LONG-TERM TREND IN GLOBAL CO_2 EMISSIONS

2011 report

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Long-term trend in global CO_2 emissions

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Contents

Summary

After a 1% decline in 2009, global carbon dioxide (CO_2) emissions increased by more than 5% in 2010, which is unprecedented in the last two decades, but similar to the increase in 1976 when the global economy was recovering from the first oil crisis and subsequent stock market crash. CO_2 emissions went up in most of the major economies, led by China and India with increases of 10% and 9% respectively. The average annual growth rate in CO_2 emissions over the last three years of the credit crunch, including a 1% increase in 2008 when the first impacts became visible, is 1.7%, almost equal to the long-term annual average of 1.9% for the preceding two decades back to 1990. However, most industrialised countries have not recovered fully from their decreases in emissions of 7 to 12% in 2009.

The industrialised countries that have ratified the Kyoto Protocol plus the non-ratifying USA have emitted approximately 7.5% less CO_2 in 2010 than in 1990 and collectively remain on target to meet the original Kyoto Protocol objective of a 5.2% reduction. However, there are large national differences, with for instance over the period 1990 – 2010 decreases in CO_2 emissions in the EU and Russia, increases in the USA and stabilisation in Japan. The efforts of the industrialised countries are increasingly hidden in the global picture where their share of CO_2 emissions has dropped from about two-thirds to less than half since 1990. Continued growth in the developing nations and economic recovery in the industrialised countries are the main reasons for a record breaking 5.8% increase in 2010 in global CO_2 emissions to an absolute maximum of 33.0 billion ton. Increased energy end-use efficiency, nuclear energy and the growing contribution from renewable energy cannot yet compensate for the globally increasing demand for power and transport. This illustrates the large and joint effort still required for mitigating climate change.

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 2008 to 2010 recently published by BP. The estimates are also based on production data for cement, lime, ammonia and steel and emissions per country from 1970 to 2008 from version 4.2 of the Emissions Database for Global Atmospheric Research (EDGAR), a joint project of JRC and PBL.

ONE

Introduction

This paper discusses the method and results of a trend assessment of global CO_2 emissions up to 2010 and updates the previous assessment of CO_2 emissions up to and including 2009 (Olivier and Peters, 2010). This assessment 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 regional trends and the achievements of the Kyoto Protocol countries we also assess the global CO_2 emissions trend of the last four decades, where we look at emission trends per main sector rather than by country or region (Chapter 4). As 2010 is the central year of the five-year Kyoto Protocol target period of 2008-2012, we compare the CO_2 emissions trend of industrialised countries of the last two decades with the targets set out in the protocol (Chapter 5). From the results we draw some conclusions for further mitigation of greenhouse gas emissions based on the large observed differences between countries in their energy mix and the historical rate of change in the mix (Chapter 6).

TWO

Methodology and data sources used

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., 2010). However, this percentage is highly uncertain and varies from 15% to 35% 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 from 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).

2.1 Methodology and data sources for the 1970-2008 period

The estimate of global CO_2 emissions from 1970 to 2008 that we use in this study is based on the results of the EDGAR 4.2 dataset, a joint project of the European Commission's Joint Research Centre (JRC) and the PBL Netherlands Environmental Assessment Agency. This dataset provides for the period 1970-2008 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 dataset under release in July 2011 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).

For fuel-related combustion emissions, the EDGAR dataset uses detailed international energy statistics from the International Energy Agency (IEA, 2010a) and a state-of-the-art technology-based methodology, and CO_2 emission factors for 56 fuel types published in the 2006 IPCC Guidelines for GHG Emission Inventories (IPCC, 2006). Other sources of CO_2 emissions include flaring and venting of associated gas from oil production, the production of minerals such as cement and lime, metals production, the production of chemicals such as ammonia and ethylene, and several other small sources such as lubricant and paraffin wax use. Moreover, to improve completeness, several other small sources identified in the 2006 IPCC Guidelines (IPCC, 2006) were added, such as waste incineration (6C) and underground coal fires in China and elsewhere (7A). These sources add about 0.3% to fuel combustion emissions.

Although not used in this study, the EDGAR 4.2 dataset 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). The study of Van der Werf et al. use the GFED model that uses high resolution satellite observations of burned areas, land use maps and a model to estimate carbon density per grid cell and the fraction of carbon burnt[1]. 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).

For this assessment, we use the EDGAR 4.2 dataset which differs slightly from the basic historical data in EDGAR 4.1 that was used in last year's assessment (Olivier and Peters, 2010), apart from being updated from 2005 to 2008. EDGAR 4.2 updated statistics for the years 2000-2005 and added new statistics for the 2006-2008. In addition, for a few sources a new or fully updated dataset for activity data was used for the whole time series 1970-2008 (flaring data primarily from NOAA /NCDC (2011), lime production was substantially changed (UNFCCC, 2010) and emissions from peat decay from drained peatlands are now based on data from Joosten (2009). Also the net carbon stock changes for forest remaining forest land, based on data from the FAO's Forest Resources Assessment (FAO, 2010), resulting in CO_2 emissions or carbon storage, have been added to the version 4.2 dataset.

EDGAR 4.2 includes the latest 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). As well as 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. More information on the data sources and methodologies used can be found in Olivier et al. (2010), which is part 3 of IEA (2010b).

2.2 Methodology and data sources for 2009-2010

For the trend estimate for the period 2008-2010, 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 was estimated using the appropriate activity data or was approximated with trends in related statistics as estimator. For the large fraction 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 2008-2010 trend was based on BP data released in June 2011 (BP, 2011).

Likewise, the fugitive emissions from fuels (1B) have been divided into solid fuels (coke production), and oil and gas (gas flaring and venting). Minerals production (2A) was divided into cement production and other sources, and for the latter, lime production was used as trend indicator. For other non-fuel combustion sources, for chemicals production (2B) – including liming of soils with urea (4D4) – ammonia was used as trend indictor, and for metal production (2B), crude steel production was used. For the other small non-energy uses of lubricants, waxes and solvents (2G+3), the 2005-2008 trend was linearly extrapolated. The same was done for category 7A that comprises the relatively small underground coal fires[2] and oil and gas fires (in Kuwait in 1992).

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 general uncertainty characteristics in global and national emission inventories in Olivier and Peters (2002).

Notes

1 Annual CO_2 emissions from forest and peat fires from 1997 to 2009 have been estimated by Van der Werf *et al*. (2010) using the GFED 3.1 model. Their analysis does not include CO_2 emissions from the decay of organic materials of plants and trees after burning and logging.

2 Underground coal fires are mainly in China and India. The global total is estimated in EDGAR 4.2 at about 46 million tonnes, of which about two-thirds originates from China, with a high uncertainty of about 50%.

THREE

Results

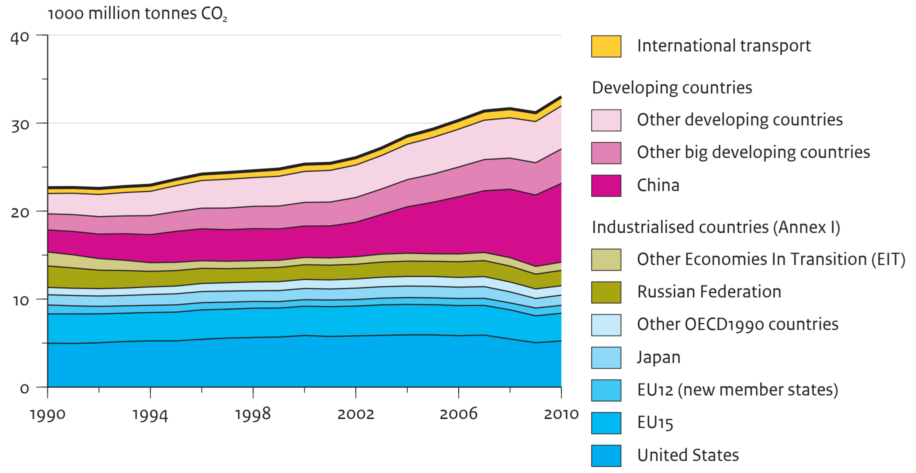
3.1 Global CO_2 emissions growth in 2010 returned to the long-term historic trend

After a decline in CO_2 emissions in 2009 of 1% (including a correction for the leap year 2008), global emissions have jumped by more than 5% in 2010, which is unprecedented in the last two decades, also the absolute figure of 1.8 billion tonnes of additional CO_2, leading to about 33.0 billion tonnes of CO_2 emissions for 2010. Global consumption of coal and natural gas (responsible for about 40% and 20% of total CO_2 emissions, respectively) grew in 2010 both by 7% and cement production emissions (contributing 4% to the total) by 11%. In 2010, colder winter months than in 2009 in many regions (Blunden et al., 2011) increased the demand for gas for space heating which also contributed to the increase. Together with a low 1% increase in 2008, when the first impacts of the global credit crunch became visible, and the 1% decline in 2009, the last three credit crunch years show an average annual growth rate of 1.7%. Since this 3-year average percentage is almost equal to the long-term annual average of 1.9% for the preceding two decades back to 1990, one could say that the very large emissions growth in 2010 made it up for the two preceding recession years. Although there is uncertainty in these figures, especially for countries with fast emerging economies and for the most recent statistics, our preliminary estimate for total global CO_2 emissions in 2010 is believed to have an uncertainty of about 5% and the increase of 5% may be accurate to 1%-point (see Annex 1 for more details).

This growth of well over 5% after a year of declining global emissions is similar to the recovery of the global economy in 1976, when the first oil crisis had caused global emissions to decrease in 1974 and 1975. It indicates that not only have emissions increased substantially in 2010 in China and India - by 10% and 9% mainly due to a similar increase in coal consumption - but also in most of the other major economies such as the European Union, the USA, Japan and Russia. The latter however have not recovered fully from their decreases in emissions of 7% to 12% in 2009.

Since 2002, an accelerated global annual CO_2 growth rate is seen as a consequence of the industrialisation of China. China's economy grew at a much faster pace and the global share of coal increased from 26% to 30%. In 2010 emissions from global coal consumption increased by more than 7%, which is the fastest global growth since 2003, as China accounts for about two-thirds of the increase according to BP statistics. Natural gas consumption grew globally by 7% last year, the largest increase since 1984, with CO_2 emissions following suit. Fossil oil consumption increased by 3% globally in 2010 where the fraction biofuels in road transport increased from 3.1 to 3.4%. This reduced the increase in demand for fossil oil products in road transport by about one tenth. In total, the use of road biofuels represented in 2010 a

Figure 3.1
Global CO_2 emissions from fossil fuel use and cement production per region



Source: EDGAR4.2 (1970-2008); IEA, 2010; USGS,2011; WSA,2011; NOAA,2011

maximum saving of at most 150 million tonnes of fossil CO_2 through substitution of regular petrol and diesel in road transport.

CO_2 emissions from the cement clinker production process, the largest of non-combustion sources of CO_2, increased globally by 11%, mainly due to a 16% increase in China. Since 1990 these emissions increased from 0.5 to 1.4 billion tonnes of CO_2. Including related combustion emissions, the cement industry accounts globally for about 8% of global CO_2 emissions, a share that has doubled since 1990.

3.2 Large regional differences: China and India jump by 10% and 9% while OECD and EIT countries increase by 3%

OECD and EIT countries

In 2010 the economy of most OECD-1990[1] countries recovered nearly all of the large drops in output of heavy, energy-intensive industries such as steel and basic chemicals production and power generation due to the recession of 2008-2009. In Europe, CO_2 emissions from industries regulated by the EU Emissions Trading Scheme (ETS) increased in 2010 by 3%, which is substantially lower than the rebound in output, after an exceptional decline of CO2 emissions of 11.8% in 2009 (EC, 2011a). In the USA, industry emissions from fuel combustion increased by 3.8% (EIA, 2011a). Total emissions in the EU-27 increased by 3% to 4.0 billion tonnes (in the EU-15 also by 3% to 3.1 billion tonnes) and in the USA by 4% to 5.2 billion tonnes (after decreases in 2009 of 4% in the EU-27 and EU-15 and 8% in the USA). The CO_2 emissions increased in Japan by 6.5% to 1.2 billion tonnes and in Russia by 4% to 1.7 billion tonnes. In other countries with Economies-In-Transition (EIT) the emissions also increased, such as Ukraine by 5% and Poland by 4%. In contrast, CO_2 emissions decreased in countries like Spain (-3%) and Australia (-8%) but also in Greece and New Zealand. Total CO_2 emissions of all industrialised countries that have quantitative greenhouse gas mitigation targets under the Kyoto Protocol increased in 2010 by 3.5% (including the USA that did not ratify the protocol), but again, most of them have not returned to pre-recession levels.

China and India

Since 2003, CO_2 emissions in China have doubled, and in India they have increased by 60%. Since the end of 2008, China has been implementing a large economic stimulus package over a two-year period. This package includes investment in transport infrastructure and in rebuilding Sichuan communities devastated by the 2008 earthquake. In 2010, CO_2 emissions jumped by 10% to 9.0 billion tonnes, even though China has doubled its installed wind and solar power capacity for the sixth year in a row. This increase of 10% is consistent with the increase in thermal power generation of 11.6% (mostly by coal-fired power stations) and steel production of 9.6% (also a large coal user) and cement production of 15.1% reported by NBS China (2011), but for a more detailed discussion of the uncertainty in Chinese fuel consumption

Table 3.1
Expenditure in China and India (unit:% of GDP)

Expenditure (% of GDP)	China	India
Private consumption	35,1	57,2
Government consumption	12,9	11,5
Total consumption	48,0	68,7
Investments	45,4	29,5
Exports - Imports (net)	4,4	-3,2

Source: Damodaram (2011)
Note: China GDP of 2009, India GDP of 2010-11.

data as reported by different sources see Annex 1, section A.1.4. India, where domestic demand makes up three-quarters of the national economy (see Table 3.1), is also relatively unaffected by the credit crunch. In India domestic consumption instead of domestic investments in the infrastructure is the main reason why it was hardly affected by the global recession. Emissions continued to increase in 2010 by 9% to 1.8 billion tonnes of CO_2. India is the fourth largest CO_2 emitter, well before Russia that is the fifth-largest and after the EU-27 (Figure 3.2).

Other developing countries
In 2010 the economy of most other developing countries also recovered from the recession in 2009, with CO_2 emissions following suit. Brazil jumped 12% (from -5% in 2009), South Korea jumped 9% (from 1% in 2009). Notable exceptions are Mexico (no growth vs. -3% in 2009) and Hong Kong (-6% vs. +5% in 2009). In total, CO_2 emissions in these countries increased on average almost 5% in 2010, up from 2% in 2009.

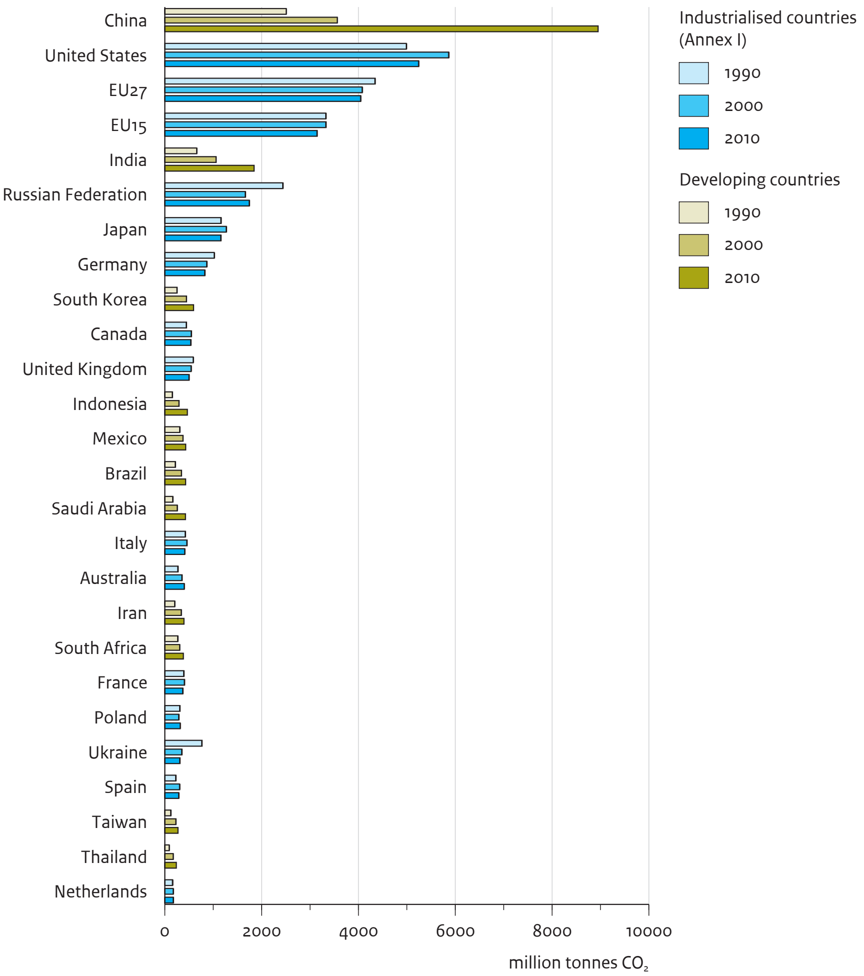
3.3 Global emissions resumed structural growth trend

In 2010, total global CO_2 emissions had increased 30% since 2000 to 33.0 billion tonnes and 45% since 1990, the base year of the Kyoto Protocol. In 1990, global emissions were 22.7 billion tonnes, an increase of 45% on the 1970 level of 15.5 billion tonnes. We observe that the growth rate of 45% of global CO_2 emissions in the 20 years since 1990 did not change compared to the 20 years before 1990. However, there is a geographical shift in the importance of the manufacturing sector as it becomes increasingly replaced by the less fuel-intensive service sector in industrialised countries. In 1990 the industrialised countries with a mitigation target for total greenhouse gas emissions under the Kyoto protocol (including the USA that did not ratify the protocol) had a share in global CO_2 emissions of 68% versus 29% for developing countries. The large regional variation in emission growth trends resulted in 2010 in shares for 54% of developing countries and 43% for mature industrialised countries. The remaining 3% is accounted for international air and sea transport. The top-6 emitting countries, including the EU-27, comprise 70% of total global emissions whereas the top-25 emitting countries capture more than 80% of total emissions (Figure 3.2). Note that most European countries listed are also part of the EU-15 or EU-27, which are shown for comparative purposes.

While emissions in China and other developing countries have increased very rapidly in recent years, also in absolute figures, the picture is different for CO_2 emissions per capita (Table 3.1 and visualised in Figure 3.3) or per unit of GDP (Figure 3.4). Since 1990, CO_2 emissions per capita have increased in China from 2.2 to 6.8 tonne per capita and decreased in the EU-27 from 9.2 to 8.1 tonne per capita (in EU-15 from 9.1 to 7.9) and from 19.7 to 16.9 tonne per capita in the USA. We note again that most European countries listed are also part of the EU-15 or EU-27. These changes reflect a number of factors including the large economic development in China, structural changes in national and global economies, and the impact of climate and energy policies. Due to its rapid economic development, per capita emissions in China are quickly approaching levels common in the industrialised countries of the Annex I group under the Kyoto Protocol. In fact, present CO_2 emissions per person in China are now equal to those of Italy, higher than France, but still smaller than that of Germany, although the sectoral shares of households, transport, power generation, manufacturing industry and the service sector are quite different. However, if the current trends in emissions by China and the industrialised countries including the USA would continue for another seven years, China will overtake the USA by 2017 as highest per capita emitter among the 25 largest emitting countries. Although per

Figure 3.2

CO_2 emissions from fossil fuel use and cement production per country



Source: EDGAR4.2

Top-25 CO_2-emitting countries in 1990, 2000 and 2010.

capita emissions of India doubled since 1990, with 1.5 tonne per capita they are much lower than industrialised countries. When comparing CO_2 trends between countries for 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 (+30%) and USA and Canada (both +23%). In contrast, the population EU and Japan increased much less (by 6% and +4%) and Russia saw a decline (Table 3.2).

Table 3.2

CO_2 emissions in 2010 (million tonnes CO_2) and CO_2/capita emissions 1990-2010 (unit: tonne CO_2/person)

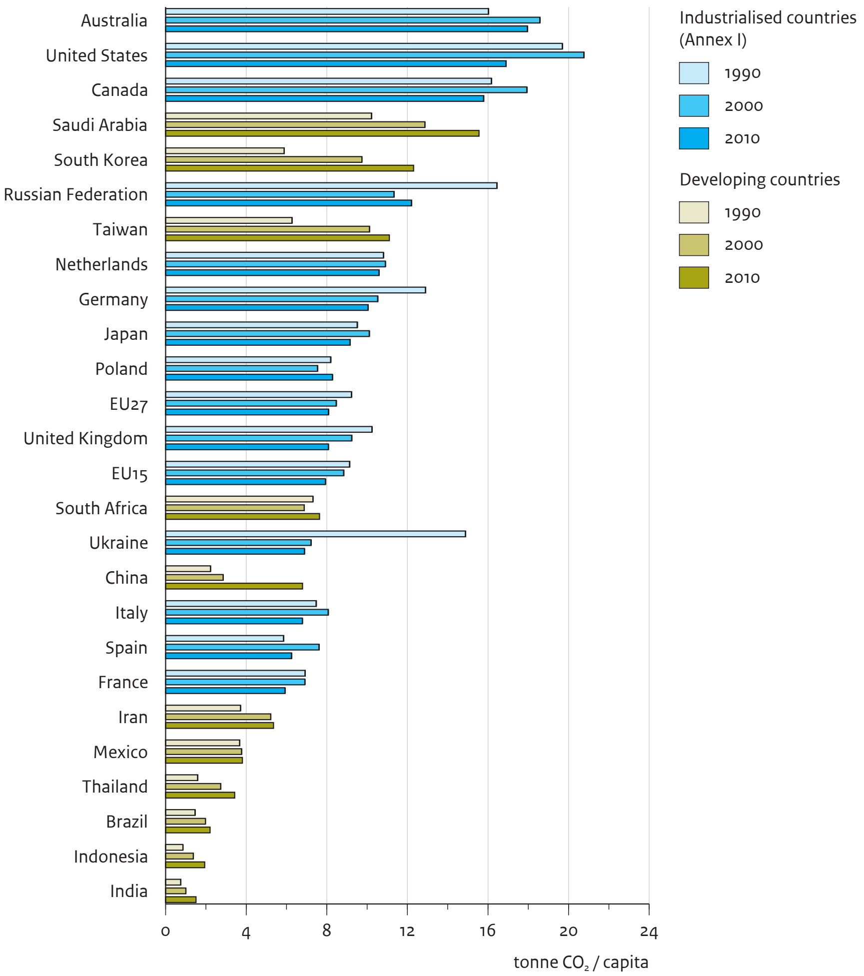
		Per capita emissions						
	Emissions 2010	1990	2000	2010	Change 1990-2010	Change in %	Change in CO_2, %	Change in population, %
Annex I *								
United States *	5.250	19,7	20,8	16,9	-2,8	-14%	5%	23%
EU-27	4.050	9,2	8,5	8,1	-1,1	-12%	-7%	6%
EU-15 **	3.150	9,1	8,8	7,9	-1,2	-13%	-5%	9%
- Germany	830	12,9	10,5	10,0	-2,9	-22%	-19%	4%
- United Kingdom	500	10,2	9,2	8,1	-2,2	-21%	-15%	8%
- Italy	410	7,5	8,1	6,8	-0,7	-9%	-3%	7%
- France	370	6,9	6,9	5,9	-1,0	-15%	-5%	11%
- Poland	320	8,2	7,5	8,3	0,1	1%	2%	1%
- Spain	290	5,9	7,6	6,3	0,4	7%	26%	18%
- Netherlands	180	10,8	10,9	10,6	-0,2	-2%	9%	12%
Russian Federation	1.750	16,5	11,3	12,2	-4,2	-26%	-28%	-4%
Japan	1.160	9,5	10,1	9,2	-0,4	-4%	0%	4%
Australia	400	16,0	18,6	18,0	1,9	12%	46%	30%
Canada	540	16,2	17,9	15,8	-0,4	-2%	20%	23%
Ukraine	310	14,9	7,2	6,9	-8,0	-54%	-59%	-12%
Non Annex I								
China	8.950	2,2	2,9	6,8	4,6	205%	257%	17%
India	1.840	0,8	1,0	1,5	0,8	100%	180%	40%
South Korea	590	5,9	9,7	12,3	6,4	109%	134%	12%
Indonesia	470	0,9	1,4	1,9	1,1	126%	194%	30%
Brazil	430	1,5	2,0	2,2	0,7	51%	96%	30%
Mexico	430	3,7	3,8	3,8	0,1	4%	39%	35%
Saudi Arabia	430	10,2	12,9	15,6	5,3	52%	159%	70%
Iran	400	3,7	5,2	5,4	1,6	44%	94%	35%
South Africa	380	7,3	6,9	7,6	0,3	4%	42%	36%
Taiwan	270	6,3	10,1	11,1	4,8	77%	118%	23%
Thailand	240	1,6	2,7	3,4	1,8	115%	160%	21%

Source of population data: WPP Rev. 2010 (UNPD, 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 USA has signed but not ratified the protocol, and thus the emission target in the protocol for the USA has no legal status.*

*** EU 15 = 15 EU Member States at the time the Kyoto Protocol was ratified.*

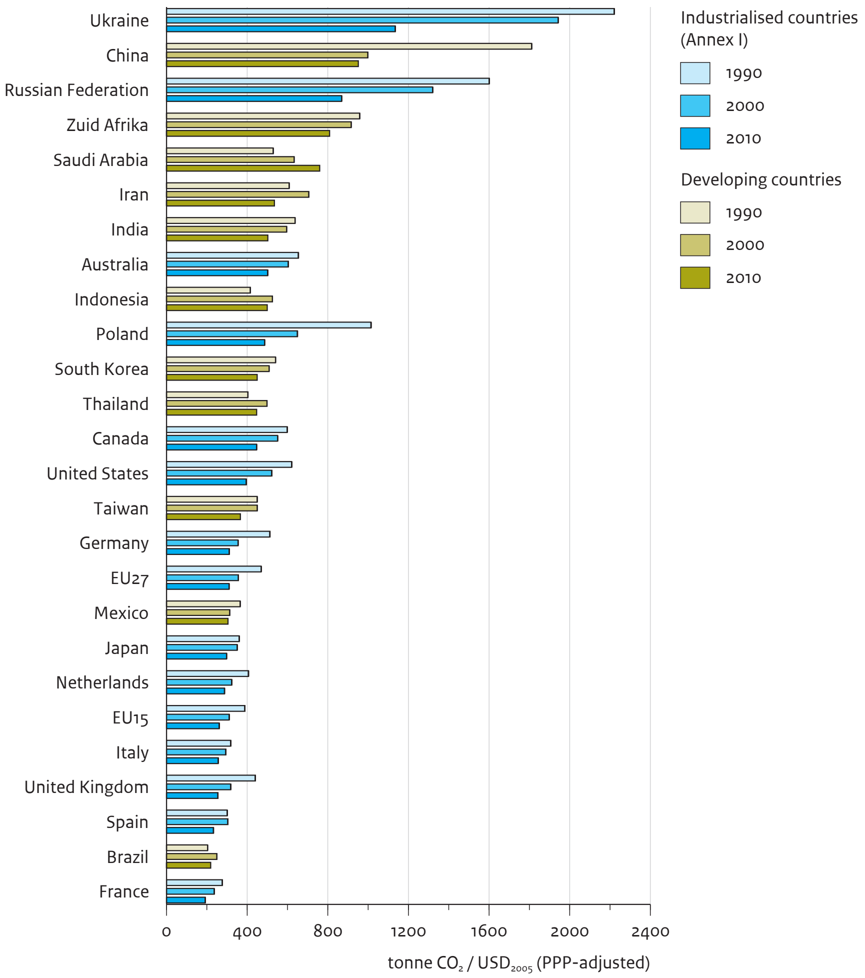
Figure 3.3
CO_2 emissions from fossil fuel use and cement production per capita



Source: EDGAR4.2

CO_2 emissions per capita in 1990, 2000 and 2010 in the top-25 CO2-emitting countries (source of population data: UNPD, 2011; WSS Rev. 2010).

Figure 3.4
CO_2 emissions from fossil fuel use and cement production per unit of GDP



Source: EDGAR4.2

CO_2 emissions per unit of GDP in 1990, 2000 and 2010 in the top-25 CO_2-emitting countries. GDP values for EIT countries in 1990 were estimated using the value of the oldest year reported (source of GDP data: IMF, 2011).

3.4 Trends in fossil fuel consumption

Fossil fuel combustion accounts for about 90% of total global CO_2 emissions excluding forest fires and woodfuel use (EDGAR 4.2, JRC/PBL, 2011). As the global economy rebounded strongly in 2010, both in mature industrialised countries and in developing countries, global energy consumption also saw a very strong growth of 5.6%, which is the largest annual growth since 1973 when the world was recovering from the recession caused by the first oil price crisis (BP, 2011).

BP (2011) states that global fossil oil consumption increased by about 2.9% in 2010 (corrected for biofuels), which is the largest increase since 2004. China's oil consumption increased by 10.4%, contributing one-third to total global growth in 2010. There is a large divergence between OECD and non-OECD countries with a 1% versus a 5.5% increase.

Natural gas consumption increased globally by 7.4% in 2010, the largest the largest annual increase since 1984. The growth was in most regions, with the growth of the USA of 5.6% contributing one-sixth to total global growth. The large increase in OECD countries was partly due to the recovery of the recession that had also affected the basic chemicals industry, a significant user of natural gas as fuel and as feedstock. Russia and China also saw the absolute increases, each contributing about one-tenth to global growth. Several Asian countries saw growth rates of more than 20% (China, India, South Korea and Taiwan). Colder winter months in 2010 than in 2009 also influenced the demand for gas for space heating, such as in northwest Europe and parts of the USA (see Annex 3 for the regional impact on the trend of winter temperatures in 2009 and 2010) (Blunden et al., 2011).

Coal consumption increased by 7.6% in 2010, which is the fasted growth since 2003. Coal consumption now accounts for 29.6% of global energy consumption, the highest share since 1970. According to BP (2011) coal consumption in China increased by 10.1% in 2010, accounting for 48% of global coal use and two-thirds of global consumption growth in 2010. Please note that the accuracy of China's coal consumption data is estimated at about 5% on average and somewhat larger for the most recent year. For more details we refer to the discussion on uncertainty in Annex A.1.4.

Consumption in OECD countries increased by 6.3%, the largest growth since 1979, recovering from the steepest decline on record in 2009 when the recession had a large impact on steel production and power generation which in many countries rely heavily on coal. In the USA, coal consumption for power generation increased in 2010 by 4.5%, mainly due to a higher electricity demand in the summer for cooling (EIA, 2011a).

3.5 Trends in non-energy sources

Recovering from the worldwide recession and continuing trends in China, global cement production increased by 11% in 2010 with resulting CO_2 emissions from limestone use in clinker production increasing by a half per cent less as the clinker fraction in cement continues to decrease. China increased cement production by 15% and was responsible for producing 55% of the world's total cement in 2010 (NBS China, 2011). Production in the other 'BRIC' countries Brazil, Russia and India, also increased rapidly in 2010 according to preliminary estimates by USGS (2011) (by 14%, 11% and 7%, respectively). Cement production is estimated to have increased in all but seven countries, the major exceptions being USA (-2%), Italia (-4%), South Korea (-8%), Mexico (-3%) and Pakistan (-6%).

A study by the World Business Council on Sustainable Development (WBCSD, 2009) has shown that in recent years the share of blended cement being produced in most countries has considerably increased relative to 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.

Both non-combustion and combustion emissions from cement production occur during the clinker production process, not the mixing of cement clinker. This has resulted in about 20% decrease in CO_2 emissions per tonne of cement produced compared to the 1980s. At that time, it was not common practice to blend cement clinker with much other mixing material, such as fly ash from coal-fired power plants or blast furnace slag. According to EDGAR 4.2 data, this has resulted in 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.

According to WSA (2011), global crude steel production rose 15% in 2010, with increases in all countries except Chile, Greece, UK and Venezuela. The 9% increase in China equated to almost one-third of the global increase in production in 2010. After production plummeted in 2009, it jumped up again in the USA (+38%), Germany (+34%) and Japan (+25%); production in India was also 6% up. Lime production increased globally by 5%, and ammonia production was estimated to be flat (USGS, 2011).

3.6 Trends in renewable and nuclear energy sources

The trends in CO_2 emissions reflect the impact of policies aiming to improve energy efficiency and to increase the use of nuclear or renewable energy sources over that of fossil fuels.

Wind power capacity in the world grew with 35.5 GW or 22.5% in 2010 to 194.4 GW (GWEC, 2010), with nearly half the new installations in China (GWEC, 2011). The new capacity added in 2010, the majority of which was in developing countries, represents investments worth 47 billion euro (USD 65 billion). The USA installed almost 50% less than in 2009. In Europe, total new installed capacity in 2010 was 7.5% down on 2009, despite a 50% growth in offshore capacity in countries like the UK, Denmark and Belgium and rapid growth in Eastern European countries such as Romania, Bulgaria and Poland. After four years of doubling its installed wind power capacity annually between 2006 and 2009, a record 16.5 GW was added in China in 2010. According to GWEC (2011), nearly a fifth of all net additional power generation capacity in China is now wind power, nearly on par with hydro. With 42.3 GW China is now the country with the largest installed wind power capacity in the world having overtaken the US with 40.2 GW. By comparison, at the end of 2010 India had 13.1 GW installed, while the European Union installed an additional 9.3 GW in 2010, bringing the total to 84.1 GW. This should, in a normal wind year, produce 5.3% of overall EU electricity consumption (up from 4.8% in 2009) according to GWEC (2011).

Total global solar photovoltaic (PV) capacity increased in 2010 by 71% to about 39.5 GW, producing in average[2] over one year approximately 50 terawatt-hours (TWh) of electrical power (EPIA, 2011). 80% of the new capacity was installed in Europe (13 GW), almost doubling the installed PV capacity in the EU. China also doubled its installed capacity, adding 0.5 GW. The global total of 16.6 GW installed in 2010 is more than double that installed in 2009 (7.2 GW) and was dominated by rapid growth in the EU, led by Germany (7.4 GW) and Italy (2.3 GW). By comparison Japan and the USA installed 1.0 and 0.9 GW, respectively. If the current rate of installation is maintained, Europe could generate an additional 1% of current electricity demand from PV every two years. Over the last 10 years, total installed PV capacity in the world has risen from 1.5 GW in 2000 to 39.5 GW in 2010, at an average annual growth rate of 40%.

Hydropower output increased by 5.3% in 2010 with China accounting for more than half of the growth, due to an increase in capacity and favourable (wet) weather in 2010. China now leads the world in large-scale hydropower with 21% of global production, well above Brazil and Canada with 11% and12% shares respectively (BP, 2011).

The annual increase in global biofuel use in road transport of 11% in 2010 continues a slowing growth trend. While the years 2006 and 2007 saw increases of about 30%, this declined to 20% and 16% and now further to 11% (Annex 2). The increase in the USA and Germany in 2010 was 18% and 7% respectively, whereas Brazil saw a 2% decrease. In the EU-27, consumption increased by 3%. Increasingly, also several other developing countries are starting to produce and use biofuels for road transport (Zhou and Thomson, 2009; World Bank, 2010; Lamers et al., 2011). Current fuel ethanol and biodiesel use represents about 3% of global road transport fuels and could be expected to have reduced CO_2 emissions by 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 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.

Fast increasing but still limited contribution of renewable energy sources

The annual growth in total renewable energy supply accelerated after 2003 from a few per cent to an average of 6%.and 2010 had the highest growth rate since 1990 of over 7%. Although in percentage terms growth in new renewable energy sources such as wind, solar and biofuels is largest, in absolute terms hydropower is the most important. Renewable energy's share of the global energy supply has increased from 7% by 2004 to over 8% by 2009 and 2010 (excluding traditional biofuels such as fuelwood and charcoal).

The share of nuclear power, the other non-fossil energy source, remained constant at about 6%, for many years, with nuclear capacity increasing in line with increasing global energy consumption. However, since 2005 the growth in nuclear capacity has slowed: the total number of nuclear power plants decreased from 444 in 2002 to 437 today and the power upgrade by using more energetic fuels (mixed oxide fuels or fuels with higher enrichment grade for longer life reactor cores) seemed to be used to the maximum potential. As a consequence the nuclear share has declined by a half per cent and it should be mentioned that nuclear power is normally used for base-load with a load-factor of 70%-90%. The Worldwatch Institute (WWI, 2011) reported that already since 2008 no nuclear reactor unit started up. Taken together nuclear and renewable energy sources have led to a decline in overall share of fossil fuels from 88% in 1990 to about 86%, the lowest in decades. However, in absolute terms both energy demand and the share being met by coal are growing faster since 1990 than the growth in new renewable energy sources, which is accelerating, but not yet fast enough to curb the increasing global CO_2 trend. The 2% decrease of the fossil fuel shares is composed of 2% shares increases of both coal and natural gas whereas the share of oil products decreased by 6%.

Notes

1 Here we use the composition of the OECD in 1990 (i.e. without Mexico, South Korea, Czech Republic, Slovakia, Hungary and Poland).
2 A load-factor of 15% is assumed.

Four decades in retrospect: sectoral trends in global CO_2 emissions

4.1 Understanding main global trends of the past four decades

The global emissions database EDGAR 4.2 allows analyses of global, regional and national trends in emissions per sector (JRC/PBL, 2011). Tracking the CO_2 emissions trends back for four decades it is possible to distinguish four periods: 1970-1979 with a global growth rate of 28%, 1979-1990 with a low growth of 13%, which continued during 1990-2003 with a growth of 15%, and 2003-2010 with an increased growth rate of 25% during the end of the Kyoto Protocol period. However, when comparing CO_2 growth rates per decade, it is important to note that each has experienced recessions, fuel hikes price and periods of turmoil.

The 1970s saw the first oil price crisis, causing recessions in 1974-1975 in most OECD and non-OECD countries, the 1980s experienced a second oil crisis, leading to a global recession in 1980-1982, the late 1980s and early 90s the fragmentation of the eastern bloc, the 90s saw the first Gulf war, leading to a global recession in 1992-1993, and the Asian financial crisis in 1998, causing a global recession in 1998 but showing negative growth rates mainly in Asian countries such as Japan, South Korea, Indonesia, but also affecting Russia. Finally the last decade saw 9-11 followed by the second Iraq war, leading to a global recession in 2001 and 2002, although only leading to negative growth in specific countries, and recently the global credit crunch, which brought a global recession, severely affecting most economies (see summary in Table 4.1).

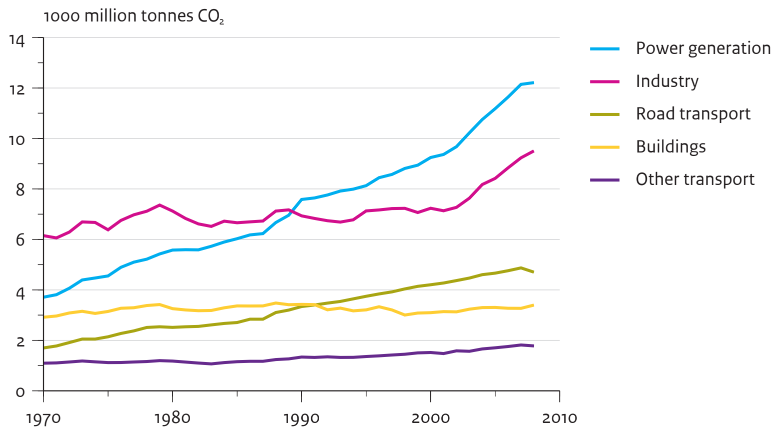
When focussing the global CO_2 emissions since 1970 for the main sectors: power generation, manufacturing industry, road transport, buildings (residential and service sectors) and other transport, two main features are visible, which apply differently to mature industrialised countries (Annex I countries) and developing countries (Figure 4.1).

4.2 Industry and buildings: limited increases

First, we can observe that, emissions from buildings (houses and offices for the residential sector and service sector) have remained rather flat over the entire period despite the global growth in the buildings stock. Similarly, industrial emissions had a relatively modest long term growth rate until 2002, when the annual growth rate increased due to the accelerating industrialisation of China (Figure 4.1). The acceleration started after China joined the World Trade Organization (WTO) in 2001, after which its export-oriented growth increased rapidly. Until 2002 direct global CO_2 emissions from industrial activities increased moderately by about 16%, with increasing emissions by developing countries mostly compensated for by decreases in the 1980s by the OECD countries and in the 1990s by the EIT countries ('Economies-In-Transition', Eastern Europe and former USSR countries).

Figure 4.1

Global CO_2 emissions from fossil fuel use and cement production per sector



Source: EDGAR4.2

Table 4.1

Summary of global recessions in the past 40 years

Period	Event	Recession years	Extent of recession
1970s	First oil crisis	1974-1975	In most OECD and non-OECD countries
1980s	Second oil crisis	1980-1982	Global recession
1990s	First Gulf war	1992-1993	Global recession
	Asian financial crisis	1998	in Asian countries such as Japan, South Korea, Indonesia, but also Russia
2000s	9-11 and second Iraq war	2001-2002	Global recession, only in specific countries
	Global credit crunch	2009	Global recession, most countries bot in China and India

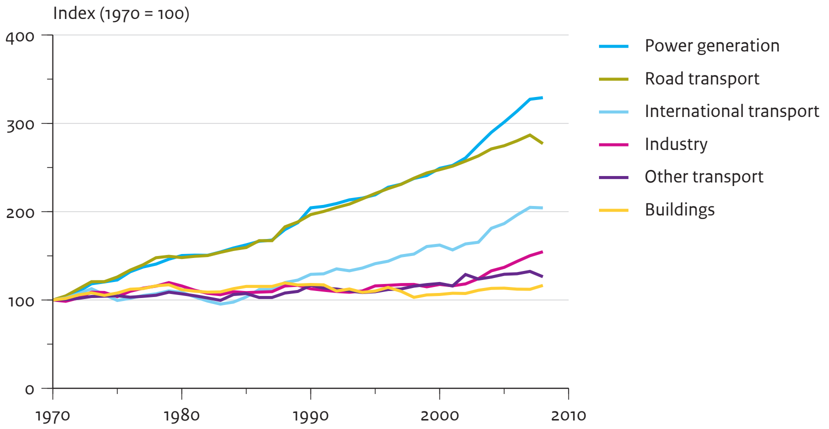
Source: IMF, 2011

In the buildings sector, global emissions increased since 1970 to 2008 by 17%, with rising CO_2 emissions from developing countries nullified in the 1970s and 1900s by decreases in the USA and in the 1990s by the economic decline of the EIT countries. In both cases the emissions from developing countries almost tripled over the four decades, while industrialised countries managed to reduce the direct CO_2 emissions from the manufacturing industry by 28% and from the buildings sector by 18% since 1970, despite large increases in production of goods, the service sector and population.

4.3 Demand for power and transport: drivers of continuous CO_2 growth

Two sectors play a pivotal role in the continued growth of global CO_2 emissions: *power generation* and *road transport*. Global CO_2 emissions from these sectors have increased steadily with very limited interruptions between 1970 and 2010. Both had almost the same growth rate over time (Figure 4.2) until 2002, when China joined the WTO. This led to an accelerating Chinese industrialisation and the demand for power reached a level where it starts to be visible in the global total trend of power generation. At global level, both sectors had consistently similar annual growth rates of 5% per year in the seventies, declining to 2.5% growth rate by the early nineties, which continued for the road transport but accelerated for the power sector to 4% from 2002 onwards. The developing countries have had continuous growth in emissions from both sectors over the entire period with increasing growth for power generation after 2002, as mentioned above, while the industrialised countries saw much lower growth in electricity consumption the early 90s due to the economic decline of the EIT countries in the early 90s. Again electricity consumption was relatively stable in these countries and the USA in the late 90s and early 2000s, due to the global recession.

Figure 4.2
Global CO_2 emissions from fossil fuel use and cement production per sector (index)



Source: EDGAR4.2

Road transport

For road transport, the increases in emissions in both industrialised and developing countries are more steady and continuous, with the exception of 2008, when the combination of a peak in fuel prices and the starting recession caused a decline in emissions. Although in Figure 4.1 road transport is a less important source of CO_2 globally than either power generation or manufacturing industry, a recent study of the net climate impacts of emissions from economic sectors rather than by individual chemical species finds on-road transportation to be the greatest net contributor to climate change now and in the near term, when the contribution of vehicle emissions to the formation of ozone in the troposphere, which is both an air pollutant and a strong greenhouse gas are also considered (Unger et al., 2010).
Among the options for reducing direct fossil fuel CO_2 emissions from the road transport sector are substitution with biofuels and electric vehicles, apart from increasing the fuel efficiency. From the perspective of climate change, an integrated view is required to evaluate the overall effect of these shifts, since increasing use of these alternatives will generate increased greenhouse gas emissions in the power generation and agricultural sectors. For these options to maximise their net effect on greenhouse gas emissions, biofuels with the largest net effect need to be favoured and the concurrent expansion of the infrastructure with (low CO_2) power generation capacity and realisation of stable grid together with introduction of electric vehicles is required for minimising the net contribution to climate change. In fast growing economies this may be a practical issue, as is illustrated by the power shortages, that parts of China experienced in the past years for various reasons and are expected to occur again in 2011 (EIA, 2011b).

Power generation

Table 4.2 shows the shares of main sectors in electricity consumption. The shares of the electricity end-use sectors in total demand differ per country according to national circumstances and the degree of economic development. When comparing the USA, the European Union and China, industrial production uses 22%, 42% and 61% respectively, the residential sector 33%, 24% and 14% respectively and service sector 32%, 21% and 5%, respectively in the three countries/groups. Within industry, electricity consumption is primarily in the production of chemicals (1/5 to 1/4), iron and steel (1/5 in China), non-ferrous metals and machinery. In many industrialised countries, e.g. Europe and in developing countries represented by China, industry has the largest share. Whereas in most developing countries electricity demand of the residential and service sector is relatively low, this is in contrast to the USA, where the service sector and the residential sectors each take about one-third. Interestingly, in all the examples shown in the table, the chemicals industry (electrolysis such as the chloralkali process) has the largest share of the industrial electricity consumption, followed by the steel industry (mills) and non-ferrous metals production (electrolysis processes).

Future CO_2 emission reduction in both sectors will require considerable structural changes to achieve a shift in the source energy mix that cannot be realised overnight. As the world-wide rate of increase in demand for energy returns to pre-recession levels, the current rate of increase in renewable and nuclear energy capacity cannot yet compensate for this globally ever increasing demand for power and transport. However, a shift to less carbon-intensive fossil fuels (from coal to gas) as well as some progress in energy efficiency savings by e.g., insulation, more energy-

Table 4.2
Sectoral shares in electricity consumption in 2008. Source: IEA, 2010a

Main sector	Other developing countries	China	EU-27	USA	Global
Industry	**55%**	**61%**	**39%**	22%	**37%**
Commercial and public services	15%	5%	26%	**32%**	21%
Other Energy Industries	3%	6%	5%	7%	11%
Agriculture and forestry	4%	3%	2%	4%	2%
Residential sector	23%	14%	28%	**33%**	24%
Industry subsectors					
Iron and steel	**8%**	**12%**	**5%**	2%	**5%**
Chemicals	**7%**	**10%**	**7%**	**6%**	**6%**
Non-ferrous metals	5%	**8%**	3%	2%	4%
Machinery	5%	**8%**	4%	3%	4%
Non-metallic minerals	4%	6%	3%	1%	2%
Pulp and paper	2%	1%	**5%**	3%	3%
Food and tobacco	2%	2%	4%	2%	2%
Wood products	0%	1%	1%	1%	1%
Textiles	3%	4%	1%	1%	1%
Other industry	**16%**	4%	**5%**	0%	**7%**

efficient end-use devices and higher fuel efficiencies have in fact been made by several Kyoto Protocol countries.

4.4 Shift in geographical distribution of the manufacturing industry

There is a geographical shift in emissions from manufacturing industry as it grows in developing countries while being increasingly replaced by the service sector, which is less fuel-intensive, in industrialised countries, and as more developing countries increase their share in global manufacturing. This is also reflected in the share of the manufacturing industry in total electricity consumption (see Table 4.2). Globally, this effect is most visible in the increases in emissions associated with increasing Chinese industrial production particularly post 2002.

This increase in industrial emissions in China since 2002 coincides with constant industrial emissions by the Annex 1 countries, a situation that has in fact persisted since 1995, when the drop in industrial emissions from the EIT countries had already occurred. Industrial emissions by developing countries other than China also start to grow faster after 2004. On this evidence, alone, it is difficult to demonstrate a clear substitution effect, whereby increasing penetration of Chinese industrial exports in the economies of the developed world has displaced the equivalent industrial production and emissions developed world. Instead, it is more a case of "business as usual" for industry in the developed world, while much of the new industrial capacity and resulting emissions required to satisfy new demand globally, has preferentially developed in China and the developing world. We note that others have performed analyses about the CO_2 emissions related to the goods manufactured in China that are exported (e.g. Weber et al., 2008; Davis and Caldeira, 2010; Peters et al., 2011), but this is outside the scope of this report.

4.5 Other transport: limited growth, less than in traded volume

When looking at emissions from other transport, which are approximately equally split between inland rail, water and air and international marine and air transport, they also remain almost constant, while showing variations due to the impact of recessions etc like the industry does until the mid 80s. From then on, emissions rise in line with rising international trade following liberalisation measures introduced in the Uruguay round of GATT. The growth rate of international transport emissions increases again after 2002, reflecting the growth in Chinese exporting industries.

Twenty Kyoto years in perspective: industrialised countries well on target

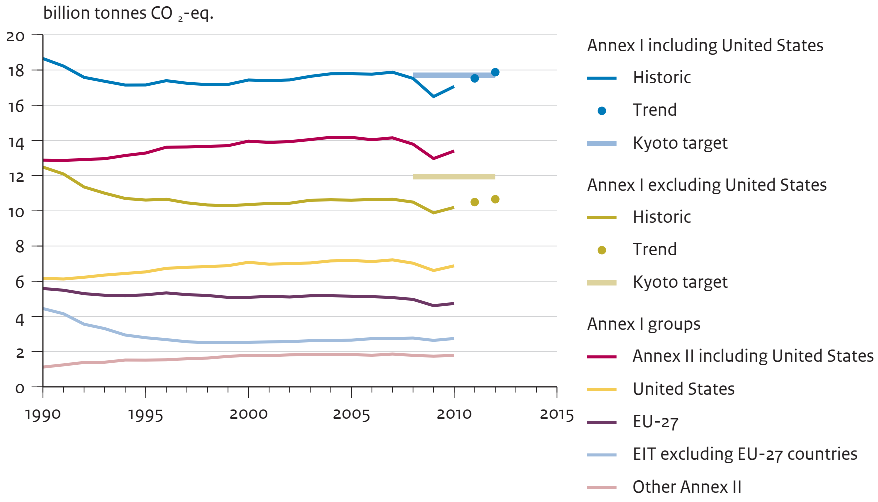
In April 2011, the industrialised countries of Annex I to the Kyoto Protocol have published new national greenhouse gas emission inventories up to and including 2009, which were officially submitted to the UN Climate Secretariat (UNFCCC, 2011). We have summarised the trend in historical greenhouse gas emissions for the period 1990-2009 of the group of countries with an emission target under the Kyoto Protocol (Annex I to the Kyoto Protocol). Turkey and Kazakhstan are excluded, since they do not have quantitative targets, as is the USA, since it did not ratify the protocol. Trends including the USA are also presented, to show the achievements of the Annex I countries with targets as intended by the protocol, over the last two decades. We include our own estimates of 2010 greenhouse gas emissions, which are based on the trend estimates for CO_2 presented in this study. This is a fair assumption since non-CO2 greenhouse gases accounted for only 25% of total greenhouse gas emissions by the industrialised countries in 2009, although their trend is somewhat lower than for CO_2. We have also tentatively extrapolated the emission trend towards 2012 under the assumption that the emissions are back at pre-recession level in 2012, to provide a comparison of total Annex I emissions with the actual Kyoto reduction target over the years 2008-2012. Note that neither 'sinks' (carbon storage in forests and soils) from Land Use Land Use Change and Forestry (so-called LULUCF) nor possible (but usually limited) corrections in response to the 2010 expert reviews of the national emissions inventories are included here.

5.1 Industrialised countries without USA will meet collective Kyoto target of -4.2%

Collectively the group of industrialised countries committed to a Kyoto target, i.e. the Annex I countries excluding the USA, have an target of reducing their greenhouse gas emissions by 4.2 % on average for the period 2008-2012 relative to the base year, which in most cases is 1990. With an estimated average emission reduction of 16% for 2008-2012, they are certain to exceed their target quite comfortably (Figure 5.1).

Their collective target will be met without accounting for emission credits purchased from certified emission reduction projects under the UN's Clean Development Mechanism (CDM). These projects aim to generate emission reductions in developing countries and fast growing economies and by purchasing the credits that fund the projects, the resulting emission reduction may be counted towards the purchaser's nation's national Kyoto target. For example, the 15 member states of the EU, constituting the EU when the Kyoto Protocol was ratified, plan a 2.7% additional reduction from CDM credits and emissions trading with other industrialized countries (e.g. JI credits). The EU 15 can also include an additional 1.0% reduction in emissions attributable to the LULUCF carbon sinks also included in the Kyoto Protocol accounting for meeting the targets (EEA, 2010). So, when including the fraction of Clean Development Mechanism

Figure 5.1
Greenhouse gas emissions of Kyoto Protocol countries and their targets (excl. LULUCF)



Collective trend greenhouse gas emissions of Annex I countries with and without the USA (Annex II = Annex I minus the EIT countries).

(CDM) projects "in the pipeline" that are presently expected to be used, the total reduction will even be somewhat larger.

The emissions reduction by the Annex I countries excluding the USA is largely due to the 40% reduction in emissions between 1990 - 1999 in the Economies In Transition (EIT) (Russia, Ukraine and other Eastern European countries). The remaining Annex I countries (the OECD countries, including the EU 15) have experienced a limited increase emissions from 1990-2006, followed by stabilisation and a more marked decrease from 2007 onwards. High fuel prices in 2008 and the recession in 2008-2009 drove 2008 and 2009 emissions down by several per cent and in 2010 remain below pre-recession levels. In the EIT countries, greenhouse gas emissions started to increase again after 2001 (at an average group rate of about 1% per year) due to their economic recoveries, while the Kyoto target of the largest EIT countries is +1% and -8% for the smaller EIT countries. The emissions reductions in the early nineties by the 12 EIT countries who have since joined the EU, assist the present EU-27 in meeting its collective Kyoto target. However, EU-15 and EU-27 emissions remain both almost constant in the period 1995-2007.

There are large national differences and some individual countries such as Australia, Canada, New Zealand and Spain, will not meet their national target without emissions trading and need to purchase emission credits from other countries. These may be either CDM credits from developing countries or credits from other industrialised countries that have a large surplus compared to their target (Den Elzen et al., 2009, 2011).

5.2 Will industrialised countries with USA meet the intended Kyoto target?

United States

Greenhouse gas emissions by the United States, which did not ratify the Kyoto Protocol, have increased by 11% since 1990. In part this is due population growth of about 23% between 1990 and 2010, much higher than other industrialised countries except for Canada and Australia (see Table 3.2). With emissions slowly increasing from 1990-2007, stabilising and declining in 2008 and 2009 and returning to growth in 2010, the United States will be unable to meet the original reduction target of 6% included in the protocol. The US has also begun to implement climate policies, both nationally and on state level, to mitigate greenhouse gas emissions. For example, through increasing energy efficiency targets, reducing of non-CO_2 emissions such as methane, and increasing the share of renewable energy such as bioethanol. Nevertheless, the increasing trend of the US greenhouse gas emissions is opposite to the decreasing trend of the EU-27 and similar to that of the other Annex II countries together (see Figure 5.1).

5.3 Industrialised countries including the USA will meet intended Kyoto target

If the United States had joined the other industrialised countries in ratifying the Kyoto protocol and accepting their 6% target, the average percentage reduction in greenhouse gas emissions for the group in total would have been 5.2% as intended by all Parties when they adopted it in 1997, including the targets. Although it will not have a great impact on global warming, as was already known at that time as the scope was limited to the Annex I countries and targets were considered as modest, it was considered as a small but very important first step by the rich countries towards more stringent and comprehensive future greenhouse gas mitigation policies. Therefore it is of interest to determine whether the industrialised countries in Annex I as group were able to meet the expectations and achieve the intended collective target set for this first step.

When including the United States in the group calculation, using the same estimate for 2010 and extrapolating to 2012, then we estimate the average collective emission reduction by the entire group over the Kyoto target period, to be 7.0 % approximately two per cent more than the group's original target (see Figure 5.1). When including the additional contribution from projects under the CDM that are currently anticipated to be used for meeting the Kyoto targets of individual countries as discussed above (including a virtual reduction percentage for the United States) the total reduction would be even larger.

Thus the group of Annex I countries that have ratified the protocol, and have a collective mitigation target under the Kyoto Protocol of -4.2%, are on course to achieve a 16% reduction relative to the base year. Including the USA, which did not ratify the protocol, the Annex 1 countries are still expected to achieve a 7 % reduction which is also lower than the intended group target of 5.2%. These figures exclude expected purchased emissions credits (see below).

5.4 Consequences of the recession on emissions trading

A consequence of the overshoot in the decrease in Annex I emissions in the Kyoto target period 2008-2012, is that less emission credits from certified emission reduction projects under the UN Clean Development Mechanism (CDM) need to be purchased to meet national Kyoto targets. The same applies to companies registered under the European Emission Trading Scheme (EC, 2011; see also section 3.2.1). By the end of 2010, 500 million tonnes of Certified Emission Reductions (CER units) had been allocated to reduction projects in developing countries since the system began (UNEP, 2011), the large majority of them being HFC-23 and N_2O destruction projects in the chemical industry (Gronewold, 2011; Bloomberg NEF, 2011). Carbon market analysts expect an additional 150-250 million tonnes to be issued in 2011, which push the traded price of CO_2 credits downwards. In 2010 the UN Environment Programme Risø centre estimated that less money will flow to developing countries where these projects are being implemented and projected that around 1.0 billion tonnes of CER units will have come to the market by the end of 2012 when the Kyoto period expires (Reuters, 2010). This represents about 200 million tonnes of CO_2 per year over the five-year period, which is roughly equal to the annual greenhouse gas emissions of the Netherlands.

Mitigating CO_2 emissions: significant changes require decades of focused policies

The two sectors that have experienced continuous, structural growth in CO_2 emissions in Annex I and non Annex I countries are power generation and (road) transport. They will therefore be central to all efforts to mitigate the growth of global greenhouse gas emissions, as desired by the UN Climate Convention, Bali declaration and the Cancun agreements.

6.1 Technical means

The principal technical means of reducing fossil fuel consumption and thus emissions in these ever growing sectors, and other sectors, are (a) improve energy efficiency, (b) replace fossil fuel with renewable energy types (biomass, wind, solar, hydro, etc.), (c) replace fossil fuel with nuclear power, (d) switch to less carbon intensive fossils fuels, in particular from coal to gas. These measures also apply to other sectors as well. In the case of the electric power sector, improving the energy efficiency of electrical appliances is an important way to reduce CO_2 from power generation. Recently the European Commission has stressed the importance of energy efficiency improvements (EC, 2010b) as this is a sector where the EU needs to improve to achieve the 2020 goal of a 20% increase in energy efficiency. Alternatively it is argued, citing the effect of fuel price increases on demand, that one of the more efficient ways of cutting fossil fuel demand is to align the consumption tax system with greenhouse gas emissions, or more general environmental impact (Hansen, 2009). A recent special IPCC report on the contribution of renewable energy as greenhouse gas mitigation option has shown the very large potential of this sector in the coming decades (IPCC, 2011). In addition, when local conditions allow, CO_2 Capture and Storage (CCS) could be applied to reduce the carbon intensity of emissions from large scale fossil fuel combustion, but this technology is still at its infancy and large scale application have yet to be developed (IPCC, 2005).

Given that each of these options has different advantages and disadvantages for local communities, economic activities and environmental impacts, arriving at the appropriate mix and enabling policies for a country will depend on national and local circumstances, public and political preferences as well as the interest of businesses promoting the various options.

6.2 Lessons learned

Past experience shows that there is no single 'silver bullet' option that can substantially curb fossil energy consumption and related CO_2 emissions in a short time. When looking at the large-scale introduction of renewable energy in countries such as Germany, France and Spain in the last decade (e.g. see power energy mix graphs in IEA (2010b)), it is clear that large shifts in the energy source mix cannot be realised overnight and will take at least a decade. Sustained policies and long-term programmes of investment in low-carbon power

generation and transport in particular, are needed to have a substantial impact on the trend in fossil fuel use, leading to the stabilisation and subsequent decrease of greenhouse gas emissions. This also applies to nuclear power, as the different national approaches taken in the 1970s shows. However, it can be concluded that strong policies aimed at the introduction of new energy technologies such as the French policy on nuclear power and the German policy on renewable energy can have a sizeable impact in a decade or so if maintained consistently. The special IPCC report on renewable energy sources draws a similar conclusion (IPCC, 2011).
Although the contribution of the Kyoto targets to global greenhouse gas emission mitigation is rather limited, as was already known at that time, it is clear that the climate and energy policies introduced after the protocol was agreed, have served to stimulate and enhance many of the new economical and technological developments in the area of so-called ‘green technologies’, which would otherwise not have been penetrated so fast on the market. The CDM projects in developing countries, although often criticised for their additional effect, have triggered worldwide project activities in various sectors of society focussing on reduction of greenhouse gas emissions.

Annex 1

Method for estimating CO_2 emissions trends for the period 2008-2010

A.1.1 Methodology and data sources

The recent trends were estimated by PBL using trends in most recent data on fossil fuel consumption for 2008-2010 from the BP Review of World Energy June 2011 (BP, 2011). For cement production, preliminary data for 2009 and 2010 were used from the US Geological Survey (USGS, 2011) except for China for which use was made of NBS China (2011).

For the trend estimate 2008-2010, the following procedure was used. Sources were disaggregated into five main sectors as follows (with the defining IPCC source category codes 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 2008-2010 emissions:

(1) Fuel combustion (IPCC category 1A+international bunkers):

- First, as starting point for the trend calculation per country the detailed CO_2 estimates for 2008 compiled by the International Energy Agency (IEA) for fuel combustion by major fossil fuel type (coal, oil, gas, other) are used (IEA, 2010a).
- For energy for 2008-2010, 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, 2011).
- 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 (IEA, 2010a) (covering about three-quarter and half of total bunker fuel consumption, respectively). This is a refinement of the method used last year, where we applied the trend in global total oil consumption.

(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 2008-2010 are assumed to be similar to the trend in crude steel production for 2008/2009 from USGS (2011) and for 2009/1010 from the Word Steel Association (WSA, 2011).
- 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 datasets as used for EDGAR 4.2 for the years up to 2008, since the NOAA dataset that was used provides flaring data from satellite observation for the most important 58 countries up to 2010 (NOAA/NCDC, 2011; Elvidge et al., 2010), which are prepared for the World Bank's Global Gas Flaring Reduction Programme (GGFR, 2010).

(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 2009-2010 published by the US Geological Survey (USGS), except for China where use was made of NBS China (2011). In addition, we extrapolated the trend in the emission factor due to trends in the fraction of clinker in the cement produced based on data reported by WBCSD (2009). Thus for 2009 and 2010, the same methodology was used as in EDGAR 4.2. For all other sources in the minerals production category (2A), we used lime production data for 2008-2010 (USGS, 2011) as proxy to estimate the trend in the other 2A emissions. All 2009 and 2010 data are preliminary estimates.

(3) 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 (2011) was used (2010 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 2009/2010 also World Steel Association (WSA, 2011) 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. 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 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. The estimates in the literature for the amount burned in China vary by a factor of 10. However, a recent analysis of available information by Van Dijk *et al.* (2009) has shown that the highest numbers refer to the amount 'lost', which includes all coal below the fire area that has been made inaccessible because of the fire. This would be a factor of 10 higher than the actual amount of coal burned. Their conclusion is that emissions from coal fires in China are at the lower end of the wide range of 15-45 and 150-450 Tg per year, thus around 30 Tg CO_2 per year. This is equivalent to about 0.3% of China's CO_2 emissions in 2010.

A.1.2 Differences between EDGAR version 4.2 and 4.1

For this assessment, we use the EDGAR 4.2 dataset which differs slightly from the basic historical data in EDGAR 4.1 that was used in last year's assessment (Olivier and Peters, 2010), apart from being updated from 2005 to 2008. EDGAR 4.2 updated statistics for the years 2000-2005 and added new statistics for the 2006-2008. In addition, for a few sources a new or fully updated dataset for activity data was used for the whole time series 1970-2008 (flaring data primarily from NOAA/NCDC (2011), lime production was substantially changed (UNFCCC, 2010) and consumption data for other manufacturing industries increased, partly due to reallocation from other subcategories in the new energy dataset. CO_2 emissions from peat decay from drained peatlands are now based on data from Joosten (2009). Also the net carbon stock changes for forest remaining forest land, based on data from the FAO's Forest Resources Assessment (FAO, 2010), resulting in CO_2 emissions or carbon storage, have been added to the version 4.2 dataset. Total 2005 CO_2 emissions excluding LULUCF are now about 250 million tonnes or 0.9% higher than in version 4.1. The main differences for 2005 are:

- venting and flaring of associated gas (1B2): + 130 million tonnes;
- other manufacturing industries (1A2f): +70 million tonnes;
- limestone and dolomite use (2A3): 40 million tonnes;
- reallocation from autoproducer of electricity to autoproducer cogeneration: 40 million tonnes.

A.1.3 Other sources of CO_2 emissions: forest and peat fires and post-burn decay

The trend estimates of CO_2 emissions do not include CO_2 emissions from forest fires related to deforestation/logging and peat fires and subsequent post-burn emissions from decay of remaining above ground biomass and from drained peat soils. Although they are also significant but highly uncertain, CO_2 emissions from the decay of organic materials of plants and trees that remain after forest burning and logging are also not included. Annual CO_2 emissions from peat in Indonesia have been estimated at 400-5000 million tonnes CO_2 (Hooijer *et al.*, 2006), including emissions from drained peat soils. New estimates by Van der Werf *et al*. (2008) indicate that except for peak years due to an El Niño, emissions from peat fires are not as large as the wide range suggests. Moreover, Joosten (2009) estimated total CO_2 emissions from drained peatlands in 2008 to amount 1.3 billion tonnes CO_2, of which 0.5 billion tonnes from Indonesia.

A.1.4 Data quality and uncertainties

For industrialised countries, total CO_2 emissions per country from EDGAR 4.2 for the period 1990-2008 are generally within 3% of officially reported emissions, except for a few economies in transition.

For recent years, trends in energy data published annually by BP appear to be reasonably accurate. 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 presently available and more detailed statistics of the International Energy Agency (IEA) for 2005, 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. Moreover, energy statistics for fast changing economies, such as China, are less accurate than those for the mature industrialised countries within the OECD.

Other analyses of CO_2 emissions from fossil fuel use and cement production have suggested that the uncertainty in CO_2 emission estimates could be about 2 to 3% for the USA and as high as 15 to 20% for China (Gregg *et al.*, 2008). However, this uncertainty in the estimate for China is based on revisions of energy data for the transition period in the late 1990s, which may not be applicable to more recent energy statistics. Based on subsequent revisions of emission estimates made by the IEA, we estimate the uncertainty in the preliminary estimates for China – caused by uncertainty in the energy data – at about 10%.

Regarding the 10.1% increase in coal consumption in China reported by BP for 2010 (in energy units) we note that the National Bureau of Statistics of China reports increases of 5.9% in coal consumption per tonne and an 8.9% increase in coal production in tonnes equivalent (NBS China, 2011). Compared to the increases in thermal electricity generation of 11.6% and steel production of 9.6% reported in the same publication, a 5.9% increase in coal consumption appears somewhat low, but may be explained by differences in units used, tonnes of coal equivalent (a unit of energy content) versus tonnes of coal (a physical unit).

Moreover, the current BP report also contains updated coal consumption data for the previous years: for 2009 it changed only slightly (+1.3%), more for 2008 (+5%) and in particular for 1999-2007 (about +10%) (BP, 2010, 2011), which may be indicative of the order of magnitude of the uncertainties in the statistics.

The uncertainty in CO_2 emissions from fossil fuel combustion using international statistics is discussed in detail in Marland *et al.* (1999), and general uncertainty characteristics in global and national emission inventories in Olivier and Peters (2002).

A.1.5 Results

Table A1.1 shows the trends in CO_2 emissions per region/country for 1990-2010 as presented in Figure 3.1. This table and the figures used in Figures 3.3 and 3.4 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

Table A1.1

Trends in CO_2 emissions per region/country 1990-2010 (unit: billion metric tonnes of CO2)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
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	5.82	5.87	5.94	5.93	5.84	5.91	5.46	5.04	5.25
EU-27	4.35	4.28	4.13	4.05	4.04	4.09	4.16	4.08	4.09	4.02	4.08	4.14	4.13	4.24	4.25	4.21	4.23	4.16	4.11	3.94	4.05
EU-15	3.33	3.36	3.28	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	3.06	3.15
- France	0.39	0.42	0.41	0.38	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	0.36	0.37
- 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	0.79	0.83
- Italy	0.42	0.42	0.42	0.41	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	0.40	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
- United Kingdom	0.59	0.59	0.58	0.56	0.55	0.55	0.57	0.54	0.55	0.54	0.54	0.56	0.54	0.56	0.55	0.55	0.55	0.54	0.53	0.48	0.50
- 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	0.17	0.18
EU-12 *(new member states)*	1.02	0.92	0.85	0.83	0.81	0.82	0.82	0.80	0.77	0.73	0.75	0.75	0.74	0.77	0.78	0.78	0.80	0.79	0.80	0.88	0.90
- 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	0.30	0.32
Japan	1.16	1.17	1.18	1.18	1.23	1.25	1.26	1.26	1.22	1.26	1.27	1.25	1.30	1.30	1.30	1.31	1.29	1.32	1.25	1.09	1.16
Other Annex II	0.83	0.82	0.85	0.85	0.87	0.89	0.92	0.96	0.99	1.01	1.03	1.03	1.05	1.08	1.09	1.12	1.11	1.14	1.13	1.09	1.07
- Australia	0.27	0.28	0.28	0.28	0.29	0.30	0.31	0.33	0.35	0.35	0.36	0.36	0.37	0.38	0.40	0.41	0.42	0.42	0.44	0.43	0.40
- 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	0.56	0.52	0.54
Russian Federation	2.44	2.30	2.08	1.99	1.76	1.75	1.72	1.59	1.57	1.62	1.66	1.67	1.66	1.72	1.73	1.72	1.78	1.81	1.80	1.67	1.75
Other Annex I-EIT*	1.59	1.50	1.33	1.16	0.99	0.94	0.87	0.84	0.85	0.82	0.82	0.83	0.86	0.90	0.90	0.86	0.89	0.94	0.95	0.89	0.93
- 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	0.30	0.31
China	2.51	2.65	2.78	3.02	3.18	3.52	3.62	3.58	3.65	3.57	3.56	3.63	3.92	4.50	5.28	5.85	6.50	7.00	7.77	8.10	8.94
- 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
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	2.71	2.81	2.90	3.08	3.19	3.37	3.55	3.53	3.67	3.91
- India	0.66	0.70	0.74	0.76	0.81	0.87	0.91	0.96	0.97	1.03	1.06	1.08	1.12	1.15	1.24	1.29	1.38	1.48	1.56	1.69	1.84
- Brazil	0.22	0.23	0.23	0.24	0.25	0.27	0.29	0.31	0.32	0.33	0.34	0.35	0.35	0.34	0.36	0.36	0.37	0.39	0.40	0.38	0.43
- Mexico	0.31	0.32	0.32	0.32	0.34	0.33	0.34	0.35	0.37	0.37	0.38	0.37	0.38	0.39	0.40	0.42	0.44	0.45	0.45	0.43	0.43
- Iran	0.20	0.23	0.24	0.24	0.27	0.28	0.29	0.30	0.31	0.32	0.34	0.35	0.37	0.39	0.42	0.45	0.48	0.51	0.37	0.38	0.40
- Saudi Arabia	0.16	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
- 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	0.37	0.38
Other non-Annex I *****	2.32	2.42	2.51	2.65	2.77	2.95	3.14	3.28	3.26	3.38	3.53	3.60	3.69	3.81	4.03	4.16	4.30	4.47	4.57	4.68	4.89
- Asian tigers**	0.71	0.79	0.84	0.92	0.99	1.07	1.16	1.23	1.17	1.24	1.31	1.36	1.40	1.45	1.53	1.57	1.60	1.65	1.68	1.70	1.81
- 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
- I ndonesia**	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	0.46
- Taiwan**	0.13	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.21	0.22	0.23	0.23	0.24	0.25	0.26	0.27	0.27	0.28	0.26	0.26	0.27
.- Thailand**	0.09	0.10	0.11	0.13	0.14	0.16	0.18	0.18	0.16	0.17	0.17	0.18	0.19	0.20	0.22	0.23	0.23	0.22	0.23	0.23	0.24
International transport	0.66	0.66	0.69	0.68	0.69	0.72	0.73	0.76	0.78	0.82	0.83	0.80	0.83	0.84	0.92	0.95	1.00	1.04	1.04	1.00	1.03
Total	22.7	22.7	22.6	22.8	22.9	23.6	24.2	24.4	24.6	24.8	25.3	25.4	26.1	27.2	28.5	29.3	30.3	31.4	31.6	31.2	33.0

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

Annex 2

Dataset on biofuel consumption for road transport per country, 2005-2010

This dataset 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 for road transport were used for 2005-2010 from the following sources:

- UNFCCC (2011) for Annex I countries (industrialised countries reporting emissions to the UN Climate Secretariat, at present data for 1990-2009), except for Bulgaria, Romania and the UK, that reported 'Not Occuring' or 'Not Estimated', although other data sources show that these countries do use road biofuels.
- For Bulgaria and Romania, these data were supplemented with fuel ethanol and biodiesel consumption data for 2005-2009 from Systèmes solaires (2007, 2008, 2009, 2010) and EBB (2010, 2011).
- Supplemental data for 2010 for the USA, Germany, UK and Brazil, comprising almost 80% of the global total consumption were taken from EIA (2011c), BMU (2011), UK (2011) and Barros (2010, 2011), respectively.
- For nine developing countries, IEA (2010a) was used for biofuel consumption in 2005-2008. For four more countries, reported biofuel consumption was found. Various sources were used to obtain bioethanol and biodiesel consumption data for 2005-2010 in Brazil and China. Reported consumption data were used for 2010 for China, India and Argentina.

Where time series were incomplete for 2010, amounts were calculated using the 2008-2010 trend of total global biofuel production from BP (2011) for Annex I countries while country-specific trends for 2008-2010 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 2008-2010 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) 2005-2010 (in TJ)\

Country	2005	2006	2007	2008	2009	2010
Annex I	504,200	752,100	1,002,300	1,262,300	1,432,400	1,648,600
United States	364,700	509,800	660,700	829,600	927,400	**1,098,000**
Canada	10,200	11,500	25,600	25,100	24,800	27,000
Australia	0	0	900	2,700	5,500	6,000
New Zealand	0	0	50	90	110	100
Switzerland	300	400	600	600	500	500
Turkey	0	100	500	3,200	400	400
EU-27, of which:	129,030	230,410	314,510	402,070	474,980	518,000
Austria	3,100	11,500	13,800	17,200	21,600	23,500
Belgium	0	0	2,000	4,300	10,900	11,900
Bulgaria	0	300	0	200	200	200
Croatia	0	0	100	100	100	100
Czech Republic	100	800	1,500	3,600	6,600	7,200
Denmark	0	200	300	200	300	300
Finland	0	0	100	3,300	5,900	6,400
France	16,700	29,300	60,200	93,400	98,300	107,100
Germany	78,600	143,600	155,600	126,100	114,000	**122,000**
Greece	0	2,000	3,600	2,900	3,300	3,600
Hungary	0	400	1,200	6,900	7,100	7,700
Ireland	0	100	900	2,400	3,200	3,500
Italy	6,600	6,400	6,600	32,700	50,900	55,400
Latvia	100	100	100	100	200	200
Lithuania	200	1,200	2,200	2,600	2,200	2,400
Luxembourg	0	0	1,900	1,900	2,000	2,200
Malta	30	30	70	40	30	30
Netherlands	0	2,000	13,000	12,000	15,400	16,800
Poland	2,000	3,800	4,000	18,500	27,800	30,300
Portugal	0	2,500	4,900	4,700	8,400	9,100
Romania	0	100	1,000	2,900	4,400	4,800
Slovakia	0	800	2,200	2,300	2,800	3,000
Spain	11,300	7,400	16,900	27,300	47,300	51,500
Sweden	7,400	10,300	13,500	16,300	17,300	18,800
United Kingdom	2,900	7,500	8,300	19,100	23,500	**28,600**
Slovenia	0	80	540	1,030	1,250	1,400
Non Annex I	313,800	330,000	446,300	478,500	584,900	653,900
Argentina	0	0	0	0	0	**19,700**
Brazil	288,900	270,500	374,900	401,100	489,200	**479,900**
China	14,800	42,200	46,400	48,500	51,300	**64,400**
Colombia	600	5,300	5,900	6,700	7,800	**8,400**
Cuba	2,200	1,700	800	900	1,000	1,100
India	4,600	5,000	5,600	5,500	3,100	5,600
Indonesia	0	0	1,700	5,000	12,900	48,100
Paraguay	700	700	600	700	800	900
Peru	0	0	0	0	2,300	3,000
Philippines	0	100	1,200	1,200	1,300	1,400
South Korea	500	1,700	3,300	3,200	5,200	**6,800**
Taiwan	0	0	0	0	2,900	7,200
Thailand	1,500	2,800	5,900	5,700	7,100	**7,400**
Global total	818,000	1,082,100	1,448,600	1,740,800	2,017,300	2,302,500

Note: Data for 2010 were extrapolated using total global production data, except for Germany, UK, USA , Brazil and some others (shown in bold).

Annex 3

Regional temperature anomalies in the winters of 2009 and 2010

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 2009 and 2008 are the annual number of Heating Degree Days for particular cities or countries, and spatial temperature anomalies across the globe.

The number of Heating-Degree Days (HDD) at a certain location or a population weighted average over a country is defined as the number of days that the average temperature is below a chosen threshold, for instance 15° C, below which space heating is assumed to be applied. The number of HDD for a particular day is defined as the difference between the threshold temperature and the average temperature that day.

Although the HDD method is a proxy for the energy demand for space heating and does not give precise values, it is often used in trend analysis of energy consumption. In Table A.3.1, the number of Heating-Degree Days in 2009 and 2010 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 it can be concluded that parts of Germany (Berlin), Netherlands (Amsterdam), UK (London) and the USA (Atlanta) experienced a very cold winter in 2010, with HDDs about one quarter higher than in 2009.

A global analysis by NOAA/NCDC (2010) characterised the winter months of 2010 as follows:

- **January-February 2010.** *Warmer-than-average* conditions were present across most of the globe's surface area, with the exception of *cooler-than-average* conditions across Mexico, northern Australia, the central and south-eastern contiguous U.S., north-eastern Pacific Ocean and most of Europe, Russia, and the high-latitude southern oceans. In January the *warmest anomalies* occurred in the high latitudes of the Northern Hemisphere, specifically in Canada, the western contiguous U.S., and parts of northern Russia. In February, *cooler-than-average* conditions were present across western and northern Europe, central Asia, southern Argentina, southern Chile, north-eastern Australia, and most of the central and eastern contiguous United States.
- **September-November 2010.** Notable *anomalous warmth* was in western Alaska, most of the contiguous United States, eastern Canada, Greenland, the Middle East, western and far eastern Russia, and north-eastern Asia. *Cooler-than-average* regions included much of Australia, western Canada, parts of the northern United States, central and eastern Europe, and central Russia.
- **December 2010.** The *warmest temperature anomalies* were present over much of the planet's surface, particularly the much of the northern high latitudes, northern Africa, eastern Europe, western Asia, and the Middle East. *Cooler-than-average* conditions were present across the central and eastern equatorial Pacific Ocean, most of Australia, and north-western Europe. In December, regionally a strong negative phase of the Arctic Oscillation resulted in the *coolest temperature anomalies* located in northern and western Europe, central Russia, southern Alaska, much of the eastern United States, interior Australia, and most of the eastern and central Pacific Ocean. Also in December the temperatures in the UK were about 5°C below normal, making it the coldest December in more than 100 years. Germany had its fourth coldest December since reliable records began in 1881 and coldest since 1969, with temperatures 4.5°C below normal.

A similar analysis by NOAA/NCDC (2009) for the winter months of 2009 concluded:

- **January-February 2009.** Anomalously warm temperatures covered much of the global land area. *Warmer-than-average* temperatures occurred in most land areas except *cooler-than-average* conditions across parts of western Alaska, north-western South America, north-central continental USA, south-eastern Canada, northern Australia, north-western Africa, western Europe, and central and eastern Russia. In Europe,

Table A.3.1

Heating-Degree Days (HDD-15) for selected cities in 2010 compared with 2009

Country	City	HDD 2009	HDD 2010	Difference
China	Beiijing	2460	2702	10%
	Shanghai	1119	1087	-3%
India	New Delhi	154	183	19%
	Mumbai	0	1	
Japan	Tokyo	941	1050	12%
	Osaka	1114	1172	5%
Russia	Moscow	3839	4105	7%
Italy	Rome	938	936	0%
Germany	Berlin	2393	2939	23%
	Düsseldorf	2297	2499	9%
Netherlands	Amsterdam	2028	2565	26%
United Kingdom	London	1734	2191	26%
United States	New York	1880	1730	-8%
	Washington, DC	1682	1618	-4%
	Atlanta	1065	1335	25%
	Los Angeles	330	307	-7%

Source: http://www.degreedays.net using 15° C as threshold temperature

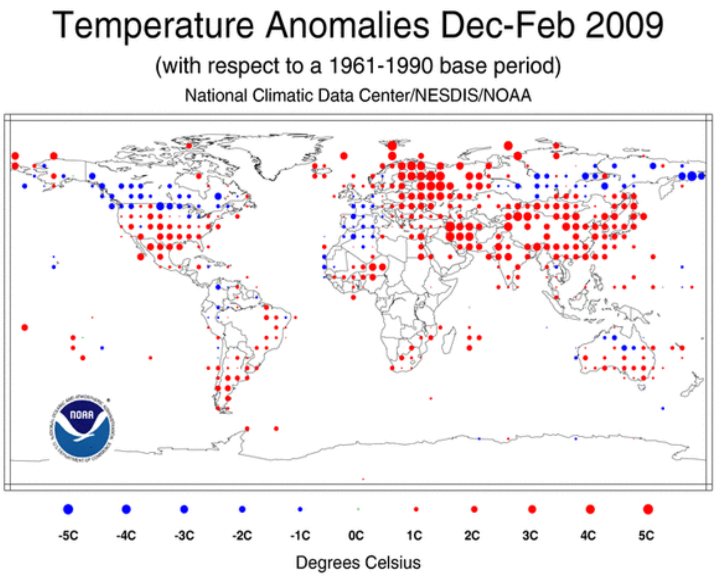
bitter cold temperatures gripped the northern and eastern region at the beginning of January.

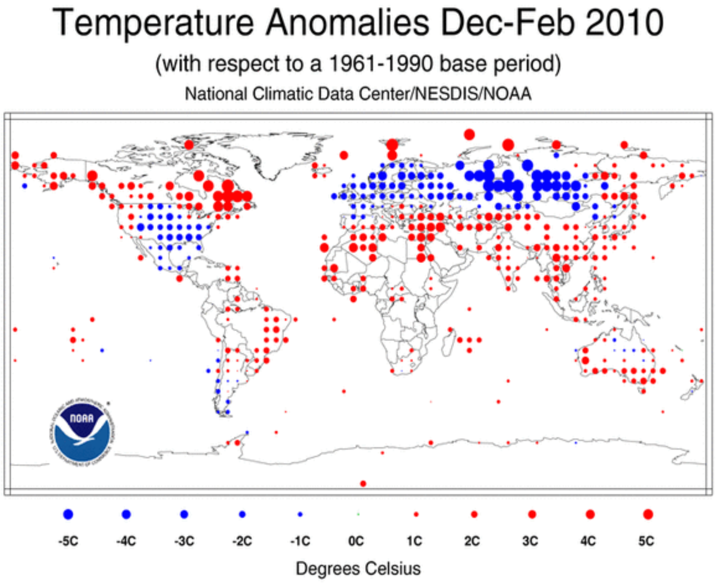
- **September-November 2009.** *Warmer-than-average* temperatures engulfed much of the planet's surface, with the exception *of cooler-than-average* conditions across central Asia, southern South America, and parts of the central contiguous USA.
- **December 2009.** The worldwide land surface temperature tied with 1915 as the 31st warmest December on record. *Warmer-than-average* conditions were observed across Alaska, eastern Canada, Australia, eastern Russia, southern Europe, southern Asia, and parts of northern Africa and northern South America. *Cooler-than-average* conditions engulfed much of the contiguous United States, south-western and south central Canada, northern Kazakhstan, Mongolia, northern China, and most of Russia. Other areas with below average conditions include New Zealand, Argentina, and southern Chile. It was abnormally cool across the United Kingdom, and Ireland experienced its coolest December in 28 years.

The difference in demand for space heating in the Northern Hemisphere winter months in 2009 and 2010 is shown visually in Figure A.3.1, which presents NOAA maps showing the spatial distribution of temperature anomalies for the winter periods (December-February) for these two years. For the USA, the Energy Information Administration calculated that HDD were in 2010 0.8% less than n 2009.

The similarly defined number of Cooling-Degree-Days (CDD), which is an indicator of electricity demand for air conditioning, was 19.4% higher than in 2009 (EIA, 2011c).

Figure A.3.1
Comparison of global temperature anomalies for the winter periods of 2009 and 2010 (source: NOAA/NCDC, 2009; 2010)





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