TRENDS IN GLOBAL CO$_2$ EMISSIONS

2012 report

Background Studies

PBL Netherlands Environmental Assessment Agency

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Joint Research Centre

Trends in global co$_2$ emissions
2012 Report

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Contents

Summary

Global emissions of carbon dioxide (CO_2) – the main cause of global warming – increased by 3% in 2011, reaching an all-time high of 34 billion tonnes in 2011. In 2011, China's average per capita carbon dioxide (CO_2) emissions increased by 9% to 7.2 tonnes CO_2. Taking into account an uncertainty margin of 10%, this is similar to the per capita emissions in the European Union of 7.5 tonnes in 2011, the year in which the European Union saw a decrease in emissions of 3%. China, the world's most populous country, is now well within the 6 to 19 tonnes/person range spanned by the major industrialised countries. In comparison, in 2011, the United States was still one of the largest emitters of CO_2, with 17.3 tonnes in per capita emissions, after a steep decline mainly caused by the recession in 2008–2009, high oil prices compared to low fuel taxes and an increased share of natural gas.

With a decrease in 2008 and a 5% surge in 2010, the past decade saw an average annual increase of 2.7%. The top 5 emitters are China (share 29%), the United States (16%), the European Union (EU27) (11%), India (6%) and the Russian Federation (5%), followed by Japan (4%). The fact that global emissions continued this historical growth trend in 2011 seems remarkable at first sight, considering that in many OECD countries CO_2 emissions in fact decreased – in the European Union by 3%, in the United States by 2% and in Japan by 2% – mainly due to weak economic conditions in many countries, mild winter weather in several countries and high oil prices. More important, however, is that CO_2 emissions from OECD countries now account for only one third of global emissions – the same share as that of China and India, where emissions increased by 9% and 6%, respectively, in 2011. 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 2011 was mainly driven by the increase in building construction and expansion of infrastructure, as indicated by the growth in cement and steel production. Domestic coal consumption grew by 9.7% and coal import increased by 10%, making China the world's largest coal importer, overtaking Japan.

Levels of global CO_2 emissions from flaring of unused gas during oil production, which have decreased by about 25% since 2003, did not significantly change in 2011. They roughly amount to the total of CO_2 emissions in Spain. However, according to satellite observations, flaring emissions in the United States are on the rise, with a steep 50% increase in 2011. The main cause is the recent sharp increase in the country's use of hydraulic fracturing, or fracking, for shale oil production and its ensuing flaring of co-produced gas. Recently, the United States also expanded shale gas fracking and has now become the largest natural gas producer in the world.

Since 2000, an estimated total of 420 billion tonnes CO_2 was cumulatively emitted due to human activities (including deforestation). 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 emissions in the 2000–2050 period do not exceed 1,000 to 1,500 billion tonnes CO_2. If the current global increase in CO_2 emissions continues, cumulative emissions will surpass this total within the next two decades.

The share of renewable energy sources excluding hydropower, such as solar and wind energy and biofuels, although still very small, is increasing with accelerated speed; it took 12 years, from 1992 to 2004, to double from a share of 0.5% to 1%, but only 6 more years to double again to 2.1% by 2011. This could represent about 0.8 billion tonnes in potentially avoided CO_2 emissions in 2011 that would have been globally emitted from fossil fuel power generation and road transport, which is similar to the current CO_2 emissions in Germany. Including hydropower, total renewable energy sources presently supply 8.5% of all the energy that is used, globally. The total potentially avoided emissions in 2011 have been estimated at roughly 1.7 billion tonnes CO_2 when including the hydropower capacity that was added from 1992 onwards. About one third of these potentially avoided emissions relate to China and one eighth to Brazil, both mainly due to the increased use of hydropower.

These preliminary estimates have been made by the PBL Netherlands Environmental Assessment Agency and the European Commission's Joint Research Centre (JRC) on the basis of energy consumption data for 2009 to 2011, which were recently published by energy company BP. The estimates are also based on production data for cement, lime, ammonia and steel as well as on emissions per country, from 1970 to 2008, from version 4.2 of the Emission Database for Global Atmospheric Research (EDGAR), a joint project of JRC and PBL.

Introduction

This report discusses the results of a trend assessment of global CO_2 emissions up to 2011 and updates last year's assessment (Olivier et al., 2011). This assessment focusses on the changes in annual CO_2 emissions from 2010 to 2011, and includes not only fossil fuel combustion on which the BP reports are based, but also incorporates all other relevant CO_2 emissions sources including flaring of waste gas during oil production, cement clinker production and other limestone uses, feedstock and other non-energy uses of fuels, and several other small sources. After a short description of the methods used (Chapter 2), we first present a summary of recent CO_2 emission trends, by region and by country, and of the underlying trend of fossil fuel use, non-fossil energy and of other CO_2 sources (Chapter 3). To provide a broader context of the global trends we also assess the cumulative global CO_2 emissions of the last decade, i.e. since 2000, and compare it with scientific literature that analyse 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 (Chapter 4). Compared to last year's report, Annex 1 includes a more detailed and updated discussion of the uncertainty in national and global CO_2 emission estimates.

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 vary widely between years. This variation 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, 2011).

Methodology and data sources used

For global CO_2 emissions from 1970 to 2008 we used the published EDGAR 4.2 data set for greenhouse gases, which resulted from a joint project of the European Commission's Joint Research Centre (JRC) and the PBL Netherlands Environmental Assessment Agency and was released 11 November 2011. This data set provides, for the 1970–2008 period, 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). 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 EDGAR 4.2 data set used for this assessment differs only very slightly from the preliminary EDGAR 4.2

data set of July 2011 that was used in last year's assessment.

EDGAR 4.2 includes CO_2 emission factors for cement production (e.g., kg CO_2/tonne cement produced), taking into account the decreasing share of clinker in cement. In addition, all sources of CO_2 related to non-energy/ feedstock uses of fossil fuels were estimated using the tier 1 methods and data recommended in 2006 IPCC Guidelines on GHG Inventories (IPCC, 2006). In addition to cement production, EDGAR 4.2 includes other industrial non-combustion processes such as production of lime and soda ash (2A) and carbon used in metal production (2C). Collectively, the other carbonate sources add about 30% to global cement production emissions in 2008. In addition, more information on the data sources and methodologies used can be found in Olivier et al. (2011), which is part 3 of IEA (2011b).

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 savannahs and other wooded land estimated by Van der Werf et al. (2006). EDGAR 4.2 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). In addition, also the 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 just for information purposes to this data set. For the trend estimate for the 2008–2011 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 transport '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 using the appropriate activity data or approximated with trends in related statistics as estimator. For the large share of 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 fuel type, the 2008–2009 trend was based on IEA data (IEA, 2011) and the 2009–2011 trend was based on BP data released in June 2012 (BP, 2012). 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

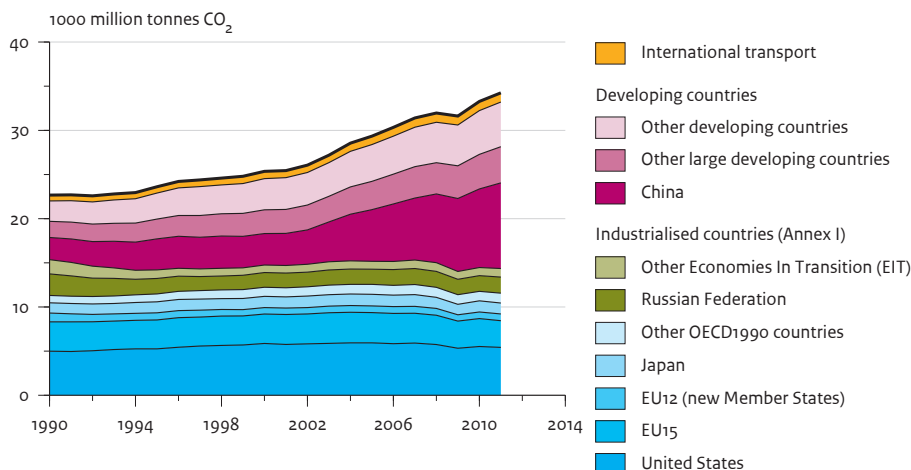## 2.1 Long-term trend in global CO_2 emissions continued in 2011

After a 1% decline in 2009 and an unprecedented 5% surge in 2010, global CO_2 emissions increased by 3% in 2011, compared to the previous year, reaching an all-time high of 34 billion tonnes (Figure 2.1). The five largest emitters are (shares in 2011 between brackets): China (29%), the United States (16%), the European Union (EU27) (11%), India (6%) and the Russian Federation (5%), closely followed by Japan (4%) (Figure 2.2.). Global consumption of coal (responsible for about 40% total CO_2 emissions) grew in 2011 by 5%, whereas global consumption of natural gas and oil products increased by only 2% and 1%, respectively (BP, 2012). Over the past decade, average annual emissions increased by 2.7%. So, with a 3% increase in 2011, global CO_2 emissions resumed this decadal trend, after two years of being heavily affected by the global financial crisis and the rebound in 2010. This was also concluded by Peters et al. (2011) in their analysis of the impact of the 2008–2009 global financial crisis on CO_2 emissions. Based on the decomposition analysis for deriving emission drivers, Jotzo et al. (2012) already expected the surge in 2010 emissions to be temporary.

The fact that global emissions have continued the historical growth rate seems remarkable, at first sight, considering that in many OECD countries CO_2 emissions in fact decreased (in the EU27 by 3% and in the United States and Japan by 2%) due to weak economic conditions in many countries, mild winter weather in several countries and high oil prices. The European Union saw a 10% decrease in natural gas consumption (BP, 2012), the largest decline on record. This is remarkable, because one third of the European gas consumption is normally used for space heating. In addition, the companies covered by the EU Emissions Trading System (EU ETS) reported 2.0% less CO_2 emissions in 2011 than in 2010, for more than 11,000 installations that cover more than 40% of the EU's CO_2 emissions (EC, 2012a). High oil prices affected fuel consumption, particularly in the United States, where average petrol prices jumped 28% in 2011 (even more than in 2008 when oil prices soared) (EIA, 2012a,d). However, even more important is the fact that CO_2 emissions from OECD countries currently account for only one third of global emissions. China and India account for the same share and their emissions increased by 9% and 6%, respectively, in 2011. Although all developing countries together increased their emissions on average by 6%, the increases in China and India caused by far the largest increase in global emissions of 1.0 billion tonnes in 2011.

CO_2 emissions from the cement clinker production process (the largest source of non-combustion-related CO_2 emissions, contributing 4% to the global total) increased globally by 6%, mainly due to an 11% increase in China. The much smaller amount of global CO_2 emissions from gas flaring did not change significantly in 2011, with the largest increases occurring in the United States and Russia, and the largest decrease occurring in Libya.

Figure 2.1

Global CO$_2$ emissions per region from fossil fuel use and cement production

1000 million tonnes CO$_2$

Legend:
- International transport
- Developing countries
  - Other developing countries
  - Other large developing countries
  - China
- Industrialised countries (Annex I)
  - Other Economies In Transition (EIT)
  - Russian Federation
  - Other OECD1990 countries
  - Japan
  - EU12 (new Member States)
  - EU15
  - United States

Source: EDGAR 4.2 (1970–2008); IEA, 2011; USGS, 2012; WSA, 2012; NOAA, 2012

The uncertainty in these figures varies between countries, from 5% to 10% (95% confidence interval), with the largest uncertainties for data on countries with fast changing or emerging economies, such as the Russian Federation in the early 1990s and for 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 revisions later. Therefore, for China and the Russian Federation, we assume 10% uncertainty, whereas for the European Union, the United States, India and Japan, a 5% uncertainty is assumed. Our preliminary estimate for total global CO$_2$ emissions in 2011 is believed to have an uncertainty of about 5% and the increase of 2.9% may be accurate to within 0.5% (see Section A1.3 in Annex 1 for more details).

2.2 Large regional differences: emissions soar in China and India and decrease in OECD countries

OECD and EIT countries

The strong economic recovery in 2010 in most OECD-1990[1] countries did not continue in 2011. In Europe, CO$_2$ emissions from industries regulated by the EU Emissions

Trading System (EU ETS) decreased in 2011 by 2%, after an increase of 3% in 2010 and an exceptional decline in CO$_2$ emissions of 12% in 2009 (EC, 2012). In the United States, industrial emissions from fuel combustion increased by 0.4% in 2011, after a 5% jump in 2010 and steep declines of 3% and 7% in 2008 and 2009, which were mainly caused by the recession in 2008–2009, high oil prices compared to low fuel taxes, and an increased share of natural gas (EIA, 2012a,b). Total emissions in the European Union (EU27) decreased in 2011 by 3% to 3.8 billion tonnes, and in the United States by 2% to 5.4 billion tonnes. In 2011, CO$_2$ emissions also decreased in Japan by 2% to 1.2 billion tonnes, whereas CO$_2$ emissions increased in, for example, Australia (by 8%) and Canada (by 2%) as well as in Spain (by 1%). In Russia, emissions increased by 3% to 1.8 billion tonnes. In other countries with Economies In Transition (EIT), emissions also increased, such as in the Ukraine by 7%. Total CO$_2$ emissions for all industrialised countries that have quantitative greenhouse gas mitigation targets under the Kyoto Protocol decreased in 2011 by 0.7% (including the United States, which did not ratify the Kyoto Protocol) (see Table A1.2).

China and India

Since 2002, annual economic growth in China accelerated from 4% to 11%, on average. CO$_2$ emissions increased by 150% in China, and in India by 75%. Since the end of 2008, China has implemented a large economic stimulus package that helped also to effectively avoid a decrease in annual economic growth, as suffered by many countries during the global recession of 2008–2009. This package was aimed at mitigating the decline in economic

[1] Here, the OECD composition of 1990 is used (i.e. without Mexico, South Korea, Czech Republic, Slovakia, Hungary and Poland).

Figure 2.2
CO$_2$ emissions per country from fossil fuel use and cement production
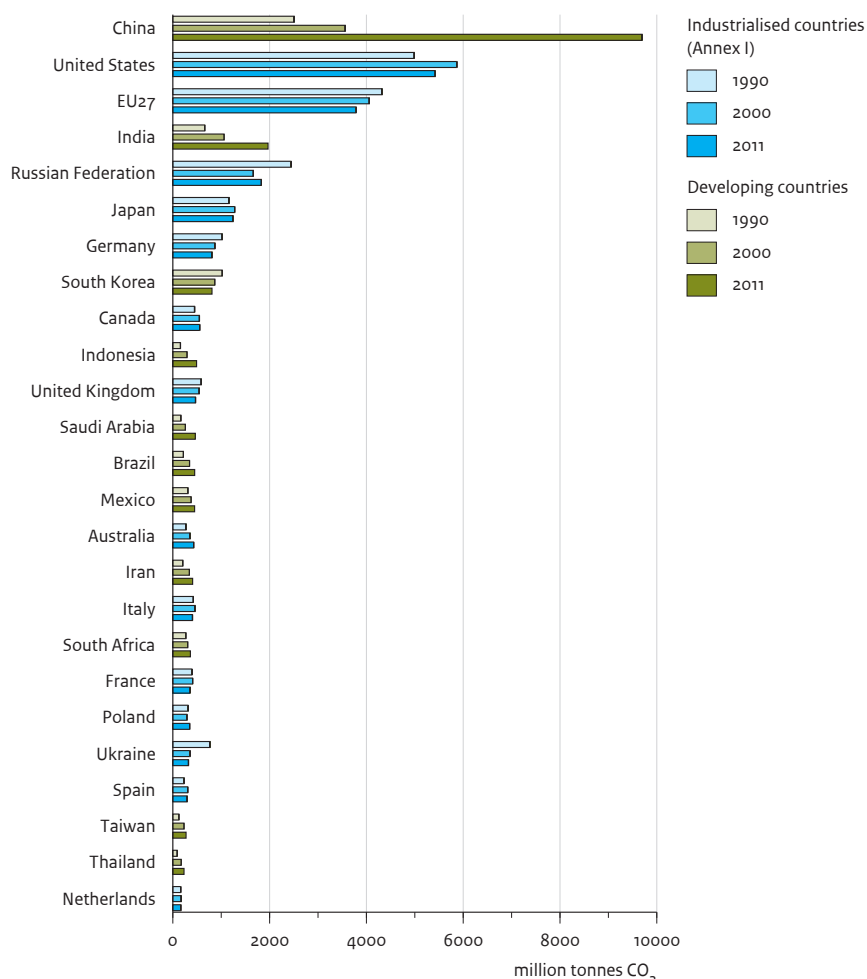
Source: EDGAR 4.2 (JRC/PBL, 2011); IEA, 2011; USGS, 2012; WSA, 2012; NOAA, 2012
Top 25 CO$_2$-emitting countries in 1990, 2000 and 2011

growth and also included investment in transport infrastructure and in rebuilding Sichuan communities devastated by the 2008 earthquake. In 2011, China's CO$_2$ emissions jumped 9% to 9.7 billion tonnes. This increase is consistent with the increase in thermal power generation of 14.7% (mostly in coal-fired power stations), in steel production of 7.3% (also a large coal user) and in cement production of 10.8% reported by the National Bureau of Statistics of China (NBS, 2012). A more detailed discussion on the uncertainty in Chinese fuel consumption data as reported by different sources is presented in Annex 1, Section A1.3. 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), led to the conclusion that the

uncertainty in our estimates would be about 5% for most industrialised countries, and for China this would be in the range of 10%.

India, where domestic demand makes up three quarters of the national economy (Damadaram, 2011), is also relatively unaffected by the global financial downturn. India was hardly affected by the global recession because it stimulated the already high share of domestic consumption in total national expenditure, instead of raising domestic investments in the infrastructure as was done in China to offset the steep decline in the exports-to-GDP ratio. Emissions continued to increase in 2011 by 6% to 2.0 billion tonnes of CO$_2$. India is the fourth largest CO$_2$ emitting country, following the EU27, and well ahead

Figure 2.3
CO_2 emissions per capita from fossil fuel use and cement production
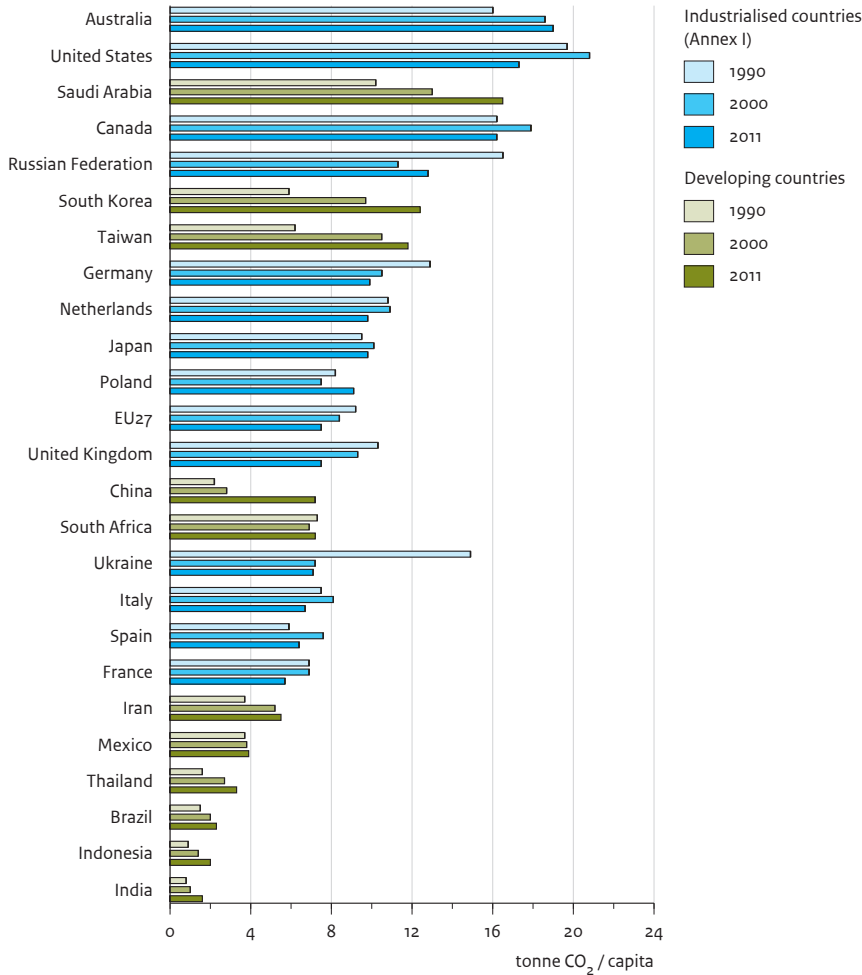
Source of population data: UNPD, 2010 (WSS Rev. 2010)
CO_2 emissions per capita in 1990, 2000 and 2011, in the top 25 CO_2-emitting countries

of Russia, which is the fifth largest (Figure 2.2). Note that most European countries listed are also part of the EU27; they are shown for comparative purposes.

Other developing countries
After the economic recovery in most other developing countries following the recession in 2009, CO_2 emissions followed suit in 2010 with large increases. However, in 2011 CO_2 emissions increased much less. Total CO_2 emissions in the other developing countries increased by almost 2% in 2011, down from the large jump of 7% in 2010, following the economic recovery in these countries after the global recession in 2009. Of the larger countries, Saudi Arabia's CO_2 emissions in 2011 jumped 7%, and Brazil and South Korea saw increases of 3%.

2.3 Comparison between emissions in the various countries

Although emissions in China and other developing countries have increased very rapidly, in recent years, in relative and in absolute figures, the picture is different for CO_2 emissions per capita (Table 2.1 and visualised in Figure 2.3) and per unit of GDP (Figure 2.4). Since 1990, in China, CO_2 emissions per capita increased from 2.2 to 7.2 tonnes, while they decreased in the EU27[2] from 9.2 to 7.5 tonnes per capita and in the United States from 19.7 to 17.3 tonnes per capita.

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[2] Most European countries listed are also part of the EU27.

Figure 2.4

CO$_2$ emissions per unit of GDP from fossil fuel use and cement production
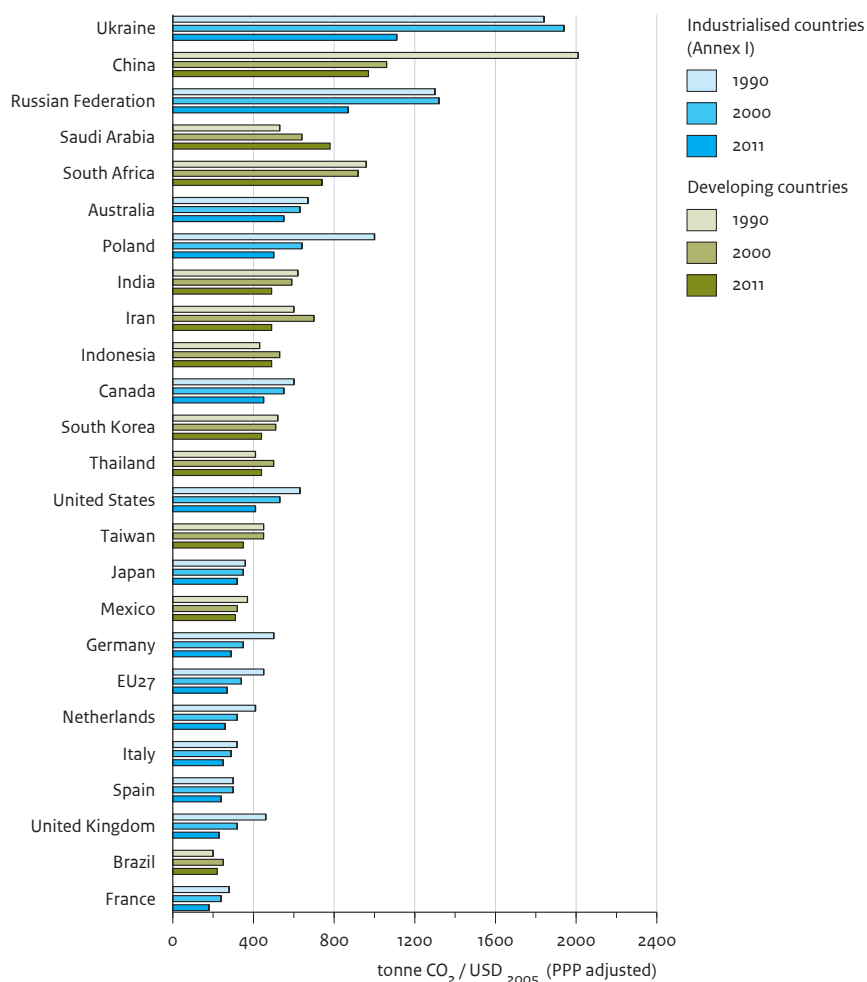
Source of GDP data: World Bank, 2012; IMF, 2012.

CO$_2$ emissions per unit of GDP in 1990, 2000 and 2011, in the top 25 CO$_2$-emitting countries

The trends in CO$_2$ emissions per inhabitant of the top 5 emitting countries are shown in Figure 2.5. These trends reflect a number of factors including the large economic development 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 and 2009, and the impact of climate and energy policies. Factors that also have contributed to the emission decrease in the United States, since 2007, are high oil prices with a relatively large impact on retail prices due to low fuel taxes and an increased share of natural gas in total national fossil fuel consumption of 3 percentage points since 2007 (EIA, 2012a,b). The EU saw a smoother decrease in emissions

during the recession years, among other things, because of the high fuel taxes, which dampened the impact on retail prices of strong international variations in oil prices. The two dashed lines in Figure 2.5 represent the range of CO$_2$ emissions per capita (minimum and maximum) spanned by the major industrialised countries (the Annex I countries listed in Figure 2.2), the highest levels being those in Australia and the United States, and the lowest those in France.

In 2011, China's average per capita CO$_2$ emissions increased by 9% to 7.2 tonnes CO$_2$. Taking into account an uncertainty margin of 10%, this is similar to the European Union's 2011 per capita emissions of 7.5 tonnes, the year

Figure 2.5

CO_2 emissions per capita from fossil fuel use and cement production in top 5 emitters
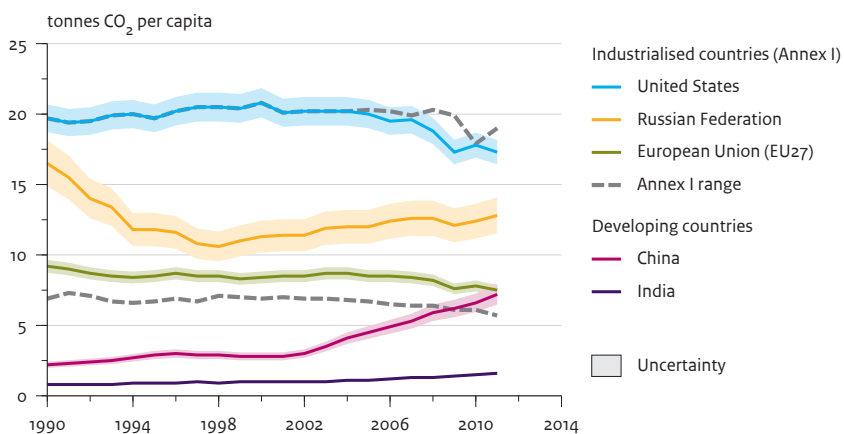
Source: EDGAR 4.2 (1970-2008); UNPD, 2010

Annex I range (grey dashed lines): indicates the minimum and maximum per capita values spanned by major industrialised countries as listed in Figure 2.2.

Uncertainty margins: 5% for the United States, EU27 and India; 10% for the Russian Federation and China (see Section A1.3)

in which the EU saw a 3% decrease in emissions. However, the sectoral shares of, notably, the manufacturing industry and transport are quite different (IEA, 2011b). Due to its rapid economic development, China, the world's most populous country, is now well within the 6 to 19 tonnes/person range spanned by the largest industrialised countries (Annex I countries under the Kyoto Protocol, including the United States (which did not ratify the protocol)). In 2011, the United States was one of the largest CO_2-emitting countries, with 17.3 tonnes per capita. Although per capita emissions in India have doubled since 1990, it is clear that with 1.6 tonnes in 2011 the country's per capita emissions are still much lower than those in industrialised countries.

When comparing CO_2 trends between countries over a decade or more, also trends in population numbers should be taken into account, since population growth rates differ considerably, also between Annex I countries, with the highest growth since 1990 seen in Australia (+32% between 1990 and 2011) and in the United States and Canada (both +24%). The population of the EU and Japan, however, increased much less (by 7% and 3%, respectively) and Russia saw a decline of 4% (see Table A1.2).

2.4 Gas flaring emissions and hydraulic fracturing technology

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. The 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 Russia and Nigeria, with shares of total 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, 2011, 2012, pers. comm.; World Bank, 2012). In Russia and Nigeria flaring emissions did not change much in 2011. However, 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 now the fifth largest gas flaring country. The main cause of the increase is the country's recent massive increase in the use of hydraulic fracturing, or fracking, for shale oil production and the ensuing flaring of co-produced gas (Nicholson, 2012); in particular, in North Dakota and Texas. In North Dakota, natural gas production has more than doubled since 2005, largely due to associated natural gas from its growing oil production, and more than one third of the total amount of gas produced is either flared or otherwise not marketed (EIA, 2012c).

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, 2012). 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% use of produced gas was set for 2012, and companies will be fined if they flare more than 5%. The ministry expects that the 95% target will be met by 2014 (Reuters, 2012c; Moscow Times, 2012). In Nigeria, a newly drafted Petroleum Industry Bill requires oil companies to stop the flaring and venting of associated gas by the end of this year, except under exceptional and temporary circumstances, or they will be fined an amount that is not less than the value of the gas. However, many foresee that implementation of the bill will be difficult, let alone meeting the deadline, since Nigeria already has a law that prohibits flaring, but that was not effectively implemented (Reuters, 2012b; Ukala, 2011).

Shale gas fracking

Recently, the United States also expanded shale gas fracking and in 2011 became the largest gas producer of the world. Although natural gas emits less CO_2 than coal and oil when combusted, there are concerns from life-cycle analyses that the methane emissions from fracking could largely offset this benefit if escaping gas is not captured (Howarth et al., 2011; Tollefson, 2012), whereas 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). In addition, the life-cycle greenhouse gas emissions of shale gas 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). The new US EPA regulation mentioned above requires that the natural gas that currently escapes to the air is captured and either used or sold. The regulation also applies to methane emissions that are currently vented as a result of shale gas fracking.

In Europe, some exploratory drilling has taken place in Sweden, Poland, France and Germany. 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. Hydraulic fracturing is currently taking place in Poland and has been tested at one location in Germany. Concern for the environmental impact of the shale gas activities resulted in shale gas impact assessment studies, leading in France to a legal ban on hydraulic fracturing. 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 Russia for its energy resources, has granted most authorisations and has the most developed exploration activities on its territory.

In conclusion, the knowledge on current and future emissions from flaring and venting related to shale oil and shale gas fracking remains highly uncertain, but may potentially be of high importance.

2.5 Cement production and other 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% to total global emissions. Fuel combustion emissions of CO_2 related to cement production are of the approximate same level, so, in total, cement production accounts for roughly 8% of global CO_2 emissions; in this section, however, we only discuss the emissions from carbonate oxidation.

Cement production

The world's cement production is heavily dominated by China, with an estimated share of 57% in global emissions from cement production, followed by India with a more than 5% share. The following 7 countries have shares of between 1.5% and 2%: the United States, Turkey, Japan, Russia, Brazil, Iran and Vietnam. With a continuing trend in China, global cement production increased by 6% in 2011. China increased cement production by 11% and was responsible for 57% of the world's cement produced in 2011 (NBS, 2012). Production in Germany, Brazil and Russia increased in 2011 by 10%, 6% and 3% in 2011, respectively, according to preliminary estimates by USGS (2012). Cement production is estimated to have increased in 2011 in ten countries and decreased in seven, among which Spain (-12%), Japan (-9%), Egypt (-6%) and Italy (-4%).

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 44% of crude steel production in 2011, followed by Japan (8%), the United States (6%), Russia and India (each 5%), South Korea (4%), Germany (3%) and the Ukraine, Brazil and Turkey (each 2%). According to WSA (2012), global crude steel production rose 6.5% in 2011, compared to 10% in 2010. The 9% increase in China equated to almost one-third of the global increase in production in 2011. Production plummeted in Australia (-12%) and South Africa (-22%). In 2011, it strongly rose in Turkey (+18%), South Korea (+17%) and Taiwan (+15%). Other significant increases were seen in Italy (+8%), India (+8%), the United States (+7%), Brazil (+7%) and Russia (3%). 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, 2012). Lime and ammonia production, other industrial sources of CO_2 emissions, increased globally by 6% and 4%, respectively, in 2011 (USGS, 2012).

2.6 Cumulative CO_2 emissions and climate mitigation targets in the 21st century

Globally, CO_2 emissions increased by 3% in 2011, reaching an all-time high of 34 billion tonnes, with CO_2 emissions from OECD countries accounting for one third of global emissions, and China and India together for another third. In 1990, the industrialised countries with a mitigation target for total greenhouse gas emissions under the Kyoto protocol (including the United States, which did not ratify the protocol) had a share in global CO_2 emissions of 68%, versus 29% for developing countries. In 2011, the shares were 55% for developing countries and 41% for mature industrialised countries. The remaining 3% is attributed to international air and sea transport. The top 6 emitting countries and regions, including the European Union (EU27), produce 70% of total global emissions, whereas the top 25 emitting countries are responsible for more than 80% of total emissions (Figure 2.2).

We observed a growth of 50% 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% in the CO_2

concentration in the atmosphere, from 356 to 392 ppm. Since 2000, an estimated total of 420 ± 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 first decade 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 current global CO_2 emission growth rate would continue, cumulative emissions would exceed this criterion within the next two decades.

However, it is uncertain how global society will develop over time, which economic and technological trends will continue; for example, regarding the shares of nuclear power and renewable energy sources. Without the use of modern renewable energy sources (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).

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. Den Elzen et al. (2012) 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 (51 to 55 billion tonnes CO_2 equivalent) and those consistent with achieving the 2 °C target ranges from 5 to 9 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 (2011). Den Elzen et al. (2012) describe a selected set of options that could result in an additional emission reduction of 4.1 billion tonnes CO_2 equivalent, which would narrow the gap. Very recently, Blok et al. (2012) estimated the impact of 21 major initiatives and claim that together these could stimulate sufficient reductions by 2020 to bridge this global greenhouse gas emission gap.

Trends in energy consumption

3.1 Trends in fossil fuel consumption

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 in most countries in 2011, global energy consumption saw a growth of 2.5%, which is roughly in line with the average growth over the last decade (BP, 2012). Global fossil oil consumption increased by about 2.9% in 2011 (corrected for biofuels). China's oil consumption increased by 5.5%, below the 10-year average, and accounted for two thirds of the growth in trade in 2011, with oil imports increasing by 13%. The CO_2 emission trends in OECD and non-OECD countries are diverging, with a 1.2% decline in OECD countries, the fifth decrease in the past six years versus a 2.8% increase in non-OECD countries.

Natural gas consumption increased globally by 2.2% in 2011, with below average consumption in all regions, except for North America, where low prices drove robust growth (BP, 2012). The largest growth took place in China (+22%), Saudi Arabia (+13%) and Japan (+12%). However the European Union saw the largest decline on record, with -11%, mainly due to warm weather, a weak economy, high gas prices and continued growth in renewable electricity production. See Annex 3 for the regional impact of winter temperatures in 2010 and 2011 on the trend in natural gas used for space heating.

Coal consumption increased globally by 5.4 % in 2011, which is an above average growth, and accounts for 30.3% of global energy consumption, the highest share since 1969. Coal consumption in China increased by 9.7% in 2011, accounting for 49% of global coal use and representing more than three quarters of global consumption growth in 2011. This increase in fuel consumption in 2011 was mainly driven by the increase in building construction and expansion of infrastructure, as indicated by the growth in the cement and steel production. Coal import by China increased by 10%, making China the world's largest coal importer, overtaking Japan (Reuters, 2012d; Tu and Johnson-Reiser, 2012; China Import Magazine, 2012). China's coal import volume, to a large extent, is determined 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 to 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 estimated at about 5% to 15%, with higher uncertainties expected regarding the data on the last 15 years. Annex A1.3 provides more details in a discussion on uncertainty. Coal consumption in India increased by 8%. Consumption in OECD countries decreased by 1.1%, with declines of 5% in the United States and Japan, and increases in the EU (+4%), driven by

Poland (+6%), Spain (+51%, after a similar decrease in 2009), Bulgaria (+24%) and Italy (+8%).

3.2 Trends in renewable and nuclear energy sources

Of the Annex I countries, Japan made the largest change to its fuel mix for electricity production, in an attempt to ensure higher nuclear safety in the wake of the Fukushima accident of 11 March 2011. Before the accident, Japan was the third largest consumer of nuclear fuel, following the United States and France, with a nuclear share in electricity production averaged for 2010 at about 29%. The 280 TWh in 2010 generated by the 54 nuclear reactors (WEC, 2011) have, since May 2012, been reduced to zero, and subsequently partially compensated by power cuts and boosted gas-fired power generation. This implies that in 2011 Japan imported 12.2% more liquefied natural gas than in 2010. Moreover, with the shutdown of the last active nuclear power plant, Japan leaves a capacity of 44 GWe nuclear electricity generation unused. In July 2012, the first nuclear facility was brought back into operation.

Germany also faced a considerable change to its fuel mix for electricity production in 2011, in the aftermath of Fukushima, shutting down 8 nuclear power plants in March 2011 with a combined capacity of 8.5 GWe, reducing the nuclear share in electricity production from 22% before March 2011 to 18% today (Reuters, 2011). This has since been compensated with a rising share of renewables in the energy mix from 16% in 2010 to almost 20% in 2011 (BDEW, 2012). Above all, photovoltaic capacities expanded appreciably in 2011, climbing from 17.3 GW to 25.8 GW and contributing 3% to the power generation in 2011, or 1% more than in 2010. The remaining difference in share is taken up by coal-fired power plants (Kempfert, 2011). At the moment, more than 20 new coal-fired power plants are being planned or already under construction in Germany; together, these plants would achieve a total output of 10 gigawatts and could, in terms of power supply, replace the nuclear power plants that are still operational.

Total renewable sources have grown to supply 16.7% of global final energy consumption, including traditional biofuels, such as fuel wood (UNEP, 2012). Renewables accounted for almost half of the estimated 208 gigawatts (GW) of electric capacity added globally in 2011. By the end of 2011, total renewable power capacity worldwide exceeded 1,360 GW, up 8% over 2010, and supplied an estimated 20.3% of global electricity. At least 118 countries, more than half of which are developing

countries, had renewable energy targets in place by early 2012, up from 96 one year before, although some slackening of policy support was seen in developed countries. In the United States, renewables provided 12.7% of total domestic electricity in 2011, up from 10.2% in 2010, and accounted for about 11.8% of domestic primary energy production (a similar amount as nuclear power). In Germany, renewable sources met 12.2% of total final energy consumption and accounted for 20% of electricity consumption (up from 17.2% in 2010) (UNEP, 2012).

Total global wind power capacity was 238 GW at the end of 2011, an increase of more than 20% over 2010, lower than the average of about 28% over the last 10 years (GWEC, 2012). In 2011, most wind power capacity was installed in Asia (52%), ahead of Europe (25%) and North America (20%). However, Europe still has the largest wind power capacity in the world, with 40% of the total in 2011, but since it has been attracting less than a quarter of the newly installed capacity, it could be overtaken by Asia in 2012. China is the world's largest wind power market, but new installations levelled off for the first time in 2011. China added 17,600 MW of new wind capacity in 2011, resulting in a total of 62.4 GW installed at the end 2011. Wind represented 1.5% of the total power generated in China last year. According to GWEC (2012), the grid remains 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 3,000 MW of new capacity to reach a total of 16.1 GW, accounting for about 6% of electricity generation, up from 2% in 1995. During 2011, 9,600 MW of new wind power was installed in the European Union, the same amount as in 2010, resulting in a total capacity of 93.9 GW. Germany installed 2,100 MW of new capacity, the United Kingdom 1,300 MW, followed by Spain (1,000 MW), Italy (950 MW), France (830 MW), Sweden (763 MW) and Romania (520 MW). The total wind power capacity installed in the EU by the end of 2011, on average, will produce 200 TWh of electricity, which is equivalent to 6.3% of total EU electricity consumption (up from 5.3% in 2010). The United States added 6,800 MW wind capacity in 31 States in 2011, a 30% increase from 2010, bringing total wind capacity to 46.9 GW.

Total global solar photovoltaic (PV) capacity increased in 2011 by 75% to about 69.2 GW, and could produce, on average, 85 terawatt hours (TWh) of electricity every year (EPIA, 2012). PV, after hydropower and wind power, currently is the third most important renewable energy in terms of globally installed capacity. Europe accounts for three quarters of the newly installed capacity (21.9 GW), adding another 75% to the already installed PV capacity in the EU. China more than doubled its installed capacity,

adding 2.2 GW; 1.8 GW from large-scale ground installations and 0.4 GW from rooftop projects. The global total of 29.7 GW installed in 2011 is almost double the capacity installed in 2010 (16.2 GW) and was dominated by rapid growth in the EU, led by Italy (9.3 GW) and Germany (7.5 GW), followed by France (1.7 GW) and the United Kingdom (0.8 GW). By comparison, the United States and Japan installed 1.9 and 1.3 GW, respectively, and India 0.5 GW. At the beginning of 2012, Germany and Italy together represent more than 50% of the world's installed capacity.

Hydropower output increased by 1.6% in 2011, the weakest growth since 2003. The top 5 hydropower producers in 2011 were China (20% share), Brazil (12%), Canada (11%), the United States (10%) and Russia (5%). Heavy rainfall drove strong growth in North America with a 5% increase in the United States, the strongest increase on record, and 19% increase in India. Other increases were seen in Canada and Brazil (both +7%). These were offsetting drought-related declines; in Europe of 16% and China of 4%. Of the 62% increase in hydropower output since 1992, China accounted for almost half and Brazil for almost one fifth (BP, 2012).

Global biofuel production stagnated, rising by just 0.7%, the weakest annual growth since 2000 (BP, 2012). In the United States, growth in consumption (+6%) slowed 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, and Brazil's consumption had the largest decline (-13%) due to a poor sugar harvest. In the EU, biofuel consumption decreased by 3% in 2011, driven by large decreases in France (-14%), the United Kingdom (-24%) and Poland (-15%), although partly offset by increases in Italy, Romania and Slovakia. 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% (Eijkhout 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.

Renewable energy supply expanding at accelerated speed, reducing emissions by 5%

The trends in CO_2 emissions reflect the impact of policies aimed to improve energy efficiency and to increase the use of nuclear or renewable energy sources over that of fossil fuels. In this context, we can observe that some CO_2 mitigation measures are increasingly applied in our society. One of the main CO_2 reduction options is the use of 'new' renewable energy sources (excluding hydropower), such as solar and wind energy and biofuels. Although still very small, their share is increasing with accelerating speed: it took 12 years since 1992 to double the share from 0.5% to 1%, but only 6 more years to double it again to 2.1% in 2011 (BP, 2012). These shares are based on the BP convention of 38% average thermal power conversion efficiency for converting renewable electricity production to primary energy. Using an emission factor mid-way between the IPCC's default values for coal and natural gas (effectively a factor for diesel fuel), this represents about 800 million tonnes CO_2 in potentially avoided emissions in 2011 that would have been globally emitted from fossil fuel power generation and road transport. This amount is similar to the current CO_2 emissions from Germany. Including hydropower, total renewable energy sources presently supply 8.5% of all energy. Total potentially avoided emissions in 2011 are estimated at roughly 1.7 billion tonnes CO_2 when including the hydropower capacity added since 1992. Thus, present global CO_2 emissions, potentially, could have been about 5% higher without the use of these renewable energy sources. About one third of these potentially avoided emissions relates to China and one eighth to Brazil, both mainly due to the increased use of hydropower. If these and other main CO_2 reduction measures, such as energy savings, are going to be applied on a large scale, the current rate of increasing emissions will slow down and the probability that the 2 °C target will be achieved (see Section 2.6) may increase, substantially.

Annex 1

Methodology and data sources for the 2008–2011 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 the 2009–2011 period from the BP Review of World Energy 2011 (BP, 2012). For cement production, preliminary data over the 2009–2011 period were used from the US Geological Survey (USGS, 2012) except for China for which use was made of National Bureau of Statistics of China (NBS) (2009, 2010, 2011).

For the 2008–2011 trend estimate, 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 2008–2011 emissions:
(1) Fuel combustion (IPCC category 1A + international bunkers):
- For energy for 2008–2009, 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, 2011) to calculate the trend per country and for international air and water transport.
- For energy for 2009–2011, 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, 2012). For oil consumption, the BP figures were corrected for biofuel (fuel ethanol and biodiesel) which are included in the BP oil consumption data. See Annex 2 for more details.
- '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 2008–2011 are assumed to be similar to the trend in crude steel production for 2008–2009 from USGS (2011) and for 2009–2011 from the Word Steel Association (WSA, 2012).
- 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.)

(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 preliminary cement production data for 2009–2011 published by the US Geological Survey (USGS), except for China where use was made of the National Bureau of Statistics of China (NBS) (2010, 2011, 2012). 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 the 2009–2011 period, 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 2008–2011 (USGS, 2012) as proxy to estimate the trend in the other 2A emissions. All 2011 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 2009–2011 World Steel Association (WSA, 2012) 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 2011 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 Tg CO_2 per year. This is equivalent to about 0.3% of China's CO_2 emissions in 2011.

A1.2 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.

A1.3 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 Russia 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

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)

Country	1990	1995	2000	2005	2008	2010	Average	Reported uncertainty	Note on uncertainty
USA	-2%	-3%	-2%	-3%	-3%	-3%	-2%	4%	for minimum: -2%
Canada	-2%	-2%	-2%	-1%	-2%	-0.3%	-2%	2.4%	for energy sector
EU27	-2%	-2%	-1%	-2%	-0.4%	0.4%	-1%	2%	for EU15
Russia	-2%	11%	13%	13%	12%	12%	10%	4%	
Ukraine	7%	25%	20%	4%	4%	5%	13%	3.7%	
Japan	2%	2%	2%	3%	3%	6%	2%	1%	
Australia	-2%	-3%	2%	8%	8%	-1%	2%	4 to 5%	
In total	**-1.4%**	**0.4%**	**0.8%**	**0.3%**	**0.6%**	**0.8%**	0.4%		

Source: EDGAR 4.2: JRC/PBL (2011); NIR/CRF data: UNFCCC (2012).

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 (2012) reported a 9.7% increase in coal consumption in China for 2011, which is the same trend reported by the National Bureau of Statistics of China (NBS, 2012). In contrast, last year, there was a 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 National Bureau of Statistics of China reported an increase of 5.9% in coal consumption per tonne. However, we note that the current BP (2012) report also contains revised coal consumption data, which for China show a 6.1% increase in 2010 and which could be indicative of the order of magnitude of the uncertainties in the statistics.

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).

A1.4 Results

Table A1.1 shows the trends in CO_2 emissions per region/country for the 1990–2011 period, as presented in Figure 2.1 and Table A1.2 shows the change in per capita CO_2 emissions for 1990–2011 and of population for a numbers of countries . These tables and the figures used in Figures 2.3 and 2.4 can also be found as spreadsheet on the PBL website: http://www.compendiumvoordeleefomgeving.nl/indicatoren/nl0533-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
Trends in CO_2 emissions per region/country, 1990–2011 (unit: billion tonnes of CO_2)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
USA	4.99	4.96	5.04	5.18	5.26	5.26	5.44	5.58	5.65	5.69	5.87	5.75	5.83	5.87	5.94	5.94	5.84	5.91	5.74	5.33	5.53	5.42
EU27	4.32	4.27	4.12	4.04	4.02	4.08	4.15	4.06	4.07	4.01	4.06	4.13	4.11	4.22	4.23	4.19	4.21	4.15	4.09	3.79	3.91	3.79
EU15	3.33	3.36	3.29	3.22	3.23	3.27	3.34	3.28	3.32	3.29	3.33	3.39	3.39	3.47	3.47	3.43	3.43	3.37	3.32	3.07	3.16	3.02
- France	0.39	0.42	0.41	0.39	0.38	0.39	0.40	0.39	0.42	0.41	0.41	0.42	0.41	0.42	0.41	0.41	0.40	0.39	0.40	0.38	0.38	0.36
- Germany	1.02	0.99	0.94	0.93	0.92	0.92	0.94	0.91	0.90	0.87	0.87	0.89	0.87	0.88	0.88	0.85	0.86	0.84	0.86	0.80	0.84	0.81
- Italy	0.43	0.42	0.42	0.42	0.41	0.44	0.42	0.42	0.43	0.43	0.46	0.46	0.47	0.48	0.48	0.48	0.49	0.47	0.46	0.41	0.42	0.41
- Spain	0.23	0.24	0.25	0.23	0.24	0.25	0.24	0.26	0.27	0.29	0.31	0.31	0.33	0.33	0.35	0.36	0.35	0.37	0.33	0.30	0.29	0.30
- United Kingdom	0.59	0.60	0.58	0.56	0.56	0.56	0.57	0.55	0.55	0.54	0.55	0.56	0.55	0.56	0.55	0.55	0.56	0.54	0.53	0.49	0.50	0.47
- Netherlands	0.16	0.17	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.17	0.17	0.18	0.18	0.18	0.18	0.18	0.17	0.17	0.17	0.16	0.17	0.16
EU12 (new) MemberSstates)	1.00	0.91	0.83	0.81	0.79	0.81	0.80	0.78	0.75	0.71	0.73	0.73	0.72	0.75	0.76	0.76	0.78	0.78	0.77	0.72	0.75	0.76
- Poland	0.31	0.31	0.30	0.31	0.31	0.32	0.30	0.30	0.29	0.28	0.29	0.28	0.28	0.29	0.31	0.31	0.32	0.32	0.32	0.31	0.34	0.35
Japan	1.16	1.17	1.18	1.18	1.23	1.25	1.26	1.26	1.22	1.26	1.28	1.26	1.30	1.31	1.31	1.32	1.30	1.33	1.25	1.18	1.26	1.24
Other Annex II	0.83	0.83	0.85	0.85	0.87	0.89	0.92	0.96	0.99	1.01	1.03	1.03	1.05	1.08	1.10	1.12	1.11	1.15	1.14	1.10	1.07	1.11
- Australia	0.27	0.28	0.28	0.28	0.29	0.30	0.31	0.33	0.35	0.36	0.36	0.36	0.37	0.38	0.40	0.41	0.42	0.42	0.44	0.44	0.40	0.43
- Canada	0.45	0.44	0.45	0.45	0.47	0.48	0.49	0.51	0.52	0.53	0.55	0.54	0.55	0.57	0.57	0.57	0.55	0.59	0.57	0.53	0.54	0.56
Russian Federation	2.44	2.30	2.08	2.00	1.76	1.75	1.72	1.59	1.57	1.62	1.66	1.67	1.66	1.72	1.73	1.72	1.79	1.81	1.80	1.74	1.78	1.83
Other Annex I-EIT*	1.62	1.53	1.35	1.19	1.02	0.97	0.89	0.87	0.87	0.85	0.85	0.86	0.89	0.93	0.93	0.89	0.92	0.97	0.99	0.89	0.92	0.97
- Ukraine	0.77	0.71	0.63	0.55	0.45	0.45	0.39	0.38	0.36	0.36	0.35	0.35	0.35	0.38	0.36	0.34	0.33	0.35	0.34	0.28	0.30	0.32
China	2.51	2.65	2.78	3.02	3.19	3.52	3.62	3.59	3.65	3.57	3.56	3.64	3.90	4.50	5.28	5.85	6.51	7.01	7.79	8.27	8.90	9.70
- cement production in China	0.09	0.11	0.13	0.16	0.18	0.20	0.21	0.21	0.22	0.24	0.24	0.27	0.29	0.34	0.38	0.42	0.48	0.53	0.54	0.64	0.73	0.82
Other large DC*	1.83	1.91	1.99	2.03	2.15	2.24	2.35	2.46	2.53	2.60	2.69	2.72	2.81	2.91	3.09	3.20	3.37	3.56	3.54	3.70	3.93	4.10
- India	0.66	0.70	0.74	0.76	0.81	0.87	0.92	0.96	0.97	1.03	1.06	1.08	1.12	1.15	1.24	1.29	1.38	1.48	1.56	1.75	1.86	1.97
- Brazil	0.22	0.23	0.23	0.24	0.25	0.27	0.29	0.31	0.32	0.33	0.35	0.35	0.35	0.34	0.36	0.37	0.37	0.39	0.41	0.39	0.44	0.45
- Mexico	0.31	0.32	0.32	0.32	0.34	0.33	0.34	0.35	0.38	0.37	0.38	0.38	0.38	0.39	0.40	0.42	0.44	0.45	0.45	0.44	0.44	0.45
- Iran	0.21	0.23	0.24	0.24	0.27	0.28	0.29	0.30	0.31	0.32	0.34	0.35	0.37	0.40	0.43	0.45	0.48	0.51	0.37	0.38	0.40	0.41
- Saudi Arabia	0.17	0.17	0.19	0.20	0.21	0.21	0.23	0.23	0.24	0.25	0.26	0.27	0.28	0.30	0.31	0.32	0.34	0.36	0.38	0.40	0.43	0.46
- South Africa	0.27	0.26	0.27	0.27	0.27	0.29	0.30	0.31	0.32	0.30	0.31	0.29	0.31	0.34	0.36	0.36	0.36	0.37	0.37	0.35	0.36	0.36
Other non-Annex I *	2.31	2.42	2.51	2.65	2.76	2.94	3.13	3.27	3.26	3.38	3.53	3.60	3.69	3.81	4.03	4.17	4.31	4.47	4.30	4.34	4.65	4.75
- Asian tigers**	0.71	0.79	0.84	0.92	0.99	1.07	1.17	1.24	1.17	1.25	1.31	1.36	1.41	1.46	1.53	1.57	1.61	1.65	1.68	1.68	1.81	1.84
- South Korea**	0.25	0.28	0.30	0.33	0.37	0.40	0.43	0.45	0.39	0.42	0.45	0.46	0.48	0.49	0.51	0.50	0.51	0.52	0.54	0.54	0.59	0.61
- Indonesia**	0.16	0.17	0.18	0.19	0.20	0.21	0.23	0.26	0.26	0.28	0.29	0.32	0.32	0.33	0.35	0.36	0.38	0.40	0.41	0.44	0.49	0.49
- Taiwan**	0.13	0.14	0.14	0.16	0.16	0.17	0.18	0.19	0.21	0.22	0.23	0.24	0.25	0.25	0.26	0.27	0.28	0.28	0.27	0.26	0.27	0.27
- Thailand**	0.09	0.10	0.11	0.13	0.14	0.16	0.18	0.18	0.17	0.17	0.17	0.18	0.19	0.20	0.22	0.23	0.23	0.22	0.23	0.22	0.23	0.23
International transport	0.66	0.66	0.69	0.68	0.69	0.72	0.73	0.76	0.77	0.82	0.83	0.80	0.84	0.85	0.93	0.95	1.00	1.05	1.04	1.01	1.04	1.04
Total	22.7	22.7	22.6	22.8	22.9	23.6	24.2	24.4	24.6	24.8	25.4	25.4	26.1	27.2	28.5	29.3	30.3	31.4	31.7	31.3	33.0	33.9

* Including other countries of the former Soviet Union and Turkey.
** Asian tigers = Indonesia, Singapore, Malaysia, Thailand, South Korea and Taiwan.
*** Other large developing countries = Brazil, Mexico, South Africa, Saudi Arabia, India and Iran.
**** Remaining developing countries.

Table A1.3

CO$_2$ emissions in 2011 (million tonnes CO$_2$) and CO$_2$/capita emissions, 1990–2011 (tonne CO$_2$/person)

Country	Emissions 2011	Per capita emissions				Change 1990–2011	Change 1990–2011 in %	Change in CO$_2$ 1990–2011 in %	Change in population 1990-2011, in %
		1990	2000	2010	2011				
Annex I*									
United States	5420	19.7	20.8	17.8	17.3	-2.4	-12%	9%	19%
EU27	3790	9.2	8.4	7.8	7.5	-1.7	-18%	-12%	6%
Germany	810	12.9	10.5	10.2	9.9	-3	-23%	-21%	4%
United Kingdom	470	10.3	9.3	8.1	7.5	-2.8	-27%	-20%	8%
Italy	410	7.5	8.1	6.9	6.7	-0.8	-11%	-4%	7%
France	360	6.9	6.9	6.1	5.7	-1.2	-17%	-9%	10%
Poland	350	8.2	7.5	8.8	9.1	0.9	11%	11%	1%
Spain	300	5.9	7.6	6.3	6.4	0.5	8%	29%	16%
Netherlands	160	10.8	10.9	10.5	9.8	-1	-9%	2%	11%
Russian Federation	1830	16.5	11.3	12.4	12.8	-3.7	-22%	-25%	-4%
Japan	1240	9.5	10.1	10	9.8	0.3	3%	7%	3%
Canada	560	16.2	17.9	16	16.2	0	0%	24%	19%
Australia	430	16.0	18.6	17.9	19.0	3	19%	57%	24%
Ukraine	320	14.9	7.2	6.7	7.1	-7.8	-52%	-58%	-14%
Non Annex I									
China	9700	2.2	2.8	6.6	7.2	5	227%	287%	15%
India	1970	0.8	1.0	1.5	1.6	0.8	100%	198%	30%
South Korea	610	5.9	9.7	12.2	12.4	6.5	110%	141%	11%
Indonesia	490	0.9	1.4	2	2.0	1.1	122%	210%	24%
Saudi Arabia	460	10.2	13.0	15.8	16.5	6.3	62%	181%	43%
Brazil	450	1.5	2.0	2.2	2.3	0.8	53%	106%	24%
Mexico	450	3.7	3.8	3.9	3.9	0.2	5%	45%	27%
Iran	410	3.7	5.2	5.4	5.5	1.8	49%	100%	27%
South Africa	360	7.3	6.9	7.1	7.2	-0.1	-1%	35%	27%
Taiwan	270	6.2	10.5	11.7	11.8	5.6	90%	119%	13%
Thailand	230	1.6	2.7	3.3	3.3	1.7	106%	155%	18%

Source of population data: UNPD, 2010 (WPP Rev. 2010)

* 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 has signed but not ratified the protocol, and thus the US emission target in the protocol has no legal status.

Annex 2

Data set on biofuel consumption in road transport per country, 2005–2011

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 A2.1). Palm oil and solid biomass used in stationary combustion such as power generation was not considered, as it is not relevant for this study.

Biofuel consumption data on road transport for the 2005–2011 period were used from the following sources:
- UNFCCC (2012) for Annex I countries (industrialised countries reporting emissions to the UN Climate Secretariat, at present data for 1990–2010), 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 over the 2005–2009 period from Systèmes solaires (2007, 2008, 2009, 2010,2011) and EBB (2010, 2011).
- Supplemental data for 2011 for the United States, Germany, the United Kingdom and Brazil, comprising almost 80% of the global total consumption were taken from EIA (2011d), BMU (2012), the United Kingdom (2011, 2012) and Barros (2010, 2011, 2012), respectively. For nine developing countries, IEA (2010a) was used for biofuel consumption in 2005–2009. For four more countries, reported biofuel consumption was found.
- Various sources were used to obtain bioethanol and biodiesel consumption data for over the 2005–2011 period in Brazil and China. Reported consumption data were used for 2011 for China, India and Argentina.

Where time series were incomplete for 2011, amounts were calculated using the 2008–2011 trend of total global biofuel production from BP (2012) for Annex I countries while country-specific trends for 2008–2011 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 2008–2011 data are used in the CO_2 estimation method used in this study. For years up to 2008, the EDGAR 4.2 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).

Table A2.1
Biofuel consumption in road transport (bioethanol and biodiesel), 2005–2011 (in TJ)

Country	2005	2006	2007	2008	2009	2010	2011
Annex I	504,840	752,870	1,004,790	1,268,780	1,490,240	1,767,950	1,813,950
United States	364,700	509,800	660,700	829,600	943,100	1,128,500	**1,197,500**
Canada	10,200	11,500	25,600	25,100	36,800	48,900	**41,300**
Australia	0	0	900	2,700	5,500	7,600	10,000
Norway	200	200	1,400	3,700	4,300	5,200	5,200
Japan	400	400	500	500	1,100	1,800	1,800
Belarus	0	0	0	400	1,000	1,400	1,400
Turkey	0	100	500	3,200	100	200	900
New Zealand	0	0	50	90	500	600	200
Switzerland	300	400	600	600	400	300	500
Monaco	0	10	10	30	30	20	20
Iceland	0	0	0	10	10	10	10
EU27, of which:	129,040	230,460	314,530	402,850	497,400	573,420	555,120
Austria	3,100	11,500	13,800	17,200	21,900	21,600	23,300
Belgium	0	0	2,000	4,300	10,900	15,600	15,000
Bulgaria	0	300	0	200	200	900	1,600
Croatia	0	0	100	100	300	100	200
Cyprus	0	0	0	600	700	700	700
Czech Republic	100	800	1,500	3,600	5,700	7,300	10,100
Denmark	0	200	300	200	300	1,100	1,400
Estonia	10	50	20	180	70	300	300
Finland	0	0	100	3,300	6,000	5,900	7,100
France	16,700	29,300	60,200	93,400	99,800	114,400	98,400
Germany	78,600	143,600	155,600	126,100	113,000	121,100	**123,300**
Greece	0	2,000	3,600	2,900	3,300	5,400	5,600
Hungary	0	400	1,200	6,900	7,100	7,300	6,700
Ireland	0	100	900	2,400	3,200	3,900	3,300
Italy	6,600	6,400	6,600	32,700	50,900	59,100	63,700
Latvia	100	100	100	100	200	1,100	1,200
Lithuania	200	1,200	2,200	2,600	2,200	1,900	2,100
Luxembourg	0	0	1,900	1,900	2,000	2,000	1,800
Malta	30	30	70	40	30	20	20
Netherlands	0	2,000	13,000	12,000	15,600	9,600	9,700
Poland	2,000	3,800	4,000	18,500	27,800	37,100	31,400
Portugal	0	2,500	4,900	4,700	8,400	12,600	14,000
Romania	0	100	1,000	2,900	4,400	4,800	9,800
Slovakia	0	800	2,200	2,300	2,600	3,400	7,200
Slovenia	0	80	540	1,030	1,200	1,900	1,900
Spain	11,300	7,400	16,900	27,300	47,300	63,300	58,600
Sweden	7,400	10,300	13,500	16,300	16,700	18,200	16,600
United Kingdom	2,900	7,500	8,300	19,100	45,600	52,800	**40,100**

Table A2.1 (continued)

Country	2005	2006	2007	2008	2009	2010	2011
Non-Annex I	314,560	331,180	450,980	486,000	682,900	737,400	664,100
Brazil	288,900	270,500	374,900	401,100	535,500	552,600	**479,400**
China	14,800	42,200	46,400	48,500	57,300	57,300	**56,300**
Thailand	1,500	2,800	5,900	5,700	30,800	30,600	30,600
Argentina	600	600	600	600	1,100	22,300	22,300
Colombia	600	5,300	5,900	6,700	18,300	20,300	20,300
South Korea	500	1,700	3,300	3,200	10,000	13,000	13,000
Philippines	0	100	1,200	1,200	6,500	8,500	8,500
Indonesia	0	0	1,700	5,000	4,200	8,000	8,000
India	4,600	5,000	5,600	5,500	4,500	5,200	5,200
Peru	0	0	800	1,000	3,800	4,600	4,600
Taiwan	0	0	200	1,200	2,100	4,100	4,100
Paraguay	700	700	600	700	2,500	3,100	3,100
Serbia	0	0	1,000	2,000	3,000	3,000	3,000
Costa Rica	0	0	60	100	600	600	1,600
Jamaica	0	0	0	100	1,200	1,200	1,200
Uruguay	60	80	120	100	200	500	500
Cuba	2,200	1,700	800	900	400	400	400
18 Other countries	100	500	1,900	2,400	900	2,100	2,000
Global total	819,000	1,084,000	1,456,000	1,755,000	2,173,000	2,505,000	2,478,000

Notes: Data for 2011 were extrapolated using total global production data, except for Germany, the United Kingdom, the United States, Brazil and some others (shown in bold). The other 16 countries with reported biofuel consumption, for 2011 estimated between 300 TJ and 20 TJ, are in decreasing order: Guadeloupe, Ecuador, Pakistan, Mexico, Hong Kong, Israel, Malaysia, Malawi, Vietnam, Singapore, Ethiopia, South Africa, Honduras, Fiji, Guatemala, Macedonia, Rwanda, and Tanzania.

Annex 3

Regional temperature anomalies in the winters of 2010 and 2011

Winter temperatures can vary considerably from year to year and can have a significant impact on the energy demand for space heating of houses and offices. Therefore, winter temperature is one of the main variables influencing inter-annual changes in fuel consumption on a national and global scale. Other key explanatory variables are economic growth and trends in fuel prices. Indicators used for estimating the difference between the winters of 2011 and 2010 are the annual number of heating degree days (HDDs) for particular cities or countries, and spatial temperature anomalies across the globe.

The number of heating degree days at a certain location or a population weighted average over a country is defined as the number of days that the average temperature is below a chosen threshold, for instance 15 °C, below which space heating is assumed to be applied (also used by Eurostat). The HDD number for a particular day is defined as the difference between the threshold temperature and the average temperature that day. Although the HDD method is a proxy for the energy demand for space heating and does not give precise values, it is often used in trend analysis of energy consumption. In Table A3.1, the number of heating degree days in 2010 and 2011 are shown in or near selected cities as indicator of winter temperatures in these countries or regions. The absolute numbers indicate the amount of fuel required for space heating per household (e.g., much more in Moscow than in Los Angeles or New Delhi). From the table can be concluded that, in particular, in north-western Europe and parts of the United States, the winter of 2011 was much milder than the very cold winter of 2010 as it was experienced in Germany, the Netherlands , the United Kingdom and in one state of the United States (Atlanta); in 2010, HDDs were about one quarter higher than in 2009. For a global analysis of the winter months of 2011 in comparison with 2010 see NOAA/NCDC (2012c). Here you can also find global maps with the global temperature anomalies for the winter periods of 2010 and 2011.

Table A3.1
Heating degree days (HDD-15) for selected cities and countries in 2011, compared with 2010

Country	City	HDD 2010	HDD 2011	Difference
China	Beijing	2642	2338	-12%
	Shanghai	1068	1181	11%
India	New Delhi	196	221	13%
	Mumbai	0	0	
Japan	Tokyo	1000	1054	5%
	Osaka	1142	1244	9%
Russia	Moscow	4040	3720	-8%
Germany	Berlin	2834	2136	-25%
	Düsseldorf	2413	1723	-29%
Netherlands	Amsterdam	2436	1749	-28%
United Kingdom	London	2105	1469	-30%
Italy	Rome	947	1062	12%
EU	**EU average**	**3269**	**2954**	**-10%**
USA	New York	1772	1761	-1%
	Washington, DC	1652	1510	-9%
	Atlanta	1373	980	-29%
	Los Angeles	285	327	15%
	US average	**4464**	**4339**	**-3%**

Source: http://www.degreedays.net, using a threshold of 15 ºC, except for US average (NOAA, 2012b) for which the threshold is 65 ºF (≈ 18.3 ºC), and the EU average (EC-DG ENER, 2011) with data on Q1+Q2+Q4.

List of abbreviations

BRIC	Brazil, Russia, India and China
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
EBB	European Biodiesel Board
EC	European Commission
EDGAR	Emission Database for Global Atmospheric Research
EIA	U.S. Energy Information Administration
EIT	Economies in Transition
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
GWEC	Global Wind Energy Council
HDD	Heating degree Day
IEA	International Energy Agency
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
JRC	European Commission's Joint Research Centre
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
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

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, 2011, 2012). Brazil Sugar Annual 2010/2011/2012. GAIN reports no. BR-10002, BR-110006 and BR-12005. USDA.

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.

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.

BP (2012). BP Statistical Review of World Energy 2012. Internet: www.bp.com/statisticalreview/.

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.

China Import Magazine (2012). China has become the top coal importing country. Internet: http://www.chinaimportexport.org/china-has-become-the-top-coal-importing-country/.

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

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.

DBEW (Federal Association of the Energy and Water Industry) (2012). Renewable Energies Second Most Important Energy Source in 2011. http://www.germanenergyblog.de/?p=8235 Original in German: http://www.bdew.de/internet.nsf/id/DE_20111216-PI-Die-Verantwortung-waechst.

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

EC (2012). 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-DG ENER (2011). Quarterly Report on European Electricity Markets: Market Observatory For Energy, Volume 4, Issue 1: January 2011 – March 2011, Issue 2: April 2011 – June 2011, Issue 4: October 2011 – December 2011. Internet: http://ec.europa.eu/energy/observatory/index_en.htm.

EC-DN ENER (2012). Quarterly Reports On European Gas Markets, Quarterly Reports On European Electricity Markets. Interrnet: http://ec.europa.eu/energy/observatory/index_en.htm.

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.

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, 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.

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.

EPIA (2012). Global Market Outlook for Photovoltaics until 2016. European Photovoltaic Industry Association, Brussels. Internet: http://files.epia.org/files/Global-Market-Outlook-2016.pdf.

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

GCP (Global Carbon Project) (2011). Internet: http://www.globalcarbonproject.org/.

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 Published online, 10 June 2012.

GWEC (2012). Global wind report. Annual market update 2011. Global Wind Energy Council. http://www.gwec.net/fileadmin/documents/NewsDocuments/Annual_report_2011_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.

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.

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.

Hunter L. (2011). Regulatory demands raising the bar for accurate flare gas measurement, Offshore, 71,78. Internet: http://www.offshore-mag.com/articles/print/volume-71/issue-10/production-operations/regulatory-demands-raising-the-bar-for-accurate-flare-gas-measurement.html.

IEA (2011a). Energy Statistics of OECD Countries and Non-OECD Countries, 2011 Edition. International Energy Agency, Paris.

IEA (2011b). CO_2 from fuel combustion. 2011 Edition. International Energy Agency, Paris.

IMF (2012). World Economic Outlook Database, International Monetary Fund, April 2012.

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 (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.

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

Jotzo F, Burke PJ, Wood PJ, Macintosh A and Stern DI. (2012). Decomposing the 2010 global carbon dioxide emissions rebound, *Nature Climate Change*, 2, 213–214, doi:10.1038/nclimate1450.

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

Kempfert C. (2011). The coming German energy turnaround, Bulletin of the Atomic Scientist, September 2011. Internet: http://www.thebulletin.org/web-edition/op-eds/the-coming-german-energy-turnaroundhttp://www.thebulletin.org/web-edition/op-eds/the-coming-german-energy-turnaround.

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.

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.

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

NBS (2010, 2011, 2012). 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.

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.

NOAA/NCDC (2010, 2011). Climate of 2010/2011. National Climatic Data Center, Internet: http://www.ncdc.noaa.

gov/sotc/global/2010/13; http://www.ncdc.noaa.gov/sotc/global/2011/13.

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

NOAA/NCDC (2012b). Contiguous U.S. Heating Degree Days, May 1895-2012. Internet: http://www.ncdc.noaa.gov/temp-and-precip/time-series/?parameter=hdd.

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, 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.

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.

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.

Reuters (2011). German energy use to fall 4.8% in 2011, 20 December 2011, http://af.reuters.com/article/energyOilNews/idAFL6E7NK2NU20111220.

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 (2012b). Nigeria oil bill to outlaw gas flaring by end-2012. 8 May 2012. Internet: http://www.reuters.com/article/2012/05/28/oil-nigeria-flaring-idUSL5E8GR2IX20120528.

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). China overtakes Japan as world's top coal importer. Internet: http://www.reuters.com/article/2012/01/26/us-coal-china-japan-idUSTRE80P08R20120126.

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

Systèmes solaires (2007–2011). Biofuels barometer 2007–2011 - 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.

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.

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.

Tu KJ and Johnson-Reiser S. (2012). Understanding China's Rising Coal Imports. Policy Outlook, February 2012. Internet: http://carnegieendowment.org/files/china_coal.pdf.

UK (2011, 2012). RTFO Quarterly Report 11: 15 April 2010 - 14 January 2011. Department of Transport. Retrieved 16 June 2011 from http://www2.dft.gov.uk/pgr/statistics/datatablespublications/biofuels/latest/rtfoqtrly11.pdf.

Ukala E. (2011). Gas Flaring in Nigeria's Niger Delta: Failed Promises and Reviving Community Voices, Washington & Lee J. Energy, Climate & Environment, 2, 97. Internet: http://scholarlycommons.law.wlu.edu/jece/vol2/iss1/4.

UNEP (2011). Bridging the Emissions Gap. United Nations Environment Programme. Internet: http://www.unep.org/publications/ebooks/bridgingemissionsgap/.

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

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.

UNPD (UN Population Division) (2010). World Population Prospects (WPP), Revision 2010.

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

USGS (U.S. Geological Survey) (2010, 2011, 2012). Cement Statistics and Information, and other commodities. Internet: http://minerals.usgs.gov/minerals/pubs/commodity/.

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.

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.

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

WEC (2011). World Energy Perspective: Nuclear Energy One Year After Fukushima, World Energy Council, http://www.worldenergy.org/documents/world_energy_perspective__nuclear_energy_one_year_after_fukushima_world_energy_council_march_2012_1.pdf.

World Bank (2010). Liquid Biofuels: Background Brief for the World Bank Group Energy Sector Strategy. World Bank, March 2010. Retrieved 17 June 2011 from 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/G2OAW2DKZo.

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