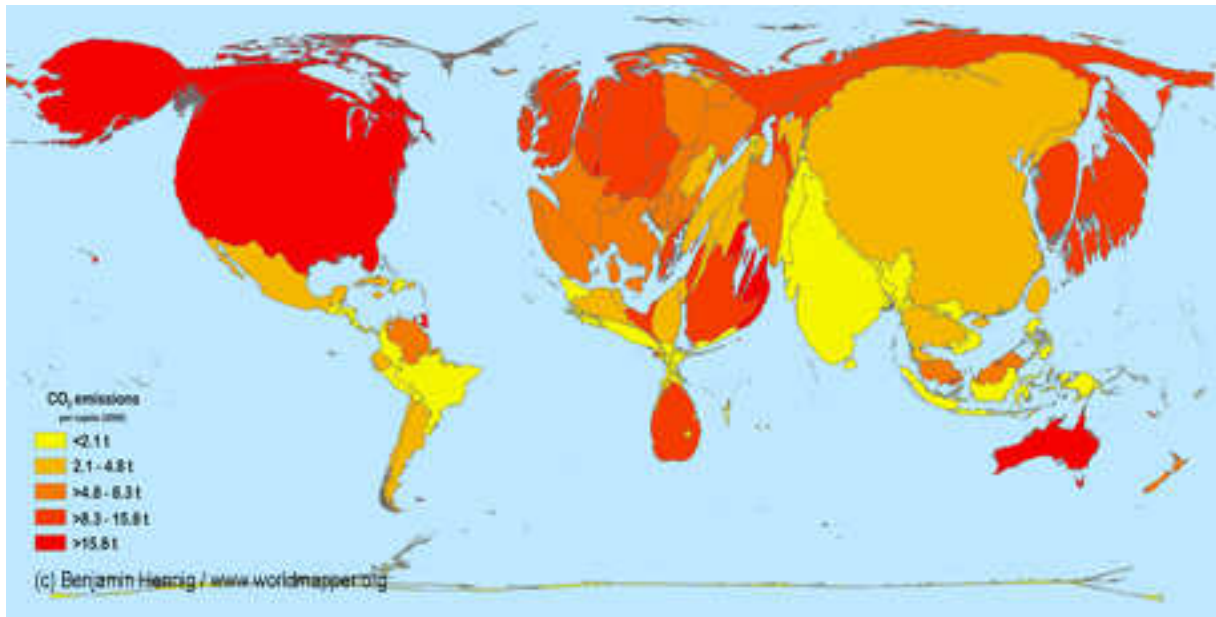


## 8) Emissions of Greenhouse Gases



Carbon Emissions Map, resizing the territories according to their proportion of global carbon dioxide emissions and colouring them according to their per capita emissions

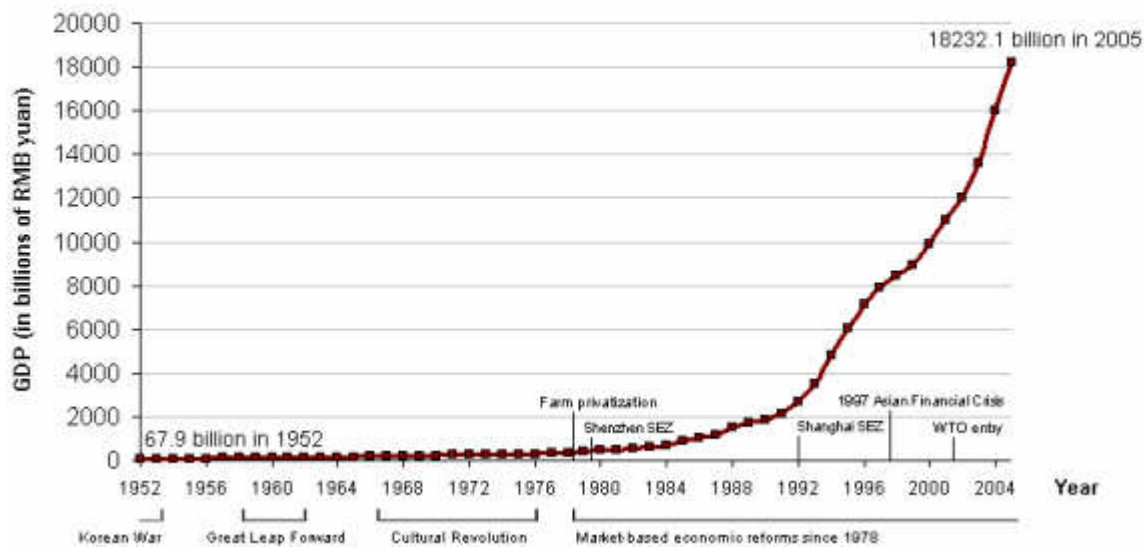
Reproduced with permission from Dr. Benjamin Hennig <http://www.viewsoftheworld.net/>.

Summary:

- The increase in CO<sub>2</sub> emissions from both fossil fuel burning and land use change are the dominant cause of the observed increase in atmospheric CO<sub>2</sub> concentration, which is now over 40% above pre-industrial levels.
- Global CO<sub>2</sub> emissions have continued to grow over the last 10 years, but there are large variations in emission trajectories between countries.
- The Ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide.
- Anthropogenic CO<sub>2</sub> emissions are currently closest to the highest emissions scenario the IPCC considered.

Case Study: Reducing greenhouse gas emissions in China, an Emerging and Developing Country (EDC)

## People's Republic of China's Nominal Gross Domestic Product (GDP) Between 1952 to 2005



Source: Wikipedia [https://en.wikipedia.org/wiki/Economic\\_history\\_of\\_China\\_\(1949–present\)](https://en.wikipedia.org/wiki/Economic_history_of_China_(1949–present))

Scatter graph of the People's Republic of China's GDP between 1952 to 2005, based on publicly available nominal GDP data published by the People's Republic of China and compiled by Hitotsubashi University (Japan) and confirmed by economic indicator statistics from the World Bank

China's emissions started to climb in the 1950s as its economy grew - at an average rate of 10% per year during the period 1990–2004. Over the past 20 years huge numbers of mainly coal fired power stations have been constructed. In 2003, following legislation to protect private property rights, construction boomed and current rates of housing construction are equivalent to building a city the size of Rome in 2 weeks! China's total emissions overtook those of the USA in 2006 and its emissions per head of population overtook those of the EU in 2014.

In China, manufacturing and construction account for two thirds of emissions by source (one third of that is steel production, a quarter is cement, chemicals and plastics produce 17%, aluminium and other metals a further 13%). Unlike most countries, household efficiency is relatively unimportant but sustainable industry is a big priority. It's worth noting that about 20% of Chinese emissions are for producing clothes, furniture and even solar panels that are shipped to Europe and America.

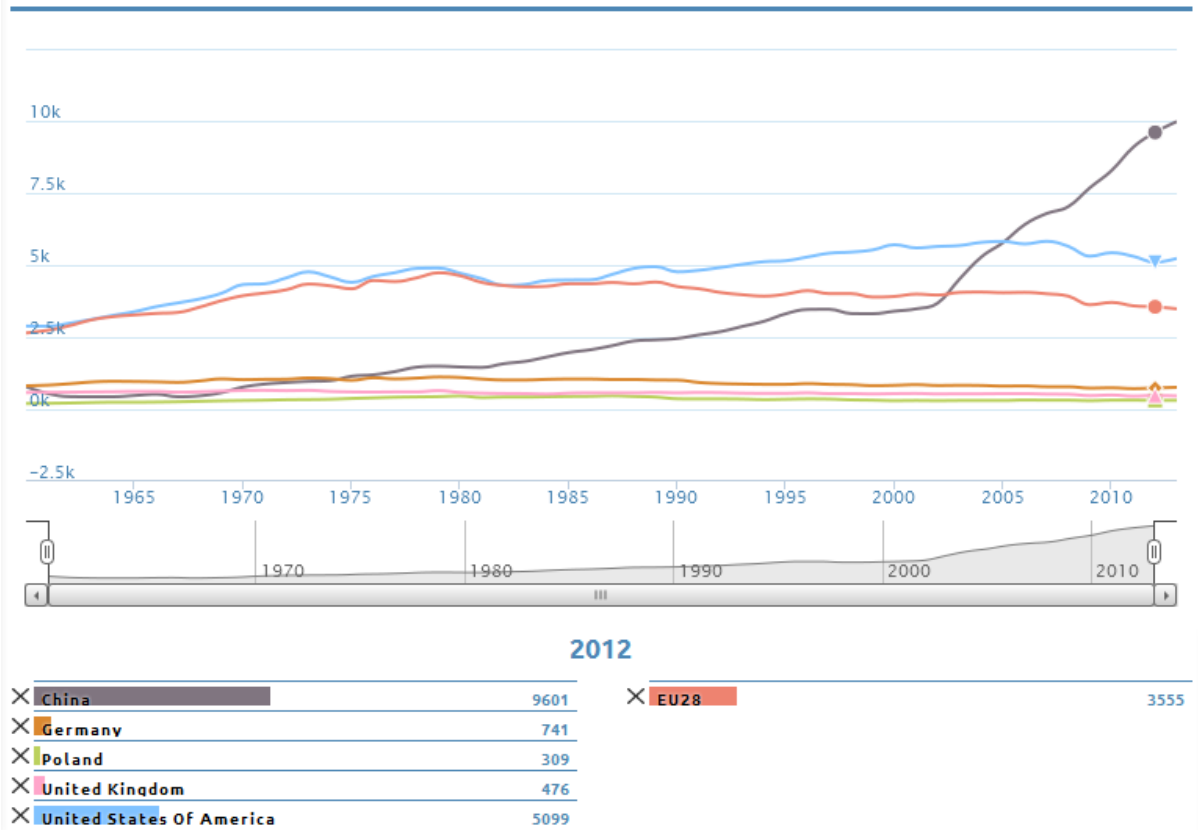
In the first third of 2015, China dramatically cut its carbon dioxide emissions, with its reduction equalling the UK's total emissions for the same period. This is largely due to the closure of more than 1,000 coal mines; coal output is down 7.4% year on year. By 2020, China hopes to reduce coal from around 66% of its energy consumption to 62% which should also improve air quality.

China will aim to cut its greenhouse gas emissions per unit of gross domestic product by 60-65% from 2005 levels under a plan submitted to the United Nations for the 2015 COP21 meeting in Paris. China said it would increase the share of non-fossil fuels (wind and solar) as part of its primary energy consumption to about 20% by 2030, and peak emissions by around the same point, though it would "work hard" to do so earlier. Indeed, China is now the world's largest investor in renewable sources of energy.

Additional Source: <http://climateactiontracker.org/countries/china.html>

### Further Information

#### Territorial ( MtCO<sub>2</sub> )



## Territorial Per capita ( tCO<sub>2</sub> per person )

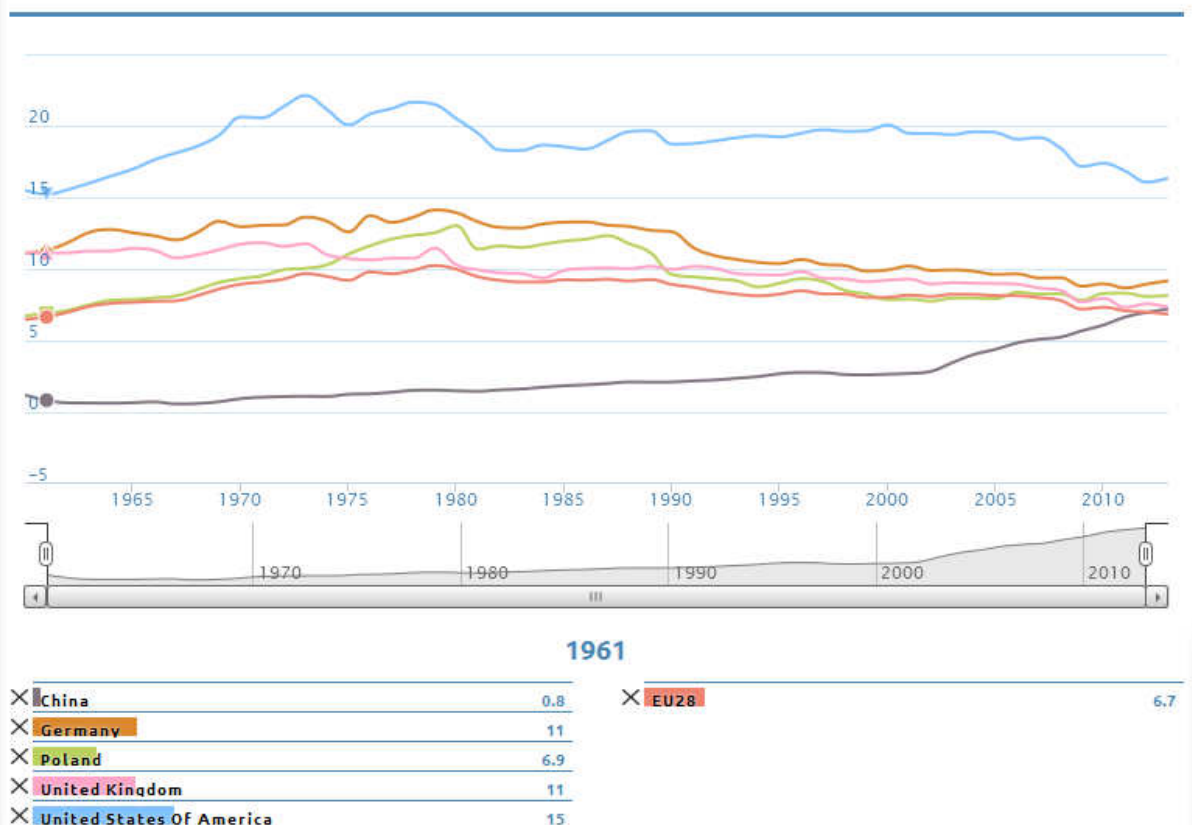


Figure reproduced with permission from the Global Carbon Atlas: [globalcarbonatlas.org](http://globalcarbonatlas.org)

Data sources CDIAC: Boden, TA, G Marland, and RJ Andres. 2013. Global, Regional, and National Fossil-Fuel CO<sub>2</sub> Emissions. Carbon Dioxide Information Analysis Center (CDIAC), Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tenn., USA doi:10.33334/CDIAC/00001\_V2013 [http://cdiac.ornl.gov/trends/emis/meth\\_reg.html](http://cdiac.ornl.gov/trends/emis/meth_reg.html) and UN: United Nations Population Division - World Population Prospects: The 2012 Revision, 2013 <http://esa.un.org/unpd/wpp/Excel-Data/population.htm>

### Case Study: Reducing greenhouse gas emissions in Germany, an Advanced Country (AC)

Between 1990 and 2014, most major German sources of emissions achieved CO<sub>2</sub> reductions. In the energy industry sector, which is responsible for the largest share (around 40%) of Germany's greenhouse gas emissions, emissions fell by 24% between 1990 and 2014. Even bigger reductions were achieved by households (32.9 %) and industry (33.8 %), helped by the fall of the Berlin wall and the subsequent decline of East German industry and power production and the 2009 economic crisis. The transport sector only reduced its emissions by 0.2 %.

Around half of German electricity is still produced in coal- and gas-fired power plants but Germany is pushing ahead with its transition to renewable energy sources. The production costs of renewable energy have dropped by 70% in the past 5 years, making them a much more competitive energy source. In 2015 the share of renewables in the country's domestic energy mix increased to 33%,

At the same time, Germany managed to cut down its power consumption in the past year by 3.8%, despite a booming economy (+1.4 %) which generally translates into a higher energy demand, by

using LED technology and energy saving measures. CO<sub>2</sub> emissions correspondingly fell by 5%. However, 4% of that figure is linked to mild weather conditions requiring less heating.

In 2011, Germany took 8 nuclear power plants off the grid after the Fukushima disaster.

Germany aims to cut greenhouse gas emissions by 40% by 2020 and up to 95% in 2050. It may struggle to meet those targets.

Additional Sources: <https://www.cleanenergywire.org/factsheets/germanys-greenhouse-gas-emissions-and-climate-targets> , <http://www.dw.com/en/renewables-help-cut-german-co2-emissions/a-18176835>

### **Case Study: Reducing greenhouse gas emissions in the USA, an Advanced Country (AC)**

Until 2006, when it was overtaken by China, the USA was the largest emitter of greenhouse gases.

The largest contributor to U.S. greenhouse gas emissions is carbon dioxide from fossil fuel combustion. Changes in this are influenced by many long-term and short-term factors, including population and economic growth, energy price fluctuations, technological changes and the mix of fuels used for electricity generation, short term economic conditions and the weather.

U.S. emissions increased by 5.9 % from 1990 to 2013.

From 2010 to 2011, CO<sub>2</sub> emissions from fossil fuel combustion decreased by 2.5 % due to:

(1) a decrease in coal consumption, with increased natural gas consumption and a significant increase in hydropower used; (2) a decrease in transportation-related energy consumption due to higher fuel costs, improvements in fuel efficiency, and a reduction in miles travelled; and (3) relatively mild winter conditions resulting in an overall decrease in energy demand in most sectors

From 2011 to 2012, CO<sub>2</sub> emissions from fossil fuel combustion decreased by 3.9 %, with emissions from fossil fuel combustion at their lowest level since 1994 due to

- (1) a slight increase in the price of coal, and a significant decrease in the price of natural gas;
- (2) the weather conditions, with no extremely hot days in the summer and much warmer than usual winter temperatures leading to heating degree days decreasing by 12.6 %. This decrease in heating degree days resulted in a decreased demand for heating fuel in the residential and commercial sector, which had a decrease in natural gas consumption of 11.7 and 8.0 %, respectively.

From 2012 to 2013, CO<sub>2</sub> emissions from fossil fuel combustion increased by 2.6 % due to: (1) the weather - heating degree days increased 18.5 % in 2013 compared to 2012. (2) The consumption of natural gas used to generate electricity decreased by 10.2 % due to an increase in the price of natural gas. Electric power plants shifted some consumption from natural gas to coal, increasing coal consumption to generate electricity by 4.2 %.

The use of fracking to extract natural gas is expected to reduce American emissions in the future, by reducing its reliance on coal.

Additional Sources:

<http://www3.epa.gov/climatechange/science/indicators/ghg/us-ghg-emissions.html>

<http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html>

<http://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Chapter-2-Trends.pdf>

<http://climateactiontracker.org/countries/usa.html>

## Case Study: Reducing greenhouse gas emissions in Poland, an Emerging and Developing Country (EDC)

Poland is not among the largest emitters of greenhouse gases globally (its share is just 1%), but its economy is among the least carbon-efficient in the EU. Among transition economies, Poland's performance appears better: its carbon intensity on a per capita basis is situated in about the middle of the countries of Eastern and Central Europe and Central Asia. In 2007, around 1.3 metric tonnes of CO<sub>2</sub>eq, 1.3t CO<sub>2</sub>eq, were required to produce €1 million in GDP, while the EU average was less than 0.5 tCO<sub>2</sub>eq.

Poland cut its emissions considerably as a side effect of the transition to a market economy, greenhouse gas emissions collapsed along with output through the 90s (declining 20%), as inefficient, often highly energy-intensive plants shut down during the early years of transition.

The period of 1996 to 2002 witnessed another 17 % decline in emissions despite GDP increasing. Overall, although Poland's GDP nearly doubled from 1988 to 2008, its GHG emissions were reduced by about 30%. During the last half decade or so, a more traditional positive correlation between GDP growth and GHG emissions has re-established itself.

Poland depends on domestically available coal far more than other EU countries (solid fuels, coal and lignite, constitute 57% of gross inland energy consumption for heat and electricity) with very little renewable energy production and no nuclear power. This reliance on coal makes future emission reduction challenging.

Transport, which contributes about 10% of overall GHG emissions, has grown by almost three-quarters since transition, with a very high share of used vehicles, which tend to be much more fuel inefficient and polluting. However, Poland still has relatively low rates of motorisation, suggesting that the growth of road transport could be high in the future.

Poland has made considerable advances in energy efficiency in the past 20 years; yet further efforts are required to bring it to Western European standards.

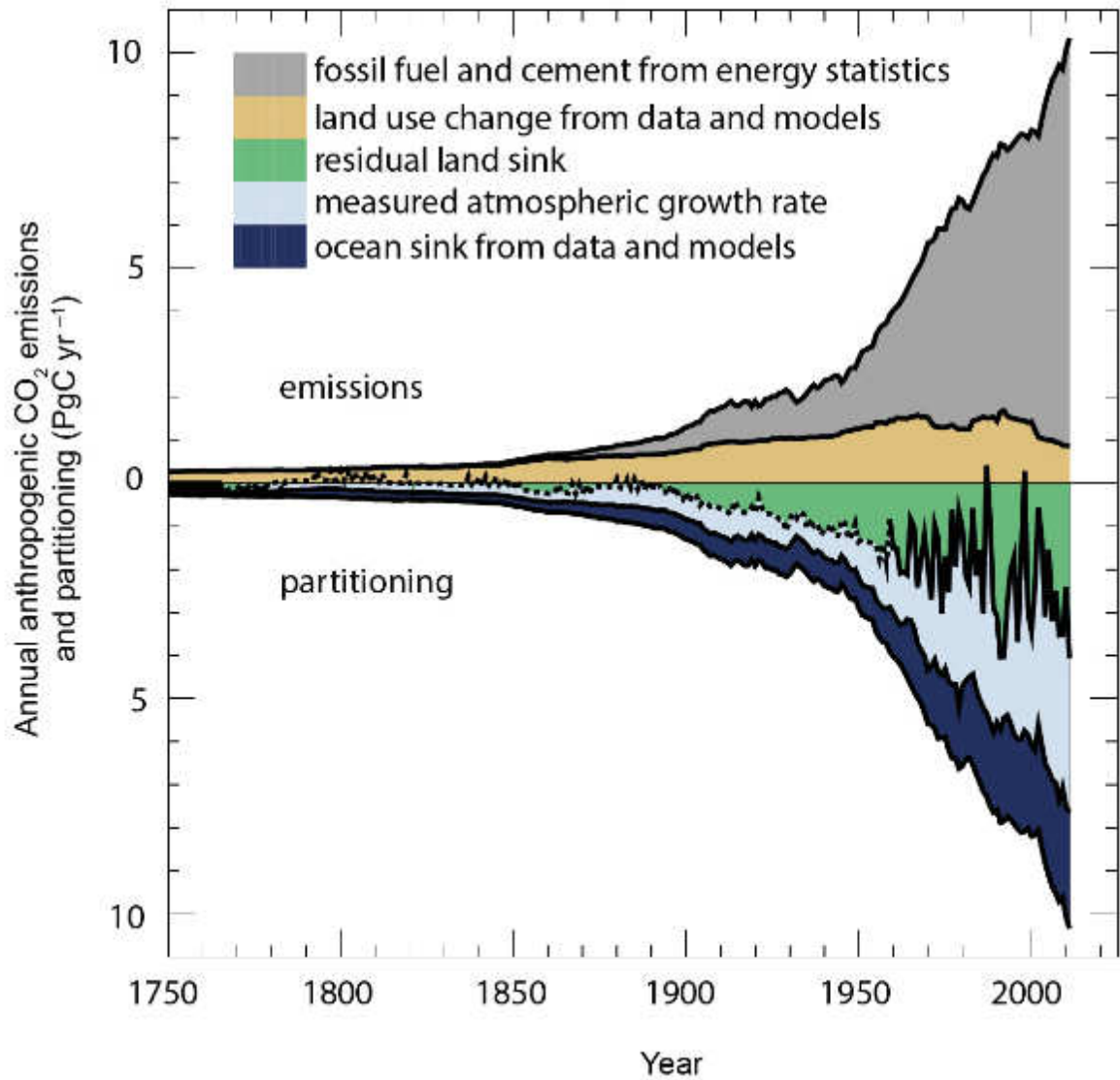
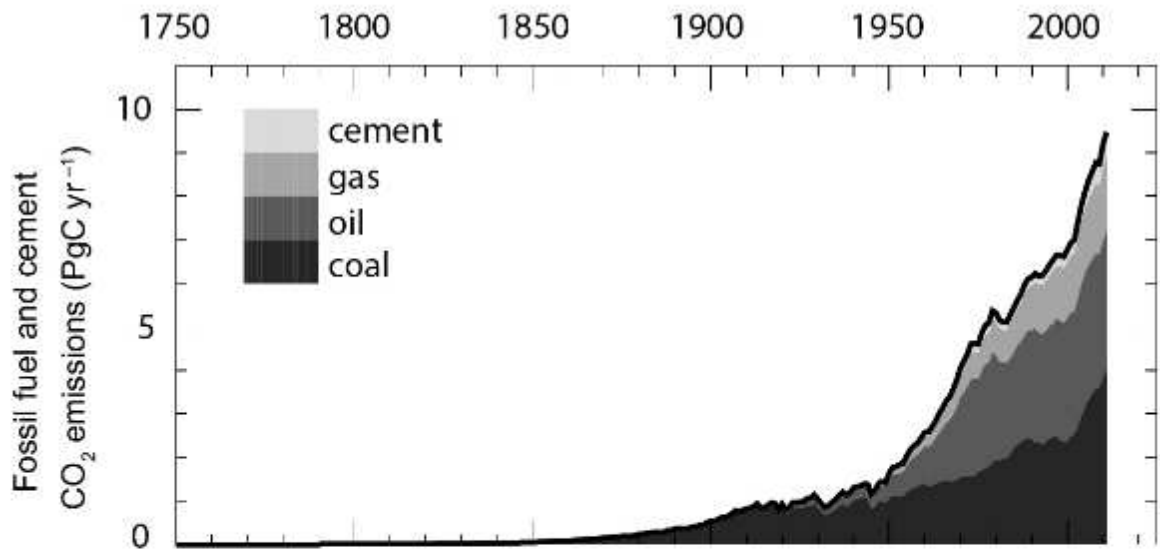
In 2014, the EU pledged a 40% reduction in greenhouse gas emissions by 2030. To help some countries achieve this, concessions including carbon credits and emissions allowances were made. Poland claimed 60% of the concessions available to 2019, which it will be able to sell to other EU countries, on the condition that it spends the proceeds on diversifying its energy mix and modernising its coal fired power stations.

Additional Sources:

<http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/ECAEXT/0,,contentMDK:22839437~pagePK:146736~piPK:146830~theSitePK:258599,00.html>

<http://www.oecd.org/newsroom/poland-needs-a-strategy-for-moving-to-a-lower-carbon-economy.htm>





WG1 Chapter 6, Figure 8. Annual anthropogenic CO<sub>2</sub> emissions and their partitioning among the atmosphere, land and ocean (PgC/year) from 1750 to 2011. (Top) Fossil fuel and cement CO<sub>2</sub> emissions by category (Bottom) Fossil fuel and cement CO<sub>2</sub> emissions, CO<sub>2</sub> emissions from net land use change (mainly deforestation), the atmospheric CO<sub>2</sub> growth rate, the ocean CO<sub>2</sub> sink and the residual land sink which represents the sink of anthropogenic CO<sub>2</sub> in natural land ecosystems. The emissions and their partitioning only include the fluxes that have changed since 1750, and not the natural CO<sub>2</sub> fluxes (e.g., atmospheric CO<sub>2</sub> uptake from weathering, outgassing of CO<sub>2</sub> from lakes and rivers, and outgassing of CO<sub>2</sub> by the ocean from carbon delivered by rivers) between the atmosphere, land and ocean reservoirs that existed before that time and still exist today.

Anthropogenic CO<sub>2</sub> emissions to the atmosphere were  $555 \pm 85$  PgC between 1750 and 2011. Of this, fossil fuel combustion and cement production contributed  $375 \pm 30$  PgC and land use change (including deforestation, afforestation (planting new forest) and reforestation) contributed  $180 \pm 80$  PgC. In 2002–2011, average fossil fuel and cement manufacturing emissions were 7.6 to 9.0 PgC/year, with an average increase of 3.2%/year compared with 1.0%/year during the 1990s. In 2011, fossil fuel emissions were in the range of 8.7 to 10.3 PgC.

Emissions due to land use changes between 2002 and 2011 are dominated by tropical deforestation, and are estimated to range between 0.1 to 1.7 PgC/year. This includes emissions from deforestation of around 3 PgC/year compensated by an uptake of around 2 PgC/year by forest regrowth (mainly on abandoned agricultural land).

The IPCC concluded that the increase in CO<sub>2</sub> emissions from both fossil fuel burning and land use change are the dominant cause of the observed increase in atmospheric CO<sub>2</sub> concentration.

#### WG1 FAQ6.2: What Happens to Carbon Dioxide After It Is Emitted into the Atmosphere?

Carbon dioxide (CO<sub>2</sub>), after it is emitted into the atmosphere, is firstly rapidly distributed between atmosphere, the upper ocean and vegetation. Subsequently, the carbon continues to be moved between the different reservoirs of the global carbon cycle, such as soils, the deeper ocean and rocks. Some of these exchanges occur very slowly. Depending on the amount of CO<sub>2</sub> released, between 15% and 40% will remain in the atmosphere for up to 2000 years, after which a new balance is established between the atmosphere, the land biosphere and the ocean. Geological processes will take anywhere from tens to hundreds of thousands of years—perhaps longer—to redistribute the carbon further among the geological reservoirs. Higher atmospheric CO<sub>2</sub> concentrations, and associated climate impacts of present emissions, will, therefore, persist for a very long time into the future.

CO<sub>2</sub> is a largely non-reactive gas, which is rapidly mixed throughout the entire troposphere in less than a year. Unlike reactive chemical compounds in the atmosphere that are removed and broken down by sink processes, such as methane, carbon is instead redistributed among the different reservoirs of the global carbon cycle and ultimately recycled back to the atmosphere on a multitude of time scales. Figure 1 shows a simplified diagram of the global carbon cycle. The open arrows indicate typical timeframes for carbon atoms to be transferred through the different reservoirs.

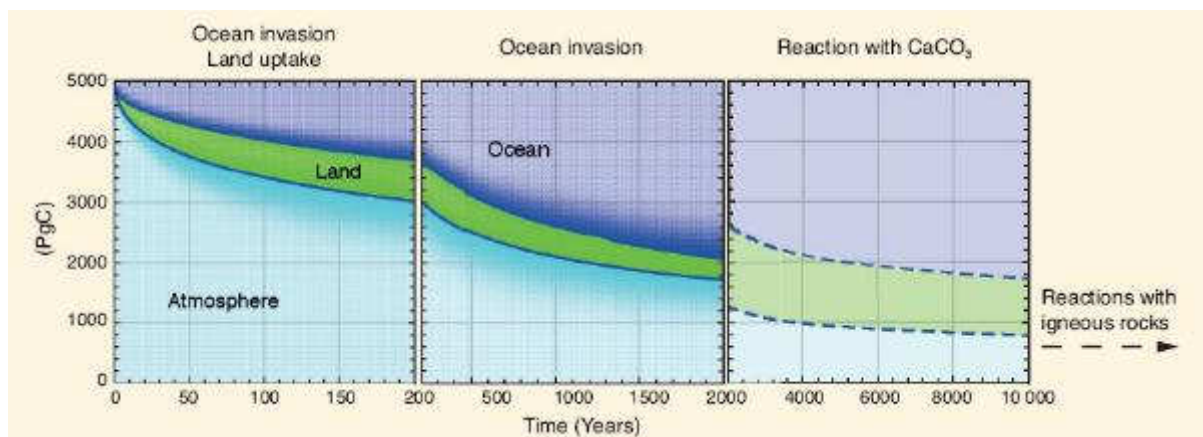
Before the Industrial Era, the global carbon cycle was roughly balanced. This can be inferred from ice core measurements, which show a near constant atmospheric concentration of CO<sub>2</sub> over the last several thousand years prior to the Industrial Era. Anthropogenic emissions of carbon dioxide into the atmosphere, however, have disturbed that equilibrium. As global CO<sub>2</sub> concentrations rise, the exchange processes between CO<sub>2</sub> and the surface-ocean and vegetation are altered, as are subsequent exchanges within and among the carbon reservoirs on land, in the ocean and eventually, the Earth crust. In this way, the added carbon is redistributed by the global carbon cycle, until the



exchanges of carbon between the different carbon reservoirs have reached a new, approximate balance.

Over the ocean, CO<sub>2</sub> molecules pass through the air-sea interface by gas exchange. In seawater, CO<sub>2</sub> interacts with water molecules to form carbonic acid, which reacts very quickly with the large reservoir of dissolved inorganic carbon—bicarbonate and carbonate ions—in the ocean. Currents and the formation of sinking dense waters transport the carbon between the surface and deeper layers of the ocean. The marine biota also redistribute carbon: marine organisms grow organic tissue and calcareous shells in surface waters, which, after their death, sink to deeper waters, where they are returned to the dissolved inorganic carbon reservoir by dissolution and microbial decomposition. A small fraction reaches the sea floor, and is incorporated into the sediments.

The extra carbon from anthropogenic emissions has the effect of increasing the atmospheric partial pressure of CO<sub>2</sub>, which in turn increases the air-to-sea exchange of CO<sub>2</sub> molecules. In the surface ocean, the carbonate chemistry quickly accommodates that extra CO<sub>2</sub>. As a result, shallow surface ocean waters reach balance with the atmosphere within 1 or 2 years. Movement of the carbon from the surface into the middle depths and deeper waters takes longer—between decades and many centuries. On still longer time scales, acidification by the invading CO<sub>2</sub> dissolves carbonate sediments on the sea floor, which further enhances ocean uptake. However, current understanding suggests that, unless substantial ocean circulation changes occur, plankton growth remains roughly unchanged because it is limited mostly by environmental factors, such as nutrients and light, and not by the availability of inorganic carbon it does not contribute significantly to the ocean uptake of anthropogenic CO<sub>2</sub>.



Decay of a CO<sub>2</sub> excess amount of 5000 PgC emitted at time zero into the atmosphere, and its subsequent redistribution into land and ocean as a function of time, computed by coupled carbon-cycle climate models. The sizes of the colour bands indicate the carbon uptake by the respective reservoir. The first two panels show the multi-model mean from a model intercomparison project. The last panel shows the longer term redistribution including ocean dissolution of carbonaceous sediments as computed with an Earth System Model of Intermediate Complexity.

On land, vegetation absorbs CO<sub>2</sub> by photosynthesis and converts it into organic matter. A fraction of this carbon is immediately returned to the atmosphere as CO<sub>2</sub> by plant respiration. Plants use the remainder for growth. Dead plant material is incorporated into soils, eventually to be decomposed by microorganisms and then respired back into the atmosphere as CO<sub>2</sub>. In addition, carbon in vegetation and soils is also converted back into CO<sub>2</sub> by fires, insects, herbivores, as well as by harvest of plants

and subsequent consumption by livestock or humans. Some organic carbon is furthermore carried into the ocean by streams and rivers.

An increase in atmospheric CO<sub>2</sub> stimulates photosynthesis, and thus carbon uptake. In addition, elevated CO<sub>2</sub> concentrations help plants in dry areas to use ground water more efficiently. This in turn increases the biomass in vegetation and soils and so fosters a carbon sink on land. The magnitude of this sink, however, also depends critically on other factors, such as water and nutrient availability.

Coupled carbon-cycle climate models indicate that less carbon is taken up by the ocean and land as the climate warms constituting a positive climate feedback. Many different factors contribute to this effect: warmer seawater, for instance, has a lower CO<sub>2</sub> solubility, so altered chemical carbon reactions result in less oceanic uptake of excess atmospheric CO<sub>2</sub>. On land, higher temperatures foster longer seasonal growth periods in temperate and higher latitudes, but also faster respiration of soil carbon. The time it takes to reach a new carbon distribution balance depends on the transfer times of carbon through the different reservoirs, and takes place over a multitude of time scales. Carbon is first exchanged among the 'fast' carbon reservoirs, such as the atmosphere, surface ocean, land vegetation and soils, over time scales up to a few thousand years. Over longer time scales, very slow secondary geological processes—dissolution of carbonate sediments and sediment burial into the Earth's crust—become important.

FAQ 6.2, Figure 2 illustrates the decay of a large excess amount of CO<sub>2</sub> (5000 PgC, or about 10 times the cumulative CO<sub>2</sub> emitted so far since the beginning of the industrial Era) emitted into the atmosphere, and how it is redistributed among land and the ocean over time. During the first 200 years, the ocean and land take up similar amounts of carbon. On longer time scales, the ocean uptake dominates mainly because of its larger reservoir size (~38,000 PgC) as compared to land (~4000 PgC) and atmosphere (589 PgC prior to the Industrial Era). Because of ocean chemistry the size of the initial input is important: higher emissions imply that a larger fraction of CO<sub>2</sub> will remain in the atmosphere. After 2000 years, the atmosphere will still contain between 15% and 40% of those initial CO<sub>2</sub> emissions. A further reduction by carbonate sediment dissolution, and reactions with igneous rocks, such as silicate weathering and sediment burial, will take anything from tens to hundreds of thousands of years, or even longer.

**The full booklet, together with a significant amount of further information, a glossary and explanation of units can be downloaded from [www.metlink.org](http://www.metlink.org)**

**Further information about the carbon and water cycles, and wider support for GCSE and A level geography can be downloaded from [www.rgs.org/schools](http://www.rgs.org/schools)**

**Unless otherwise stated, all the figures, tables and Frequently Asked Questions referenced in this booklet may be downloaded from the [IPCC website](http://ipcc.ch) or [www.metlink.org](http://www.metlink.org)**

IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2014: *Climate Change 2014: Impacts, Adaptation and Vulnerability. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2014: *Climate Change 2014: Mitigation of Climate Change. Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

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