 8.4 | 2010 | Enhanced oil recovery |
| **Total** | **Open** | **23.1** | **in 2012** | |

Source: IEA (2013b)

hydrocarbon reservoirs, often at depths of 1 km or more.

Carbon capture and storage (CCS) can be a viable complement to reach EU emission reduction targets for the energy industry (power and heat generation plants), and large $CO_2$ emitting industries (cement, iron and steel, and refinery plants). Captured $CO_2$ is compressed under high pressure until it reaches supercritical state, then stored in deep geological structures. Capturing technologies can be classified in 3 large groups: Post-Combustion, Pre-Combustion and Oxyfuel (IPCC, 2005). These technologies differ in mass transfer mechanism used for separation and in the integration downstream or upstream in the combustion/gasification process.

Post-combustion processes capture $CO_2$ coming from the flue gas of combustion devices, such as boilers and gas turbines. For flue gas from coal combustion, $CO_2$ concentration levels may be about 15% to 17%, while, for natural gas, levels are typically three times lower (DOE). Three different kinds of unit operations can be used as post-combustion technologies for power plants: amines (the chemical most widely used in absorption technology[1]), adsorption (in the pores of solids) and membranes (in cascade configuration) (Ahn, 2013; Bocciardo et al., 2013). Pre-combustion technologies involve the separation of $CO_2$ upstream the combustion device. They are applied in Integrated Gasification Combined Cycle (IGCC) power plants. Oxyfuel technologies are based on the use of $O_2$ instead of air to burn the fuels. Air is separated using cryogenic (and energy-intensive) distillation, without requiring downstream separation.

In general, challenges regarding CCS continue to be those of demonstrating the technology on a large scale, the commercialisation of the technology, limited public acceptance due to concerns associated with the safety and permanence of $CO_2$ storage underground, and the application of a suite of measurement, monitoring and verification technologies. Potential consequences of pressure build up with induced seismicity, with $CO_2$ migration out of the primary injection zone and with changes in water formation have been quantified in several scientific studies (e.g. Mazzoldi et al., 2012) but remain controversial issues.

At present, 8 large-scale CCS projects are storing about 23 million tonnes of $CO_2$ each year, globally (Table 3.3). With 9 projects currently under construction (2 in the electricity generation sector), the amount stored annually could increase to 37 million tonnes $CO_2$ by 2015. This is about 70% of the IEA's target for mitigation through CCS for 2015. Of the 59 remaining projects in the Global CCS Institute's annual project survey, only 51 are currently scheduled to be operational by 2020 (Global CCS Institute, 2012, 2013). The next project, which is scheduled to start in 2015 with the capture of about 2.6 million tonnes of $CO_2$, annually, is located at the newly built North West Sturgeon refinery in Canada, where the $CO_2$ will be sold for enhanced oil recovery.

At the beginning of 2013, only a handful of new commercial CCS facilities with geological $CO_2$ storage were underway; mainly in Australia (Queensland), Norway (Sleipner, Snøvit) and Algeria (Salah) (Global CCS institute, 2011, Eiken et al., 2011, Shell, 2013), but many more demonstration projects exist.

In the EU, a legal framework has been setup for demonstration projects with the EU Directive on $CO_2$ storage (EC directive 2009/31, in force since 2011). Even though the European Commission as early as in 2007 started to develop initiatives for carbon capture and storage as part of the Energy and Climate programme, progress has been very limited (EC, 2011). Two EU funding mechanisms were set up to push the CCS technology (ENGO Network on CCS, 2013). The first of these mechanisms is the New Entrant's Reserve (NER) under the revised Emissions Trading Directive 2009/29/EC. The NER300 scheme would sell 300 million allowances under the EU ETS to create a funding mechanism in support of innovative renewable energy technology development and a suite of CCS demonstration projects, but no CCS project was funded in the first NER300 round of 2013. The second mechanism, in 2009, is the European Energy Programme for Recovery (EEPR), in which six projects were selected to receive fast-track support, but EEPR funding provided by DG Energy also failed to secure a single project that has been able to move forward (ENGO, 2013).

However, at the end of 2012, Germany started a number of CCS demonstration plants, albeit with very low $CO_2$ storage limits. The Netherlands has funded two CCS demonstration projects that store $CO_2$ offshore. The United Kingdom has put several regulatory frameworks in place to underpin CCS development on an industrial scale. Last year, it funded six pilot projects on CCS and, in 2013, Shell UK Ltd. and SSE in Peterhead on the North Sea coast began the development of the world's first commercial-scale full-chain gas carbon capture and storage facility (LCICG-UK, 2012; Shell, 2013).

European countries that are constructing new coal power plants should be especially encouraged to ensure these plants will be CCS ready. However, a CCS-ready plant in itself has no practical meaning unless there is a nearby network infrastructure for connecting CCS facilities to a pipeline to transport the $CO_2$ to depleted oil or gas fields, as Socolow (2012) also pointed out.

# Conclusion: signs of a slowdown in the annual increase in global $CO_2$

Global emissions of carbon dioxide ($CO_2$) – the main cause of human-induced global warming – increased by only 1.1% in 2012, yielding a slowdown in annual global $CO_2$ emissions, at 34.5 billion tonnes in 2012. While the past decade saw an average annual $CO_2$ emission increase of 2.7%, in 2012 the actual increase was only 1.4% (1.1% after leap-year correction). Nevertheless, in 2012, the mean annual global growth rate of atmospheric $CO_2$ concentrations was rather high with 2.4 ppm. Inter-annual variation in net carbon storage of forests and absorption by the oceans could explain this difference in trends. In May 2013, an unprecedented concentration $CO_2$ level of more than 400 ppm was measured in the atmosphere, up from 355 ppm in 1990. Scientific literature suggests that limiting average global temperature rise to 2 °C above pre-industrial levels – the target internationally adopted in UN climate negotiations – is possible if cumulative $CO_2$ emissions over the 2000–2050 period do not exceed 1,000 to 1,500 billion tonnes (Meinshausen et al., 2009). Since 2000, an estimated total of about 466 billion tonnes $CO_2$ was cumulatively emitted due to human activities (including deforestation), according to the EDGAR statistics (JRC/PBL, 2012) with an uncertainty range of ±10%.

The $CO_2$ trend reflects mainly energy-related human activities that, over the past decade, were determined by economic growth, mainly in emerging countries. For 2012, a 'decoupling' of $CO_2$ emission increases and global economic growth (in GDP) could be noted, which points towards a shift to less fossil-fuel intensive activities, more use of renewable energy and more energy saving. The energy carriers in the primary energy supply all show continuous increases over the past decade, except nuclear energy, which decreased since 2012 in the aftermath of the Fukushima accident. However, the good news is that renewable energy has shown an accelerated increase since 2002: the use of hydropower has shown an accelerated growth since 2002 and its output increased by 4.3% from 2011 to 2012. The share of the 'new' renewable energy sources solar, wind energy and biofuels also increased at an accelerating speed: it took 15 years since 1992 to double the share from 0.5% to 1.1%, but only 6 more years to double it again to 2.4% by 2012. The bad news is that fossil-fuel consumption also increased in 2012: in particular, of natural gas (+2.2%), but also oil (+0.9%) and coal (+0.6%). The increase in the use of coal after 2002 yielded a share in coal combustion in present global total $CO_2$ emissions of almost 40%, and for coal-fired power plants this share was 28%. There are policy measures in place to level off coal use for power generation, by shifting to gas or renewable energy, converting present coal-fired power plants to biomass, or by making new coal-fired power plants ready for carbon capture and storage. However, such changes do not happen overnight.

A comparison of regional $CO_2$ emission trends revealed large differences in underlying sources, which complicates the evaluation of the robustness of observed trends. The top 6 emitting countries/regions are China (29%), the United States (16%), the European Union

(EU27) (11%), India (6%) and the Russian Federation (5%), followed by Japan (4%). In 2012, in the United States and the EU, $CO_2$ emissions decreased by 4% and 1.6%, respectively. Total $CO_2$ emissions from all OECD countries currently account for one third of global emissions – the same share as that of China and India, where in 2012 emissions increased by 3% and 7%, respectively. $CO_2$ emissions decreased by 1% in the Russian Federation and by 6% in Japan.

In 2012, China's average emission level of 7.1 tonnes $CO_2$/cap results from a smoothing of their $CO_2$ growth, to only 3% in 2012 after an annual growth rate of about 10% over the last decade. The increase in China's $CO_2$ emissions was mainly due to a continued high economic growth rate, with related increases in fossil-fuel consumption. This increase in fuel consumption in 2012 was mainly driven by the increase in building construction and expansion of infrastructure, as indicated by the increase in the cement and steel production. Domestic coal consumption grew by 2.5% and coal import increased by 10%, making China the world's largest coal importer. While China's $CO_2$ emissions per capita would be comparable to those of the EU and to almost half of those in the United States, its $CO_2$ emissions per USD are almost double those of the EU and the United States, and, since 2004, are similar to $CO_2$ emissions per USD (in PPP) in the Russian Federation. China's large economic stimulus package intended to avoid a decrease in annual economic growth during the recent global recession has ended. With electricity and energy growth at half the pace of its GDP growth, China's energy intensity per unit of GDP declined in 2012 by 3.6%, twice as fast as in 2011. The slower and structurally changed growth, thus, puts the country back on track to achieve both the national energy consumption target for 2015 and that of its 12th Five Year Plan, with an almost 17% cumulative reduction in energy intensity per unit of GDP, compared to 2010. China also increased its hydropower capacity and output by 23% in 2012, which had a significant mitigating effect of about 1.5 percentage points on its $CO_2$ emissions in that year.

The United States, the second largest $CO_2$ emitting country, showed a decrease in $CO_2$ emissions since 2005, but with 16.4 tonnes $CO_2$ per capita in 2012, their emissions per capita still rank among the highest of the major industrialised countries. Until 2007, the $CO_2$ per capita remained fairly constant, whereas from 2007 onwards, per-capita emissions decreased, partially because of a population growth that was much larger than in other OECD countries, but also because of an absolute decrease in emissions. In fact, in 2012, under an economic growth of 2%, emission levels were reduced by 4%, mainly through a further fuel shift from coal to gas in the power sector, and due to low gas prices. According to satellite observations, flaring emissions in the United States have been on the rise, with a steep 50% increase in 2011. The main cause is believed to be the recent sharp increase in the country's use of hydraulic fracturing for shale oil production, and the related flaring of co-produced gas. The United States has also expanded shale gas fracturing, and as such has become

the largest natural gas producer in the world. Over the past five years, the share of shale gas has increased to one third of the total US gross gas production, and the share of shale oil in 2012 represented almost one quarter of total US crude oil production.

The European Union, as a whole, remained in economic recession in 2012: the GDP of EU27 in 2012 declined by 0.3%, compared to 2011. However, actual $CO_2$ emissions declined by 1.3% in 2012, compared to 2011 (1.6% with leap-year correction), less than the 3.1% decrease in 2011. Main causes were a decrease in primary energy consumption of oil and gas with respectively 4% and 2%, a decrease in road freight transport by 4% and a decrease of 2% in total emissions from power generation and manufacturing installations participating in the EU Emissions Trading System. While the total $CO_2$ emissions for power generation in EU27 decreased by 2.3% in 2012, very different trends are noticed for various EU Member States, in particular for coal. There was renewed interest in the use of coal in electricity production in Europe's energy mix. In 2012, increased coal consumption was observed in the United Kingdom (+24%; the highest consumption level since 2006), Spain (+24%; the second year with an increase after two years of decreasing consumption), Germany (+4%) and France (+20%), versus decreases in Poland (4%) and the Czech Republic (8%).

The low increase in emissions, in 2012, of 1.1% may be the first sign of a slowdown in the increase in global $CO_2$ emissions, and of ultimately declining global emissions; for example, if (a) China achieves its own target for the maximum level of energy consumption by 2015 and its shift to gas with a natural gas share of 10% by 2020; (b) if the United States would continue its shift in the energy mix towards more gas and renewable energy; and (c) if EU Member States agree on restoring the effectiveness of the EU Emissions Trading System to further reduce emission levels.

Obviously, it is uncertain how the global society will develop, over time, and which economic and technological trends will continue, in particular the global and regional prices of different fossil fuels and the shares of nuclear power and renewable energy sources. However, there also is additional uncertainty due to possible major changes in various areas that have a large

impact on global energy use; for example, an increase in the production of shale gas may affect natural gas prices worldwide; expansion of intercontinental trade in LNG through increased transport and storage capacity may influence natural gas markets; overcapacity and flexibility in fuel mix for power generation may cause rapid changes in the fuel mix of utilities in case of changes in the relative price of gas and coal (as observed in the United States and some European countries); the ability of China to make a smooth transition towards a more service-based economy; and a prolonged recession may hinder the functioning of the carbon market of the EU ETS being restored and, thus, the ability to set and meet more ambitious emission reduction targets.

Various technological developments are now moving from a developmental phase to a mature sustained global growth and market penetration, not only for renewable energy sources but also for oil and gas, as observed with the production of shale gas by hydraulic fracturing. Without the use of modern renewable energy sources (e.g. wind, solar, biofuel, hydropower), annual global $CO_2$ emission levels, potentially, could have been about 5% higher than they are today.

# Annex

## Annex 1 Methodology and data sources over the 2010–2012 period

### A1.1 Methodology and data sources

The recent trends were estimated by PBL using trends in most recent data on fossil-fuel consumption for 2009-2012 from the BP Review of World Energy 2012 (BP, 2013) for 2010-2012 and from the International Energy Agency (IEA, 2012e) for 2009-2010. For cement production, preliminary data for 2009-2012 were used from the US Geological Survey (USGS, 2013) except for China for which use was made of National Bureau of Statistics of China (NBSC) (2009-2013). For other sources of $CO_2$ a similar method was used.

For the trend estimate 2008-2012, 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 2008-2012 emissions:
(1) Fuel combustion (IPCC category 1A + international bunkers):

- For energy for 2008-2010, the most recent detailed $CO_2$ estimates compiled by the International Energy Agency (IEA) for fuel combustion by major fossil-fuel type (coal, oil, gas, other) for these years (IEA, 2012) to calculate the trend per country and for international air and water transport.
- For energy for 2010-2012, the BP Review of World Energy is used to calculate the trend of fuel consumption per main fossil-fuel type: coal, oil and natural gas (BP, 2013). 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-quarter and half of 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 2008-2012 are assumed to be similar to the trend in crude steel production for 2008-2009 from USGS (2011) and for 2009-2012 from the Word Steel Association (WSA, 2013).
- Fugitive emissions from oil and gas (1B2), which refers to leakage, flaring and venting: trends per country for 2008-2010 were estimated using the same method and data sets as used for EDGAR 4.2 for the years up to 2008, since the NOAA data set that was used provides flaring data from satellite observation for the most important 58 countries up to 2010 (NOAA/NCDC, 2011; 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 data set was used (NOAA, 2012, pers. comm.). For 2012 no updated NOAA data.

(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, which amount to more than 90% of 2A category, were calculated using cement production data for 2010-2012 (2012 preliminary data) published by the US Geological Survey (USGS, 2013), except for China where use was made of the National Bureau of Statistics of China (NBS) (2012, 2013). In addition, we extrapolated the trend in the emission

factor due to trends in the fraction of clinker in the cement produced based on data reported by WBCSD (2009). Thus for 2009-2012 the same methodology was used as in EDGAR 4.2. For all other sources in the minerals production category (2A), we used the trend in lime production data for 2008-2012 (USGS, 2013) as proxy to estimate the trend in the other 2A emissions. All 2012 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 (2012) was used (2011 data are preliminary estimates). 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 for 2008-2009 USGS (2011) and for 2009-2012 World Steel Association (WSA, 2013) was used to estimate the recent trend in the total emissions. For the very small emissions in categories 2G and 3, the 2005-2008 trend was extrapolated to 2011. 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 2005-2008 trend was extrapolated to 2012 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 4.2, although the magnitude of these sources is very uncertain. Van Dijk et al. (2009) concluded that $CO_2$ emissions from coal fires in China are at around 30 million tonne $CO_2$ per year. This is equivalent to about 0.3% of China's $CO_2$ emissions in 2012.

## A1.2 Data set on biofuel use in road transport

This data set is restricted to bioethanol or fuel ethanol and biodiesel used in road transport as substitute for fossil oil products (petrol, diesel or LPG) (see Table 3.2). 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 were used for 2005-2012 from the following sources:

- UNFCCC (2013) for Annex I countries (industrialised countries reporting emissions to the UN Climate Secretariat, at present data for 1990-2011), except for Bulgaria, Romania and the United Kingdom, that reported 'Not Occurring' or 'Not Estimated', although other data sources show that these countries do use road biofuels.
- For Bulgaria and Romania, these data were supplemented with fuel ethanol and biodiesel consumption data for 2005-2011 from Systèmes solaires (2007-2012) and EBB (2010, 2011, 2012).
- Supplemental data for 2012 for the United States, Germany, the United Kingdom and Brazil, comprising almost 80% of the global total consumption were taken from EIA (2013g), BMU (2013), the United Kingdom (DECC 2012) and Barros (2010-2013), respectively. For nine developing countries, IEA (2012g) was used for biofuel consumption in 2005-2010. For four more countries, reported biofuel consumption was found.
- Various sources were used to obtain bioethanol and biodiesel consumption data for 2005-2012 in Brazil and China. Reported consumption data were used for 2012 for China, India and Argentina.

Where time series were incomplete for 2012, amounts were calculated using the 2008-2012 trend of total global biofuel production from BP (2013) for Annex I countries while country-specific trends for 2008-2012 were used for selected developing countries where it could be assumed that all domestic production was used for domestic consumption (World Bank, 2010).

Although data for 2005 onwards are presented, only 2011-2012 data are used in the $CO_2$ estimation method used in this study. For years up to 2010, the EDGAR 4.2 FT2010

Table A1.1

**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).**

| Country | 1990 | 1995 | 2000 | 2005 | 2008 | 2010 | 2011 | Average | Reported uncertainty (95% CI) | Note on uncertainty |
|---|---|---|---|---|---|---|---|---|---|---|
| United States | -2% | -3% | -2% | -3% | -3% | -4% | -4% | -2% | 4% | for minimum: -2% |
| Canada | -2% | -2% | -3% | -2% | -1% | -1% | 1% | -2% | 2.4% | for energy sector |
| EU27 | -2% | -1% | -1% | -1% | -0.3% | 0.5% | 1% | -1% | 2% | for EU15 |
| Russian Federation | -2% | 11% | 13% | 13% | 12% | 7% | 6% | 10% | 4% | |
| Ukraine | 7% | 25% | 19% | 6% | 5% | 4% | 5% | 13% | 3.7% | |
| Japan | 2% | 2% | 2% | 2% | 3% | 4% | 0% | 2% | 1% | |
| Australia | -3% | -1% | 3% | 7% | 9% | 6% | 8% | 3% | 4 to 5% | |
| **Total** | **-1.4%** | **0.5%** | **0.9%** | **0.3%** | **0.5%** | **-0.1%** | **-0.1%** | **0.3%** | | |

Source: EDGAR 4.2FT2010: JRC/PBL (2012); NIR/CRF data: UNFCCC (2013).

data are used, which were calculated with fossil-fuel statistics from the IEA, which are separate 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 0.1-0.2 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.

## A1.4 Data quality and uncertainties

For industrialised countries, total $CO_2$ emissions per country, according to EDGAR 4.2, for the 1990–2008 period, are generally within 3% of officially reported emissions, except for a few economies in transition (EIT) (see examples provided in Table A1.1). Also most industrialised countries (Annex I) 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 most EIT countries, such as the Russian Federation and the Ukraine. For developing countries, 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 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 mature industrialised 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.

$CO_2$ emission trends over recent years, estimated using energy data published annually by BP, appear to be reasonably accurate for estimating global $CO_2$ trends. For example, based on older BP energy data, the increase in 2005 in global $CO_2$ emissions from fuel combustion 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 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, 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 remains 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 4.1 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 and for 2007 the EDGAR estimate is also closer to the higher 'provincial' $CO_2$ estimate than to the estimated 'national total'. Thus, it could be tentatively concluded that the uncertainty range of the EDGAR 4.2 data for China may be not symmetrical, but may have a larger uncertainty to the low end than to the high end of the range. 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 reporting by Annex I countries (Olivier et al., 2010), we conclude that the uncertainty in the EDGAR 4.2 estimate for China is about 10%, possibly with an asymmetrical range. This conclusion was also based on subsequent revisions of $CO_2$ emission estimates made by the IEA.

This year, BP (2013) reported a 6.4% increase in coal consumption in China for 2012, whereas the National Bureau of Statistics of China reported a 2.5% increase (NBS, 2013). Two years ago there was a similar large discrepancy between these data sources: BP (2011) reported a 10.1% increase in coal consumption in China for 2010 (in energy units), whereas the NBSC reported an increase of 5.9% in coal consumption per tonne. In the next BP (2012) the 2010 increase was revised to 6.1%, very similar to the preliminary increase reported by the NBSC. These subsequent changes could be indicative of the order of magnitude of the uncertainties in the statistics.

The coal consumption data for China were in the BP (2013) release updated for the last four years with annual increases very similar to NBSC reported values. In particular, whereas BP estimated last year the increase in China's coal consumption in 2011 to be 10.1%, which was reported by NBSC is 5.9%. However, BP has now revised their estimate for 2011 in this year's report to 6.4%. Global consumption of natural gas and oil products increased by 2.2% and 0.9% (leap year corrected), respectively, somewhat below historical trends of 2.7% and 1.2% per year (BP, 2013).

In conclusion, we estimate the uncertainty in our estimates of total national annual $CO_2$ emissions at 5% for the United States, EU27, other OECD countries and India, and at 10% for the Russian Federation, China and developing 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 (2012), which applied the methods described in the IPCC good practice guidance (IPCC, 2006).

## A1.5 Results

Table 2.2 in Chapter 2 shows the trends in $CO_2$ emissions per region/country for 1990-2012 as presented in Figure 2.1 and Table A1.2 shows the change in per capita $CO_2$ emissions for 1990-2012 and of population for a numbers of countries. These tables and the figures used in Figures 2.1 to 2.6 can also be found as spreadsheet on the PBL website: http://www.compendiumvoordeleefomgeving.nl/indicatoren/nlo533-Koolstofdioxide-emissie-door-gebruik-van-fossiele-brandstoffen%2C-mondiaal.html?i=9-20 and on the EDGAR website at JRC: http://edgar.jrc.ec.europa.eu

Table A1.2

**$CO_2$ emissions in 2012 (million tonnes $CO_2$) and $CO_2$/capita emissions, 1990–2012 (tonnes $CO_2$/person)**

| Country | Emissions 2012 | Per capita emissions 1990 | 2000 | 2010 | 2011 | 2012 | Change '90-'12 | Change 1990-2012 in % | Change in $CO_2$ 1990-2012 in % | Change in population 1990-2012 in % |
|---|---|---|---|---|---|---|---|---|---|---|
| **Annex I*** | | | | | | | | | | |
| United States | 5,200 | 19.6 | 20.6 | 17.6 | 17.1 | **16.4** | -3.2 | -17% | 4% | 25% |
| European Union | 3,700 | 9.1 | 8.4 | 7.8 | 7.5 | **7.4** | -1.7 | -19% | -14% | 7% |
| Germany | 810 | 12.7 | 10.4 | 9.9 | 9.6 | **9.7** | -2.9 | -23% | -21% | 3% |
| United Kingdom | 490 | 10.3 | 9.2 | 8.2 | 7.5 | **7.7** | -2.5 | -25% | -17% | 10% |
| Italy | 390 | 7.5 | 8.1 | 6.9 | 6.7 | **6.3** | -1.2 | -16% | -9% | 7% |
| France | 370 | 6.9 | 6.9 | 6.2 | 5.8 | **5.8** | -1.1 | -15% | -5% | 12% |
| Poland | 320 | 8.2 | 7.5 | 8.7 | 8.7 | **8.4** | 0.2 | 3% | 3% | 0% |
| Spain | 290 | 5.9 | 7.6 | 6.1 | 6.2 | **6.1** | 0.3 | 4% | 26% | 20% |
| Netherlands | 160 | 10.8 | 10.9 | 10.7 | 10.0 | **9.8** | -1.0 | -9% | 0% | 12% |
| Russian Federation | 1,770 | 16.5 | 11.3 | 11.9 | 12.4 | **12.4** | -4.1 | -25% | -27% | -3% |
| Japan | 1,320 | 9.5 | 10.2 | 9.7 | 9.8 | **10.4** | 0.9 | 9% | 14% | 4% |
| Canada | 560 | 16.2 | 17.9 | 16.2 | 16.3 | **16.0** | -0.2 | -1% | 24% | 26% |
| Australia | 430 | 16.0 | 18.5 | 19.4 | 19.4 | **18.8** | 2.7 | 17% | 59% | 35% |
| Ukraine | 320 | 14.9 | 7.2 | 6.6 | 7.0 | **7.1** | -7.8 | -52% | -58% | -12% |
| **Non-Annex I** | | | | | | | | | | |
| China | 9,900 | 2.1 | 2.8 | 6.4 | 6.9 | **7.1** | 5.0 | 233% | 293% | 18% |
| India | 1,970 | 0.8 | 1.0 | 1.5 | 1.5 | **1.6** | 0.8 | 110% | 198% | 42% |
| South Korea | 640 | 5.9 | 9.8 | 12.2 | 12.9 | **13.0** | 7.1 | 121% | 151% | 14% |
| Indonesia | 490 | 0.9 | 1.4 | 1.9 | 2.0 | **2.0** | 1.1 | 126% | 213% | 38% |
| Saudi Arabia | 460 | 10.2 | 12.9 | 15.6 | 15.6 | **16.2** | 6.0 | 58% | 177% | 75% |
| Brazil | 460 | 1.5 | 2.0 | 2.2 | 2.3 | **2.3** | 0.8 | 58% | 109% | 33% |
| Mexico | 490 | 3.6 | 3.6 | 3.9 | 3.9 | **4.0** | 0.4 | 12% | 58% | 40% |
| Iran | 410 | 3.6 | 5.2 | 5.2 | 5.3 | **5.3** | 1.7 | 47% | 99% | 40% |
| South Africa | 330 | 7.3 | 6.9 | 6.4 | 6.3 | **6.3** | -1.0 | -14% | 22% | 42% |
| Taiwan | 280 | 6.2 | 10.5 | 11.9 | 11.9 | **11.8** | 5.7 | 92% | 121% | 15% |
| Thailand | 260 | 1.6 | 2.8 | 3.6 | 3.8 | **3.9** | 2.3 | 144% | 189% | 18% |

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

** Annex I countries: industrialised countries with annual reporting obligations under the UN Framework Convention on Climate Change (UNFCCC) and emission targets under the Kyoto Protocol. The United States signed but not ratified the protocol, and thus the US emission target in the protocol has no legal status.*

# List of abbreviations and definitions

| | |
|---|---|
| Annex I Countries | Group of industrialised countries defined in the UNFCCC, most of which have specific emission targets under the *Kyoto Protocol* for the period 2008-12 ("Annex B" of the protocol). They include the 24 original OECD member countries in 1990, the European Union, and 14 countries with economies in transition (EIT). |
| BDEW | BDEW German Association of Energy and Water Industries (Bundesverband der Energie- und Wasserwirtschaft) |
| BMU | German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit) |
| BP | BP p.l.c. (energy company; formerly British Petroleum Company plc) |
| DMSP-OLS | Defense Meteorological Satellite Program - Operational Linescan System |
| CCS | Carbon Capture and Storage |
| EBB | European Biodiesel Board |
| EC | European Commission |
| EDGAR | Emission Database for Global Atmospheric Research |
| EIA | U.S. Energy Information Administration |
| EIT | Economies in Transition, group of countries defined under the UNFCCC: the former centrally-planned economies of Russia and Eastern Europe |
| EPA | U.S. Environmental Protection Agency |
| EPIA | European Photovoltaic Industry Association |
| ETS | Emissions Trading System |
| GCP | Global Carbon Project |
| GDP | Gross domestic product |
| GGFR | World Bank's Global Gas Flaring Reduction Partnership |
| GHG | Greenhouse Gas |
| GW | Gigawatt (1 billion W = $10^9$ W) (unit of power) |
| GWth | Gigawatt thermal (unit of power input, as opposed to GWe, which refers to electricity output) |
| TWh | Terawatt hour (1000 billion W hour = $10^{12}$ Wh = 3.6 Petajoule) |
| GWEC | Global Wind Energy Council |
| IAEA | International Atomic Energy Agency |
| IEA | International Energy Agency |
| IES | Institute for Environment and Sustainability of the Joint Research Centre JRC |
| IMF | International Monetary Fund |
| IPCC | Intergovernmental Panel on Climate Change |
| JRC | Joint Research Centre of the European Commission |
| LPG | Liquefied petroleum gas |
| LULUCF | Land use, land-use change and forestry |
| MODIS | Moderate Resolution Imaging Spectroradiometer (satellite instrument for remote sensing) |
| 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 Center |
| OECD | Organisation for Economic Co-operation and Development |
| PBL | PBL Netherlands Environmental Assessment Agency |
| ppm | parts per million (dry air mole fraction of a compound relative to the number of all molecules in air, including the compound itself, after water vapour has been removed) |
| PPP | Purchasing Power Parity |
| PV | Photovoltaic |
| UN | United Nations |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UNPD | United Nations Population Division |
| USGS | United States Geological Survey |
| WBCSD | World Business Council on Sustainable Development |
| WBSCSD | World Business School Council on Sustainable Development |
| WSA | Word Steel Association |
| WPP | World Population Prospects of UNPD |

# References


AEA (2012a). Climate impact of potential shale gas production in the EU. Report for European Commission DG CLIMA. No. AEA/R/ED57412. Issue 2. Date 30/07/2012. AEA Technology, Harwell, Didcot, UK. Internet: http://ec.europa.eu/clima/policies/eccp/docs/120815_final_report_en.pdf

AEA (2012b). Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe. Report for European Commission DG Environment. No. AEA/R/ED57281, Issue 17c. Date 28/05/2012 (Re-issued with minor corrections 11 February 2013). AEA Technology, Harwell, Didcot, UK. Internet: http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf

Ahn H, Lueberti M, Zhengyl L and Brandani S. (2013). Process Configuration Studies of the Amine Capture Process for Coal-fired Power Plants Energy Procedia,Vol GHGT 11.

Airlie C. (2011). RWE's Coal-Power Plant in Tilbury to Become Britain's Largest Wood Burner. Bloomberg, April 8, 2011. Internet: http://www.bloomberg.com/news/2011-04-08/rwe-s-coal-power-plant-in-tilbury-to-become-britain-s-largest-wood-burner.html

Allen DT, Torresa VM, Thomas J, Sullivan DW, Harrison M, Hendler A, Herndon SC, Kolb CE, Fraser MP, Hill AD, Lamb BK, Miskimins J, Sawyer RF and Seinfeld JH. (2013) Measurements of methane emissions at natural gas production sites in the United States, *Proc. Natl. Acad. Sci.*, 16 September 2013, doi: 10.1073/pnas.1304880110. Internet: http://www.pnas.org/content/early/2013/09/10/1304880110.full.pdf+html

Andres RJ, Boden TA, Bréon F-M, Ciais P, Davis S, Erickson D, Gregg JS, Jacobson A, Marland G, Miller J, Oda T, Olivier JGJ, Raupach MR, Rayner P and Treanton K. (2012). A synthesis of carbon dioxide emissions from fossil-fuel combustion, *Biogeosciences*, 9, 1845–1871, doi:10.5194/bg-9-1845–2012.

Barros S. (2010-2013). Brazil Sugar Annual 2010-2013. GAIN reports no. BR-10002, BR-110006,BR-12005 and BR 130015. USDA.

Bertoldi P, Hirl B and Labanca N. (2012). Energy efficiency status report 2012: electricity consumption and efficiency trends in the EU27, EUR 25405 EN, JRC report 2012. Internet: http://iet.jrc.ec.europa.eu/energyefficiency/sites/energyefficiency/files/energy-efficiency-status-report-2012.pdf

Biofuelsdigest (2013). Internet: http://www.biofuelsdigest.com/bdigest/2012/11/22/biofuelsmandates-around-the-world-2012/earth/

Blok K, Höhne N, Van der Leun K and Harrison N. (2012). Bridging the greenhouse gas emissions gap. *Nature Climate Change*, 2, 471–474, doi:10.1038/nclimate1602.

Bloomberg (2012). China to Restrict Coal Demand, Output to 3.9 Billion Tons. Bloomberg News. Internet: http://www.businessweek.com/news/2012-03-22/china-to-restrict-coal-demand-output-to-3-dot-9-billion-tons

BMU (2012). Renewable energy sources 2010, 23 March 2011, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) Division KI II 1 (General and Fundamental Aspects of Renewable Energy Sources). Internet: http://www.bmu.de/files/english/pdf/application/pdf/ee_in_zahlen_2010_en_bf.pdf.

Bocciardo D, Ferrari M and Brandani S. (2013). Modelling and multi-stage design of membrane processes applied to carbon capture in coal-fired power plants. Energy Procedia,Vol GHGT 11

BP (2010-2013). BP Statistical Review of World Energy, June 2010-June 2013. Internet: www.bp.com/statisticalreview/.

Cancun Agreements (2010). UNFCCC, COP16/CMP6, Internet: http://unfccc.int/meetings/cancun_nov_2010/items/6005.php

Cathles LM, Brown L, Taam M and Hunter A. (2012). A commentary on 'The greenhouse gas footprint of natural gas in shale formations' by R.W. Howarth, R. Santoro, and A. Ingraffea, *Climatic Change*, doi:10.1007/s10584-011-0333-0.

CCE Bankwatch (2013). Poland energy policy to 2030, Internet: http://bankwatch.org/our-work/projects/coal-fired-power-plants-poland

Chinadaily (2013). China coal imports to continue affecting global prices: Platts. http://www.chinadaily.com.cn/bizchina/2013-05/22/content_16518558.htm

Clean Technica (2013). Cleantech News & Commentary to Help the World. Bloomberg new energy finance. Internet: http://cleantechnica.com/2013/05/06/solar-pv-module-prices-have-fallen-80-since-2008-wind-turbines-29/

CLIMA (2013). Structural reform of the European carbon market Internet: http://ec.europa.eu/clima/policies/ets/reform/index_en.htm

Damodaran H. (2011). How India's growth story differs from China's. In: The Hindu Business Line, 4 June, 2011.

Davis SJ and Caldeira K. (2010). Consumption-based accounting of $CO_2$ emissions. *Proc. Natl. Acad. Sci.*, 107, 5687-5692.

De Bruyn S, Nelissen D and Koopman M. (2013). Carbon leakage and the future of the EU ETS market: Impact of recent developments in the EU ETS on the list of sectors deemed to be exposed to carbon leakage Final report Delft, April 2013. www.cedelft.eu/art/uploads/CE_Delft_7917_Carbon_leakage_future_EU_ETS_market_Final.pdf

DECC (2012). Power stations in the United Kingdom, May 2012. UK Department of Energy and Climate Change, May 2012.

Den Elzen MGJ, Hof AF and Roelfsema M. (2011). The emissions gap between the Copenhagen pledges and the 2 °C climate goal: Options for closing and risks that could widen the gap. *Global Environmental Change*, 21, 733–743.

Den Elzen MGJ, Roelfsema M, Hof AF, Böttcher H and Grassi G. (2012). Analysing the emission gap between pledged emission reductions under the Cancún Agreements and the 2 °C climate target. PBL Netherlands Environmental Assessment Agency, The Hague, report no. 500114021, ISBN 978-90-78645-95-5.

Den Elzen MGJ, Hof AF, Roelfsema, M. (2013a). Analysing the greenhouse gas emission reductions of the mitigation action plans by non-Annex I countries by 2020, *Energy Policy*, 56, 633–643.

Den Elzen MGJ, Olivier JGJ, Höhne N and Janssens-Maenhout G (2013b). Countries' contributions to climate change: effect of accounting for all greenhouse gases, recent trends, basic needs and technological progress. Climatic Change, DOI 10.1007/s10584-013-0865-6.

DG CLIMA (2013). Emissions trading: 2012 saw continuing decline in emissions but growing surplus of allowances. Press release, May 2013 http://europa.eu/rapid/press-release_IP-13-437_en.htm

EBB (European Biodiesel Board) (2010, 2011, 2012). Statistics. The EU biodiesel industry.

EC (2011). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A Roadmap for moving to a competitive low carbon economy in 2050, COM(2011) 112 final of 8.3.2011. Internet: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0112:FIN:EN:PDF

EC (2012a). Emissions trading: annual compliance round-up shows declining emissions in 2011. Press release. Internet: http://europa.eu/rapid/pressReleasesAction.do?reference=IP/12/477.

EC (2012b). The state of the European carbon market in 2012. Brussels, 14.11.2012. COM(2012) 652 final. Internet: http://ec.europa.eu/clima/policies/ets/reform/docs/com_2012_652_en.pdf

EC (2013a). The EU Emissions Trading System (EU ETS). Internet: http://ec.europa.eu/clima/policies/ets/index_en.htm

EC (2013b). Emissions trading: 2012 saw continuing decline in emissions but growing surplus of allowances. Press release European Commission, Brussels, 16 May 2013. Internet:
http://europa.eu/rapid/press-release_IP-13-437_en.htm

EC (2013c). Commission decision of 5 September 2013 concerning national implementation measures for the transitional free allocation of greenhouse gas emission allowances in accordance with Article 11(3) of Directive 2003/87/EC of the European Parliament and of the Council. (2013/448/EU). Internet: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:240:0027:0035:EN:PDF

EEW (Energy Efficiency Watch) (2013) Improving and implementing national energy efficiency strategies in the EU framework. Findings from Energy Efficiency Watch II analyses (June 2013). Wuppertal Institute, Ecofys, ESV O.Ö. Energiesparverband. Internet: http://energy-efficiency-watch.org/fileadmin/eew_documents/images/Event_pictures/EEW2_Logos/EEW-Final_Report.pdf

Economist (2013a). Europe's dirty secret. The unwelcome renaissance. Europe's energy policy delivers the worst of all possible worlds. *The Economist*, 5 January 2013. Internet: http://www.economist.com/news/briefing/21569039-europes-energy-policy-delivers-worst-all-possible-worlds-unwelcome-renaissance

Economist (2013b). Renewable energy in Spain. The cost del sol. Sustainable energy meets unsustainable costs. *The Economist*, 20 July 2013. Internet: http://www.economist.com/news/business/21582018-sustainable-energy-meets-unsustainable-costs-cost-del-sol

Edwards R, Larivé J-F, Mahieu V and Rouveirolles P. (2008). Well-to-Wheels analysis of future automotive fuels and powertrains in the European context. TANK-to-WHEELS Report; Version 3, October 2008. JRC/CONCAWE/EUCAR, Ispra.

EIA (2012a). Monthly Energy Review May 2012, Table 9.4 Motor Gasoline Retail Prices, U.S. City Average. Release Date: May 29, 2012. Internet: http://205.254.135.7/totalenergy/data/monthly/#prices

EIA (2012b). Monthly Energy Review May 2012. Table 1.3 Primary Energy Consumption by Source. Release Date: 29 May 2012.

EIA (2012c). Over one-third of natural gas produced in North Dakota is flared or otherwise not marketed. Today in Energy, 23 November 22011. Internet: http://205.254.135.7/todayinenergy/detail.cfm?id=4030.

EIA (2012d). Monthly Energy Review May 2012. Table 2.5 Transportation Sector Energy Consumption. Release Date: 29 May 2012.

EIA (2012e), Trends in Eagle Ford drilling highlight the search for oil and natural gas liquids, Today in energy, 3 November 2011, Internet: http://www.eia.gov/todayinenergy/detail.cfm?id=3770

EIA (2013a). Today in Energy: Energy-related carbon dioxide emissions declined in 2012, US Energy Information Administration, April 5, 2013, Internet: http://www.eia.gov/todayinenergy/detail.cfm?id=10691

EIA (2013b). Today in Energy: Year-to-date natural gas use for electric power generation is down from 2012, US Energy Information Administration, April 11, 2013, Internet: http://www.eia.gov/todayinenergy/detail.cfm?id=10771

EIA (2013c). Today in Energy: Extending current energy policies would reduce U.S. energy use, carbon dioxide emissions, April 30, 2013, Internet: http://www.eia.gov/todayinenergy/detail.cfm?id=11051

EIA (2013d) Annual Energy Outlook 2013. With Projections to 2040, April 2013, U.S. Energy Information Administration. Internet: http://www.eia.gov/forecasts/aeo/pdf/0383(2013).pdf Online: www.eia.gov/forecasts/aeo

EIA (2013e). Today in Energy: Coal regains some electric generation market share from natural gas, US Energy Information Administration - Electric Power Monthly, May 23, 2013, Internet: http://www.eia.gov/todayinenergy/detail.cfm?id=11391

EIA (2013f). Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States, June 2013. Internet: http://www.eia.gov/analysis/studies/worldshalegas/

EIA (2013g). June 2013. Monthly Energy Review, US Energy Information Administration, June 25, 2013, Internet: http://www.eia.gov/totalenergy/data/monthly/

EIA (2013h). Today in Energy: U.S. natural gas spot prices increased during first-half 2013, July 22, 2013, Internet: http://www.eia.gov/todayinenergy/detail.cfm?id=12191

EIA (2013i). Spot Prices for Crude Oil and Petroleum Products [West Texas Intermediate for 1970-1978; Brent (North Sea) from 1988 onwards]. Internet: http://www.eia.gov/dnav/pet/pet_pri_spt_s1_m.htm

EIA (2013j). U.S. Natural Gas Gross Withdrawals and Production. Internet: http://www.eia.gov/dnav/ng/ng_prod_sum_dcu_nus_a.htm

Eiken O, Ringrose P, Hermanrud C, Nazarian B, Torp TA, Høier L (2011). Lessons learned from 14 years of CCS operations: Sleipner, In Salah and Snøhvit. Energy Procedia, 4, 5541-5548, doi:10.1016/j.egypro.2011.02.541.

Eickhout B, Van den Born GJ, Notenboom J, Van Oorschot M, Ros JPM, Van Vuuren DP and Westhoek HJ. (2008). Local and global consequences of the EU renewable directive for biofuels. Testing the sustainability criteria. Report no. 500143001. PBL Netherlands Environmental Assessment Agency, The Hague/Bilthoven.

Elvidge CD, Baugh KE, Tuttle BT, Ziskin D, Ghosh T, Zhizhin M and Pack DW. (2009). Improving Satellite Data Estimation of Gas Flaring Volumes. Year Two Final Report to the GGFR, 17 August 2009. Internet: http://s3.amazonaws.com/zanran_storage/www.ngdc.noaa.gov/ContentPages/15507168.pdf

Elvidge CD, Ziskin D, Baugh KE, Tuttle BT, Ghosh T, Pack DW, Erwin EH and Zhizhin M. (2009a). A Fifteen Year Record of Global Natural Gas Flaring Derived from Satellite Data. *Energies*, 2, 595–622; doi:10.3390/en20300595.

ENGO (2013), Environmental Non-Governmental Organisation, Perspectives on Carbon Capture and Storage, May 2013, http://www.engonetwork.org/engo_perspectives_on_ccs_digital_version.pdf

Environment Canada (2013). National Inventory Report 1990-2011: Greenhouse gas sources and sinks in Canada. Internet: http://www.ec.gc.ca/ges-ghg/ or http://unfccc.int/files/national_reports/annex_i_ghg_inventories/national_inventories_submissions/application/zip/can-2013-nir-15apr.zip

EPIA (2013). Global Market Outlook for Photovoltaic 2013-2017. Internet: http://www.epia.org/fileadmin/user_upload/Publications/GMO_2013_-_Final_PDF.pdf

Ernst and Young (2012). Renewable energy country attractiveness indices. November 2012. CAI, 35, November 2012._DE0372. Internet: http://www.ey.com/Publication/vwLUAssets/CAI_issue-35_Nov-2012/$FILE/CAI_issue-35_Nov-2012_DE0372.pdf

Eurostat (2013a). EU27 statistics from Eurostat. Electricity consumption

Eurostat (2013b). EU27 statistics from Eurostat. Oil products consumption.

Eurostat (2013c). Early estimates of $CO_2$ emissions from energy use 2012, 29 May 2013, STAT-13-80_EN, http://epp.eurostat.ec.europa.eu/cache/ITY_PUBLIC/8-29052013-AP/EN/8-29052013-AP-EN.PDF

FAO (2010). Global Forest Resources Assessment 2010. FAO Forestry Paper 163. FAO, Rome.

Fung E and Peng Y. (2012). Forces driving China's economic growth in 2012. New thoughts, new strategies, new initiatives - KPMG Insight Series. Internet: http://www.kpmg.com/cn/en/IssuesAndInsights/ArticlesPublications/Documents/China-12th-Five-Year-Plan-China-Economic-Growth-201203-2.pdf

Gazprom (2013). Gazprom boosting efficiency of associated petroleum gas utilization, Press release of March 21, 2013, Internet: http://www.gazprom.com/press/news/2013/march/article158616/

GCP (Global Carbon Project) (2013). Internet: http://www.globalcarbonproject.org/.
GFRA (Global Renewable Fuels Alliance) (2013). Global Biofuel Mandates. Internet: http://globalrfa.org/biofuels-map/
(GGFR, 2012). Global Gas Flaring Reduction public-private partnership. Internet: http://go.worldbank.org/Q7E8SP9J90.
Gilbertson T and Reyes O. (2009). Carbon Trading - How it works and why it fails. Internet: http://www.tni.org/tnibook/carbon-trading-how-it-works-and-why-it-fails
Giordano V, Meletiou A, Covrig AF, Mengolini A, Adelean M, Fulli G, Sanchez-Jiminez M and Filiou C. (2013). Smart grid projects in Europe: lessons learned and current developments, JRC report 2013, EUR 25815EN
Global CCS Institute (2012). The global status of CCS. 2012. Global CCS Institute, Canberra, Australia. ISBN 978-0-9871863-1-7.
Global CCS Institute (2013). The global status of CCS. Update January 2013. Global CCS Institute, Canberra, Australia.
Gregg JS, Andres RJ and Marland G. (2008). China: Emissions pattern of the world leader in $CO_2$ emissions from fossil fuel consumption and cement production. *Geophys. Res. Lett.*, 35, L08806, doi:10.1029/2007GL032887.
Guan D, Liu Z, Geng Y, Lindner S and Hubacek K. (2012). The gigatonne gap in China's carbon dioxide inventories, *Nature Climate Change*, June 2012, doi:10.1038/nclimate1560
Guardian (2013). After Fukushima, Japan beginning to see the light in solar energy. *The Guardian*, 18 June, 2013. Internet: http://www.guardian.co.uk/world/2013/jun/18/japan-solar-energy-fukushima-nuclear-renewable-abe
GWEC (Global Wind Energy Council) (2013). Global Wind Report – Annual Market update 2012.
Internet: http://www.gwec.net/wp-content/uploads/2012/06/Annual_report_2012_LowRes.pdf
Harris NL, Brown S, Hagen SC, Saatchi SS, Petrova S, Salas W, Hansen MC, Potapov PV and Lotsch A. (2012). Baseline Map of Carbon Emissions from Deforestation in Tropical Regions, *Science*, 336, 1573-1576, doi:10.1126/science.1217962.
Hof AF, den Elzen MGJ, Roelfsema M (2013) The effect of updated pledges and business-as-usual projections, and new agreed rules on expected global greenhouse gas emissions in 2020. Environ Sci Policy 33:308-319
Höhne N, Blum H, Fuglestvedt J, Skeie RB, Kurosawa A, Hu G, Lowe J, Gohar L, Matthews B, Nioac de Salles AC, Ellermann C. (2011). Contributions of individual countries' emissions to climate change and their uncertainty. Climatic Change, 106:359-391.
Houser and Mohan (2013a). American Energy Productivity. Rhodium group report. Internet: http://rhg.com/reports/american-energy-productivity
Houser and Mohan (2013b). Natural gas isn't the only reason U.S. carbon emissions are falling, Rhodium group report. Internet:
http://www.washingtonpost.com/blogs/wonkblog/wp/2013/02/15/natural-gas-isnt-the-only-reason-u-s-carbon-emissions-are-plummeting/
Howarth R, Santoro R, Ingraffea A, Phillips N and Townsend-Small A. (2012). Methane Emissions from Natural Gas Systems. Background Paper Prepared for the National Climate Assessment, Reference number 2011-0003, 25 February 2012. Internet: http://www.eeb.cornell.edu/howarth/Howarth%20et%20al.%20--%20National%20Climate%20Assessment.pdf.
Howarth RW, Santoro R and Ingraffea A. (2011). Methane and the greenhouse-gas footprint of natural gas from shale formations. *Climatic Change*. DOI 10.1007/s10584-011-0061-5.
Hultman N, Rebois D, Scholten M, and Ramig C. (2011). The greenhouse impact of unconventional gas for electricity generation, *Environ. Res. Lett.*, 6, 044008,
IAEA (2013). PRIS database. Power reactor information system. Internet: http://www.iaea.org/pris/
ICAP (International Carbon Action Partnership). Internet: http://icapcarbonaction.com/
IEA (2004). Oil Crises and Climate Challenges: 30 Years of Energy Use in IEA Countries. IEA, Paris. ISBN 92-64-01882-4.
IEA (2007). Energy Use in the New Millennium. Trends in IEA Countries. IEA, Paris.
IEA (2008). Worldwide Trends in Energy Use and Efficiency. Key Insights from IEA Indicator Analysis. IEA, Paris.IEA (2011a). Energy Statistics of OECD Countries and Non-OECD Countries, 2011 Edition. International Energy Agency, Paris.
IEA (2012a). World Energy Outlook. OECD/WEO. Internet: http://www.worldenergyoutlook.org/
IEA (2012b), Key World Energy Statistics, OECD, IEA. Internet: http://www.iea.org/publications/freepublications/publication/name,31287,en.html
IEA(2012d). Golden rules for a golden age of gas. WEO Special Report on unconventional gas. International Energy Agency (IEA), Paris. Internet: http://www.iea.org/publications/freepublications/publication/WEO2012_GoldenRulesReport.pdf
IEA (2012e). $CO_2$ emissions from fuel combustion, 2012 Edition. International Energy Agency (IEA), Paris. ISBN 978-92-64-17475-7.
IEA (2012f). Energy statistics of OECD countries and non-OECD countries, 2012 edition. International Energy Agency (IEA), Paris

IEA (2013a) Natural Gas Information 2013, ISBN 978-92-64-20314-3, Internet: http://www.iea.org/W/bookshop/add.aspx?id=629

IEA (2013b) $CO_2$ Capture Facilities and Capacities. Internet: http://www.iea.org/etp/tracking/ccs/

IEA (2013c). Redrawing the energy-climate map. World Energy Outlook Special Report. IEA, Paris. Internet: http://www.iea.org/publications/freepublications/publication/WEO_RedrawingEnergyClimateMap.pdf

IMF (2013). World Economic Outlook Database. International Monetary Fund, 2013.

International Transport Forum (2013). Key Transport Statistics – 2012 Data. Internet: www.internationaltransportforum.org/statistics/shortterm/QCountryNotes.pdf

IPCC (1996). Revised 1996 IPCC Guidelines for National Greenhouse Gas Emission Inventories. Three volumes: Reference manual, Reporting Guidelines and Workbook. IPCC/OECD/IEA. IPCC WG1 Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, United Kingdom.

IPCC (2005). Carbon Capture and Storage Report. Internet: http://www.ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf.

IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme (NGGIP), Eggleston H.S., L. Buendia, K. Miwa, T. Ngara and K. Tanabe (eds), IGES, Japan

Jäger-Waldau A. (2013). Concentrated Solar Thermal Electricity (CSP) snapshot 2012, published in Arnulf Jaeger-Waldau, Fabio Monforti-Ferrario, Manjola Banja, Hans Bloem, Roberto Lacal Arantegui, Márta Szabó, "Renewable Energy Snapshots 2012" . Report EUR 25756 EN.

Jiang M, Griffin WM, Hendrickson C, Jaramillo P, Van Briesen J and Benkatesh A. (2011). Life cycle greenhouse gas emissions of Marcellus shale gas, *Environ. Res. Lett.*, 6, 034014, doi:10.1088/1748-9326/6/3/034014

Joosten H. (2009). The Global Peatland $CO_2$ Picture. Peatland status and drainage related emissions in all countries of the world. Wetlands International, Ede.

JRC/PBL European Commission, Joint Research Centre (JRC) and PBL Netherlands Environmental Assessment Agency (2011). Emission Database for Global Atmospheric Research (EDGAR), release version 4.2 of 11 November 2011 and v 4.2 FT 2010. Internet: http://edgar.jrc.ec.europa.eu.

Kunzig R. (2013). Climate Milestone: Earth's $CO_2$ Level Passes 400 ppm. *National Geographic News*, May 9, 2013. Internet: http://news.nationalgeographic.com/news/energy/2013/05/130510-earth-co2-milestone-400-ppm/

LCICG Programme UK (2012). Cross-Government Carbon Capture and Storage R&D Programme 2011-2015: list of projects. Internet: https://www.gov.uk/government/publications/cross-government-carbon-capture-and-storage-r-d-programme-2011-2015-list-of-projects

Macmillan S, Antonyuk A, Schwind H. (2013). Gas to Coal Competition in the U.S. Power Sector. IEA Insight Series 2013, April 2013. Internet: http://www.iea.org/publications/insights/CoalvsGas_FINAL_WEB.pdf

Marland G, Brenkert A and Olivier JGJ. (1999). $CO_2$ from fossil fuel burning: a comparison of ORNL and EDGAR estimates of national emissions. *Environmental Science & Policy*, 2, 265–274.

Mauther M and Weiss M. (2013). Solar Heat Worldwide. Markets and Contribution to the Energy Supply. IEA Solar Heating & Cooling Programme. http://www.iea-shc.org/data/sites/1/publications/Solar-Heat-Worldwide-2013.pdf

Mazzoldi A, Rinaldi AP, Borgia A and Rutqvist J. (2012). Induced seismicity within geological carbon sequestration projects: Maximum earthquake magnitude and leakage potential from undetected faults. International Journal of Greenhouse Gas Control 10, 434–442.

Meinshausen M, Meinshausen N, Hare W, Raper SCB, Frieler K, Knutti R, Frame DJ and Allen MR. (2009). Greenhouse-gas emission targets for limiting global warming to 2 °C, *Nature*, 458, 1158-1162, doi:10.1038/nature08017.

Morbee J. (2012). Analysis of energy saving potentials in energy generation: final results. JRC scientific and policy report 2012, EUR 25409 EN

Moscow Times (2012). Oil Companies' Fines for Gas Flaring to Hit $500M in 2012. *Moscow Times*, 27 June 2012. Internet: http://www.themoscowtimes.com/business/article/oil-companies-fines-for-gas-flaring-to-hit-500m-in-2012/461221.html.

Moya JA, Pardo N, Mercier A. (2010). Energy efficiency and $CO_2$ emissions: prospective scenarios for the cement industry, EUR 24592 EN – JRC report 2010

NBSC (2009, 2010, 2011, 2012, 2013). Statistical Communiqué of the People's Republic of China on the 2011 National Economic and Social Development. National Bureau of Statistics of China, 22 February 2012; and previous editions. Internet: http://www.stats.gov.cn/english/newsandcomingevents/t20120222_402786587.htm.

NEI (Nuclear Engineering International) (2012, 2013). World Nuclear Industry Handbook, 2012, 2013. Internet: http://viewer.zmags.com/publication/95b5bc6a#/95b5bc6a/1

Nicholson B. (2012). Survey of Flaring Regs for Arkansas, Colorado, Louisiana, North Dakota, Pennsylvania, Texas and Wyoming. Hydraulic fracking, 30 May 2012. Internet: http://fulbrightfrackingblog.blogspot.nl/2012/05/survey-of-flaring-regs-for-arkansas.html.

Nigerian Tribune (2013). Oil sector reform: Challenges of curbing gas flaring. Internet: http://tribune.com.ng/news2013/en/business-package/2012-10-29-11-35-35/energy/item/13503-oil-sector-reform-challenges-of-curbing-gas-flaring.html

NOAA/NCDC (2011). Climate of 2011. National Climatic Data Center, Internet: http://www.ncdc.noaa.gov/sotc/global/2011/13.

NOAA (2012). Global Gas Flaring Estimates through 2011. Pers. comm., 15 April 2012.

Nordau's T, Schellenberger M. (2012). Lessons from the Shale Revolution. http://www.american.com/archive/2012/february/lessons-from-the-shale-revolution

Olivier JGJ, Van Aardenne JA, Monni S, Döring UM, Peters JAHW and Janssens-Maenhout G. (2010). Application of the IPCC uncertainty methods to EDGAR 4.1 global greenhouse gas inventories. In: '3rd International Workshop on Uncertainty in Greenhouse Gas Inventories, 22–24 September, 2010'. Proceedings. Lviv Polytechnic National University, Lviv, Ukraine. ISBN: 978-966-8460-81-4, p. 219–226. Available at: http://ghg.org.ua/fileadmin/user_upload/book/Proceedengs_UncWork.pdf.

Olivier JGJ and Janssens-Maenhout G. (2011). Part III: Greenhouse gas emissions: 1. Shares and trends in greenhouse gas emissions; 2. Sources and Methods; Total greenhouse gas emissions. In: '$CO_2$ emissions from fuel combustion, 2011 Edition', pp. III.1-III.49. International Energy Agency (IEA), Paris. ISBN 978-92-64-102835. Internet: http://wds.iea.org/wds/pdf/documentation_CO2_2011.pdf.

Olivier JGJ and Janssens-Maenhout G. (2012). $CO_2$ Emissions from Fuel Combustion - 2012 Edition, IEA $CO_2$ report 2012, Part III, Greenhouse-Gas Emissions, ISBN 978-92-64-17475-7. Internet: http://www.pbl.nl/en/publications/2012/co2-emissions-from-fuel-combustion-2012-edition

Olivier JGJ, Janssens-Maenhout G, Peters JAHW. (2012). Trends in global $CO_2$ emissions. 2012 report, EUR 25388 EN 2012.

Olivier JGJ and Peters JAHW. (2002). Uncertainties in global, regional and national emission inventories. In: Van Ham, J., A.P.M. Baede, R. Guicherit and J.F.G.M. Williams-Jacobse (eds.):'Non-$CO_2$ greenhouse gases: scientific understanding, control options and policy aspects. Proceedings of the Third International Symposium, Maastricht, Netherlands, 21-23 January 2002', pp. 525–540. Millpress Science Publishers, Rotterdam. ISBN 90-77017-70-4.

Olivier JGJ (2013). Alternative international policy routes for climate change mitigation. Description and quantitative contribution to global emission reductions. PBL Netherlands Environment Assessment Agency, The Hague. In prep.

O'Sullivan F and Paltsev S. (2012). Shale gas production: potential versus actual greenhouse gas emissions. *Environ. Res. Lett.*, 7, 1748-9326. doi:10.1088/1748-9326/7/4/044030

Pearson I, Zeniewski P, Gracceva F, Zastera P, McGlade C, Sorrell S, Speirs J and Thonhause G. (2012). Unconventional Gas: Potential Energy Market Impacts in the European UnionJRC scientific and policy report, EUR25305 EN, ISBN 978-92-79-19908-0. Internet: http://ec.europa.eu/dgs/jrc/downloads/jrc_report_2012_09_unconventional_gas.pdf

Peters GP, Minx JC, Weber CL and Edenhofer O. (2011). Growth in emission transfers via international trade from 1990 to 2008. *Proc. Natl. Acad. Sci.* Internet: www.pnas.org/cgi/doi/10.1073/pnas.1006388108.

Peters GP, Marland G, Le Quéré C, Boden T, Canadell JG and Raupach MR (2012). Rapid growth in $CO_2$ emissions after the 2008–2009 global financial crisis, *Nature Climate Change*, 2, 2–4, doi:10.1038/nclimate1332.

Petron G, Frost G, and Miller BJ, et al. (2012). Hydrocarbon emissions characterization in the Colorado Front Range - A pilot study, *J. Geophys. Res.*, 117, D04304, 19 pp., 20, doi:10.1029/2011JD016360.

Phillippe & partners (2011). Final report on unconventional gas in Europe. 8 November 2011, service contracted by TREN/R1/350-2008 lot 1. Internet: http://ec.europa.eu/energy/studies/doc/2012_unconventional_gas_in_europe.pdf.

Platts (2013). China's coal imports in 2012 rise 58% on year to 289 million mt. Internet: http://www.platts.com/RSSFeedDetailedNews/RSSFeed/Coal/8086761

PLC (Practical Low Company) (2013). Oil and gas regulation in Nigeria: overview. Internet: http://uk.practicallaw.com/5-523-4794?q=*&qp=&qo=&qe=#a353512

Pöyry (2013). Outlook for new coal-fired power stations in Germany, the Netherlands and Spain. Report to DECC, April 2013. Pöyry Management Consulting.

Reuters (2012a). Fracking rules let drillers flare till 2015. 18 April 2012. Internet: http://www.reuters.com/article/2012/04/18/us-usa-fracking-emissions-idUSBRE83H0UH20120418.

Reuters (2012c). Russia oil firms face heavy fines for gas flaring. 16 June 2012. Internet: http://www.reuters.com/article/2012/06/16/russia-oil-flaring-idUSL5E8HG33G20120616.

Reuters (2012d). UPDATE 1-RWE to close UK coal, oil power plants in March 2013. 18 September 2012. Internet: http://www.reuters.com/article/2012/09/18/britain-rwe-closures-idUSL5E8KIB2120120918

Ros JPM, Overmars KP, Stehfest E, Prins AG, Notenboom J and Van Oorschot M. (2010). Identifying the indirect effects of bio-energy production. Report no. 500143003. PBL Netherlands Environmental Assessment Agency, The Hague/Bilthoven.

Saikia K and Sarkar BC. (2013). Coal Exploration Modelling using Geostatistics in Jharia Coalfield, India, *Int. Journal of Coal Geology*, 112, 36-52.

Schneider M and Froggatt A. (2013). World Nuclear Industry Status Report, July 2013. Internet: http://qualenergia.it/sites/default/files/articolo-doc/20130710MSC-WorldNuclearReport2013-LR-V1.pdf

Sgamma KM. (2012). Fracking: Colorado methane study not clear-cut, *Nature*, 483, 407, doi:10.1038/483407e.

Shell (2013). Shell UK ltd. and SSE, Peterhead CCS Project. Internet: http://www.shell.co.uk/gbr/environment-society/environment-tpkg/peterhead-ccs-project.html

Shellenberger M and Nordhaus T. (2013). Has There Been a Great Progressive Reversal? How the Left Abandoned Cheap Electricity. AlterNet, June 3, 2013

Socolow R. (2012). Truths we must tell ourselves to manage climate change. *Vanderbilt Law Review*, 65:6,1455-1478.

Sourcewatch (2013a). Coal power plants proposals in Germany. Internet: http://www.sourcewatch.org/index.php?title=Coal_power_plant_proposals_in_Germany

Sourcewatch (2013b). ALEC 40: Turning Back the Clock on Prosperity and Progress: United Kingdom and Coal. Internet: http://www.sourcewatch.org/index.php/United_Kingdom_and_coal

Stevens P. (2012). The 'Shale Gas Revolution'. Developments and Changes, Chatham House. August 2012. Briefing paper EERG BP 2012/04.

Steinberger JK, Timmons Roberts J, Peters GP and Baiocchi G. (2012). Pathways of human development and carbon emissions embodied in trade. *Nature Climate Change*, 2, 81–85. DOI: 10.1038/nclimate1371).

Systèmes solaires (2007–2012). Biofuels barometer 2007–2012 - EurObserv'ER, *Systèmes solaires, Le journal des énergies renouvelables* n° 179, s. 63-75, 5/2007; n° 185, p. 49-66, 6/2008; n° 192, p. 54-77, 7/2009; n° 198, p. 72-96, 7/2010; n° 198, p. 72-96, 7/2010.

Swart NC and Weaver AJ. (2012). The Alberta oil sands and climate, Commentary, *Nature Climate Change*, 2, 134–136.

Tollefson J. (2012). Air sampling reveals high emissions from gas field. Methane leaks during production may offset climate benefits of natural gas. *Nature*, 482, 139–140.

Tollefson, (2013), Methane leaks erode green credentials of natural gas, *Nature*, 493, 12, doi:10.1038/493012a. Internet: http://www.nature.com/news/methane-leaks-erode-green-credentials-of-natural-gas-1.12123

Tollefson, J. (2013). China slow to tap shale-gas bonanza. *Nature*, 494, 294, doi:10.1038/494294a. Internet: http://www.nature.com/news/china-slow-to-tap-shale-gas-bonanza-1.12457

Trembath A, Jenkins J, Nordhaus T and Shellenberger M. (2012). Where the shale gas revolution came from. Government's role in the development of hydraulic fracturing in shale. Breakthrough Institute. http://thebreakthrough.org/blog/Where_the_Shale_Gas_Revolution_Came_From.pdf

Tu J. (2011). Industrial organisation of the Chinese coal industry. Freeman Spogli Institute for International Studies. Working Paper 103, July 2011. Internet: http://pesd.stanford.edu/publications/23284.

UK Department of Transport (2011, 2012). RTFO Quarterly Report 11: 15 April 2010 - 14 January 2011. Internet: http://www2.dft.gov.uk/pgr/statistics/datatablespublications/biofuels/latest/rtfoqtrly11.pdf.

UNEP (2012). Renewables 2012. Global Status Report. Paris, REN21 Secretariat. Internet: http://www.ren21.net/default.aspx?tabid=5434.

UNEP (2013). Renewable 2013. Global Status Report. REN21 Secretariat, Paris. ISBN 978-3-9815934-0-2. Internet: http://www.ren21.net/Portals/0/documents/Resources/GSR/2013/GSR2013_lowres.pdf

UNFCCC (2012). National submissions of National Inventory Reports (NIR) with inventory data in CRF files. Internet: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/6598.php.

UNFCCC (2013). NIR submissions of the greenhouse gas inventories for Annex I countries. Internet: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/7383.php

UNPD (UN Population Division) (2013). World Population Prospects (WPP), The 2012 Revision . United Nations, Department of Economic and Social Affairs, Population Division.

US EPA (2012a). EPA Issues Final Air Rules for the Oil and Natural Gas Industry. Internet: http://www.epa.gov/airquality/oilandgas/actions.html.

US EPA (2012b). Oil and Natural Gas Sector: Standards of Performance for Crude Oil and Natural Gas Production, Transmission, and Distribution. Background Supplemental Technical Support Document for the Final New Source Performance Standards.

US EPA (2013). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2011. Report no. EPA 430-R-13-001, submitted to the UNFCCC.

USGS (US Geological Survey) ( 2011, 2012, 2013). Cement Statistics and Information, and other commodities. Internet: http://minerals.usgs.gov/minerals/pubs/commodity/.

Van der Werf GR, Randerson JT, Giglio L, Collatz GJ, Kasibhatla PS and Arellano Jr AJ (2006). Interannual variability in global biomass burning emissions from 1997 to 2004, *Atmos. Chem. Phys.*, 6, 3423-3441, 2006, www.atmos-chem-phys.net/6/3423/2006/ doi:10.5194/acp-6-3423-2006

Van der Werf GR, Dempewolf J, Trigg SN, Randerson JT, Kasibhatla PS, Giglio L, Murdiyarso D, Peters W, Morton DC, Collatz GJ, Dolman AJ and DeFries RS. (2008). Climate regulation of fire emissions and deforestation in equatorial Asia, *Proc. Natl. Acad. Sci.*, 150, 20350–20355.

Van der Werf GR, Morton DC, DeFries RS, Olivier JGJ, Kasibhatla PS, Jackson RB, Collatz GJ and Randerson JT. (2009). $CO_2$ emissions from forest loss, *Nature Geoscience*, 2, 737–738. doi:10.1038/ngeo671.

Van Dijk PM, Kuenzer C Zhang J, Wolf KHAA and Wang J. (2009). Fossil Fuel Deposit Fires. Occurrence Inventory, design and assessment of Instrumental Options. WAB report 500102021. PBL Netherlands Environmental Assessment Agency, The Hague/Bilthoven.

Verdonk M, Brink C, Vollebergh H, Roelfsema H. (2013). Evaluation of policy options to reform the EU Emissions Trading System. PBL Netherlands Environment Assessment Agency. Report no. 934. ISBN 978-94-91506-36-9.

Versteeg P., and E.S. Rubin (2011). A technical and economic assessment of ammonia-based post-combustion $CO_2$ capture at coal-fired power plants. *Int. J. of Greenhouse Gas Control*, 5, 1596–1605.

Vivoda V. (2013). After Fukushima: the future of nuclear power in Asia. Internet: www.eastasiaforum.org/2013/03/16/after-fukushima-the-future-of-nuclear-power-in-asia/

Wall T, Stanger R, and Santos S. (2011). Demonstrations of coal-fired oxy-fuel technology for carbon capture and storage and issues with commercial deployment. *Int. J. of Greenhouse Gas Control*, 5, Supplement 1, S5–S15.

Wang Z. and Krupnick A. (2013.) A Retrospective Review of Shale Gas Development in the United States. What Led to the Boom? Resources for the Future, Washington DC, April 2013. Discussion Paper RFF DP 13-12. Internet: http://www.rff.org/RFF/documents/RFF-DP-13-12.pdf

WANO (World Association of Nuclear Operators) (2013). Performance Indicators 2012 of the World Association of Nuclear Operators. http://www.wano.info/wp-content/uploads/2013/04/2012WANO-PI-eng_web-SP.pdf

WBCSD (2009). Cement Industry Energy and $CO_2$ Performance: 'Getting the Numbers Right'. World Business Council for Sustainable Development.

Wei T, Yang S, Moore JC, Shi P, Cui X, Duan Q, Xu B, Dai Y, Yuan W, Wei X, Yang Z, Wen T, and Teng F. (2012). Developed and Developing World Responsibilities for Historical Climate Change and $CO_2$ Mitigation. *Proc. Natl. Acad. Sci.*, 109, 12911–12915. doi: 10.1073/pnas.1203282109.

Wood R, Gilbert P, Sharmina M, Anderson K, Footitt A, Glynn S and Nicholls F. (2011). Shale gas. A provisional assessment of climate change and environmental impacts. A report commissioned by the Cooperative and undertaken by researchers at the Tyndall Centre, University of Manchester.

World Bank (2010). Liquid Biofuels: Background Brief for the World Bank Group Energy Sector Strategy. World Bank, March 2010. Internet: http://siteresources.worldbank.org/EXTESC/Resources/Biofuel_brief_Web_version.pdf.

World Bank (2012). Estimated Flared Volumes from Satellite Data, 2007-2011. Published at the website of the Global Gas Flaring Reduction (GGFR) partnership. Internet: http://go.worldbank.org/G2OAW2DKZ0.

World Bank (2013a). World Development Indicators. Internet: http://data.worldbank.org/data-catalog/world-development-indicators

World Bank (2013b). Mapping Carbon Pricing Initiatives. Developments and Prospects, May 2013, Washington DC

WSA (2012, 2013). Crude steel production statistics. World Steel Association.

Xinhua (2013). China's cabinet approves energy consumption control target. Internet: http://news.xinhuanet.com/english/china/2013-01/30/c_132139588.htm

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