GLOBAL CARBON PROJECT

Global Carbon Budget

2013

future earth
research for global sustainability

GLOBAL IGBP CHANGE
International Geosphere-Biosphere Programme

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Contributors: 77 people - 46 organisations - 14 countries

Corinne Le Quéré Tyndall Centre for Climate Change Research, Uni. of East Anglia, UK
Glen Peters Center for International Climate & Environmental Research - Oslo (CICERO), Norway
Pep Canadell Global Carbon Project, CSIRO Marine & Atmospheric Research, Australia
Philippe Ciais LSCE, CEA-CNRS-UVSQ, France
Róisín Moriarty Tyndall Centre for Climate Change Research, Uni. of East Anglia, UK
Robbie Andrew Center for International Climate & Environmental Research - Oslo (CICERO), Norway
Pierre Friedlingstein College of Engineering, Mathematics & Physical Sciences, Uni. of Exeter, UK
Bob Andres Carbon Dioxide Information Analysis Center (CDIAC), Oak Ridge National Laboratory, US
Tom Boden Carbon Dioxide Information Analysis Center (CDIAC), Oak Ridge National Laboratory, US
Skee Houghton Woods Hole Research Centre (WHRC), US
Gregg Marland Research Inst. for Environment, Energy & Economics, Appalachian State Uni., US
Stephen Sitch College of Life & Environmental Sciences Uni. of Exeter, UK
Pieter Tans Nat. Oceanic & Atmosphere Admin., Earth System Research Laboratory (NOAA/ESRL), US
Almut Arneth Karlsruhe Inst. of Tech., Inst. Met. & Climate Res./Atmospheric Envir. Res., Germany
Thanos Arvanitis Karlsruhe Inst. of Tech., Inst. Met. & Climate Res./Atmospheric Envir. Res., Germany
Dorothee Bakker School of Environmental Sciences, Uni. of East Anglia, UK
Laurent Bopp LSCE, CEA-CNRS-UVSQ, France
Louise Chini Dept. of Geographical Sciences, Uni. of Maryland, US
Scott Doney Woods Hole Oceanographic Institution (WHOI), US
Anna Harper College of Engineering, Mathematics & Physical Sciences, Uni. of Exeter, UK
Harry Harris Climatic Research Unit (CRU), Uni. of East Anglia, UK
Jo House Cabot Inst., Dept. of Geography, University of Bristol, UK
Atul Jain Dept. of Atmospheric Sciences, Uni. of Illinois, US
Steve Jones Tyndall Centre for Climate Change Research, Uni. of East Anglia, UK
Etsushi Kato Center for Global Envir. Research (CGER), Nat. Inst. for Envir. Studies (NIES), Japan
Ralph Keeling Uni. of California - San Diego, Scripps Institution of Oceanography, US
Kees Klein Goldewijk PBL Netherlands Envir. Assessment Agency & Utrecht Uni., the Netherlands
Arne Körtzinger GEOMAR Helmholtz Centre for Ocean Research, Germany
Charles Koven Earth Sciences Division, Lawrence Berkeley National Lab, US
Nathalie Lefèvre IRD LOCEAN, France
Abdirahman Omar Bjerknes Centre for Climate Research, Norway
Tsuneo Ono Fisheries Research Agency, Japan
Guen-Ha Park East Sea Research Inst. Korea Inst. of Ocean Science & Tech. (KIOST), South Korea
Benjamin Pfeil Geophysical Inst., Uni. of Bergen & Bjerknes Centre for Climate Research, Norway
Ben Poulter LSCE, CEA-CNRS-UVSQ, France
Mike Raupach Global Carbon Project, CSIRO Marine & Atmospheric Research, Australia
Pierre Regnier Dept. of Earth & Environmental Sciences, Uni. Libre de Bruxelles, Belgium
Christian Rödenbeck Max Planck Institute for Biogeochemistry, Germany
Shu Saito Marine Division, Global Environment & Marine Dept., Japan Meteorological Agency
Jörg Schwinger Geophysical Inst., Uni. of Bergen & Bjerknes Centre for Climate Research, Norway
Joachim Segschneider Max Planck Institute for Meteorology, Germany
Beni Stocker Physics Inst., & Oeschger Centre for Climate Change Research, Uni. of Bern, Switzerland
Brönte Tilbrook CSIRO Marine & Atm. Res., Antarctic Cli. & Ecosystems Co-op. Res. Centre, Australia
Steven van Heuven Centre for Isotope Research, Uni. of Groningen, the Netherlands
Nicolas Viovy LSCE, CEA-CNRS-UVSQ, France
Rik Wanninkhof NOAA/AOML, US
Andy Wiltshire Met Office Hadley Centre, UK
Chao Yue LSCE, CEA-CNRS-UVSQ, France
Sönke Zaehle Max-Planck-Institut für Biogeochemie, Germany

Atlas Science Committee | Atlas Engineers (not already mentioned above)
Philippe Peylin | Anna Peregon | Patrick Brockmann | Vanessa Maigné | Pascal Evano
LSCE, CEA-CNRS-UVSQ, France
Jacques Zegbeu CLIMMOD Engineering SARL, France

Atlas Editorial Board (not already mentioned above)
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Asher Minns Tyndall Centre for Climate Change Research, University of East Anglia, UK
James Orr LSCE, CEA-CNRS-UVSQ, France
Chris Sabine National Oceanic and Atmospheric Administration (NOAA), US
Anatoly Schvidenko International Institute for Applied Systems Analysis (IIASA), Austria
Gyami Shrestha Carbon Cycle Science Program Office, US Global Change Research Program, US
Sylvain Taboni Foundation BNP Paribas, Climate Initiative, France
Maciej Telszewski International Ocean Carbon Coordination Project (IOCCP), Poland
Simon Torok CSIRO, Australia
Yoshiki Yamagata Center for Global Envir. Research (CGER), Nat. Inst for Envir. Studies (NIES), Japan

Atlas Designers WeDoData, France
Karen Bastien | Brice Terdjman | Vincent Le Jeune | Anthony Vessière

Publications

Earth Syst. Sci. Data Discuss., 6, 689–760, 2013
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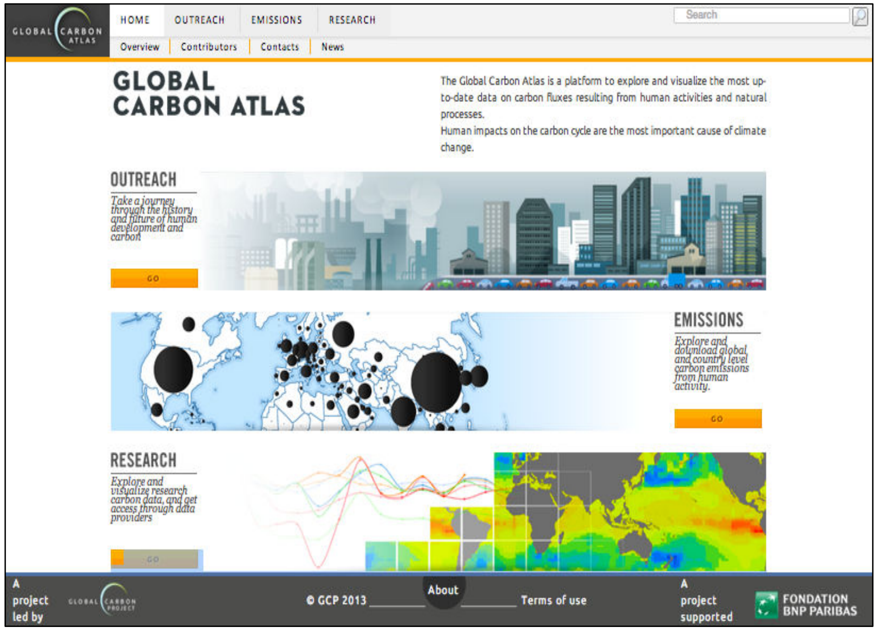
Open Access Earth System Science Data Discussions

This discussion paper is/has been under review for the journal Earth System Science Data (ESSD). Please refer to the corresponding final paper in ESSD if available.

Global carbon budget 2013

C. Le Quéré[1], G. P. Peters[2], R. J. Andres[3], R. M. Andrew[2], T. Boden[3], P. Ciais[4], P. Friedlingstein[5], R. A. Houghton[6], G. Marland[7], R. Moriarty[1], S. Sitch[8], P. Tans[9], A. Arneth[10], A. Arvanitis[10], D. C. E. Bakker[11], L. Bopp[4], J. G. Canadell[12], L. P. Chini[13], S. C. Doney[14], A. Harper[15], I. Harris[16], J. I. House[17], A. K. Jain[18], S. D. Jones[1], E. Kato[19], R. F. Keeling[20], K. Klein Goldewijk[21], A. Körtzinger[22], C. Koven[23], N. Lefèvre[24], A. Omar[25], T. Ono[26], G.-H. Park[27], B. Pfeil[25,28], B. Poulter[4], M. R. Raupach[12], P. Regnier[29], C. Rödenbeck[30], S. Saito[31], J. Schwinger[25,28], J. Segschneider[32], B. D. Stocker[33], B. Tilbrook[34], S. van Heuven[35], N. Viovy[4], R. Wanninkhof[36], A. Wiltshire[37], S. Zaehle[30], and C. Yue[4]



More information, data sources and data files at www.globalcarbonproject.org

Contact: Corinne Le Quéré
c.lequere@uea.ac.uk

More information, data sources and data files at www.globalcarbonatlas.org

Contact: Philippe Ciais
philippe.ciais@lsce.ipsl.fr

All the data is shown in GtC

1 Gigatonne (Gt) = 1 billion tonnes = 1×10^{15}g = 1 Petagram (Pg)

1 kg carbon (C) = 3.664 kg carbon dioxide (CO_2)

1 GtC = 3.664 billion tonnes CO_2 = 3.664 $GtCO_2$

Disclaimer

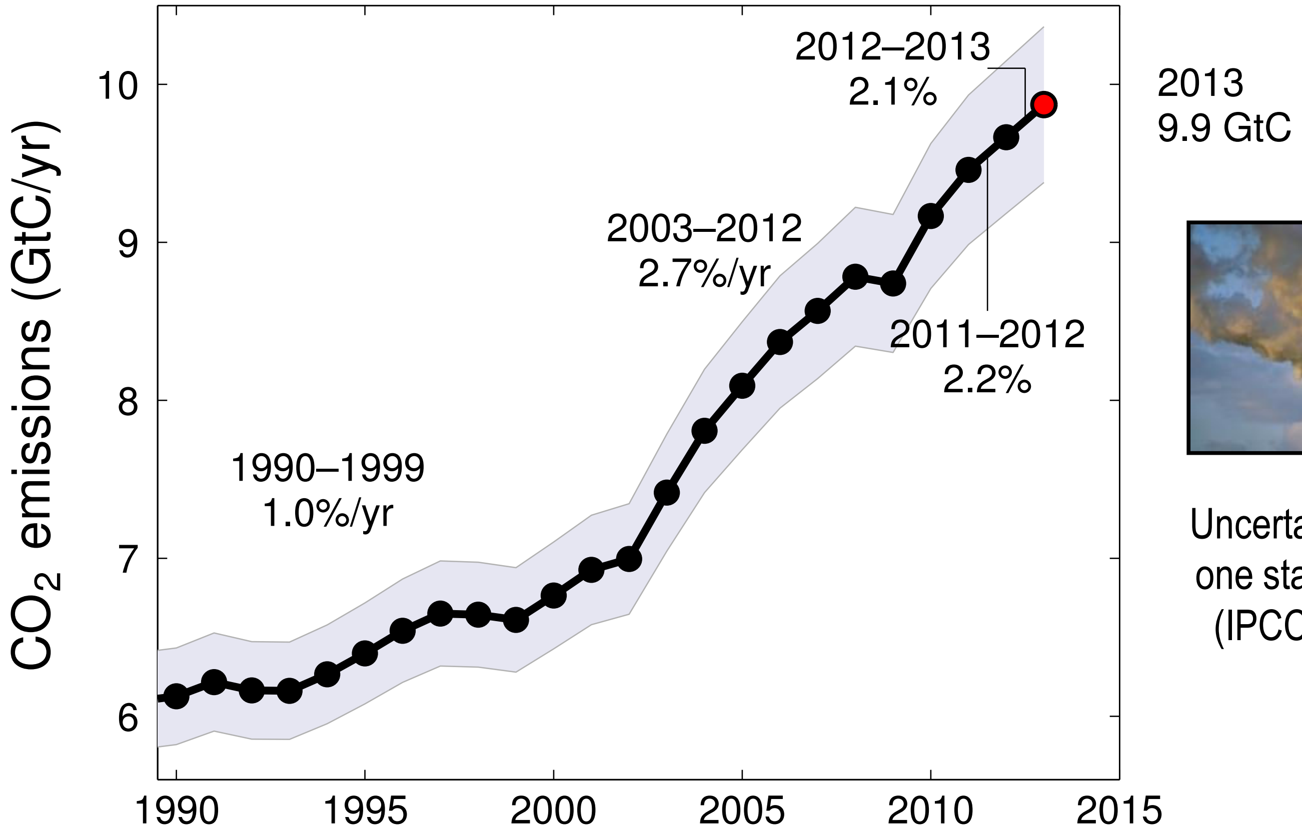
The Global Carbon Budget and the information presented here are intended for those interested in learning about the carbon cycle, and how human activities are changing it. The information contained herein is provided as a public service, with the understanding that the Global Carbon Project team make no warranties, either expressed or implied, concerning the accuracy, completeness, reliability, or suitability of the information.

Fossil Fuel and Cement Emissions

Fossil Fuel and Cement Emissions

Global fossil fuel and cement emissions: 9.7 ± 0.5 GtC in 2012, 58% over 1990

● Projection for 2013 : 9.9 ± 0.5 GtC, 61% over 1990



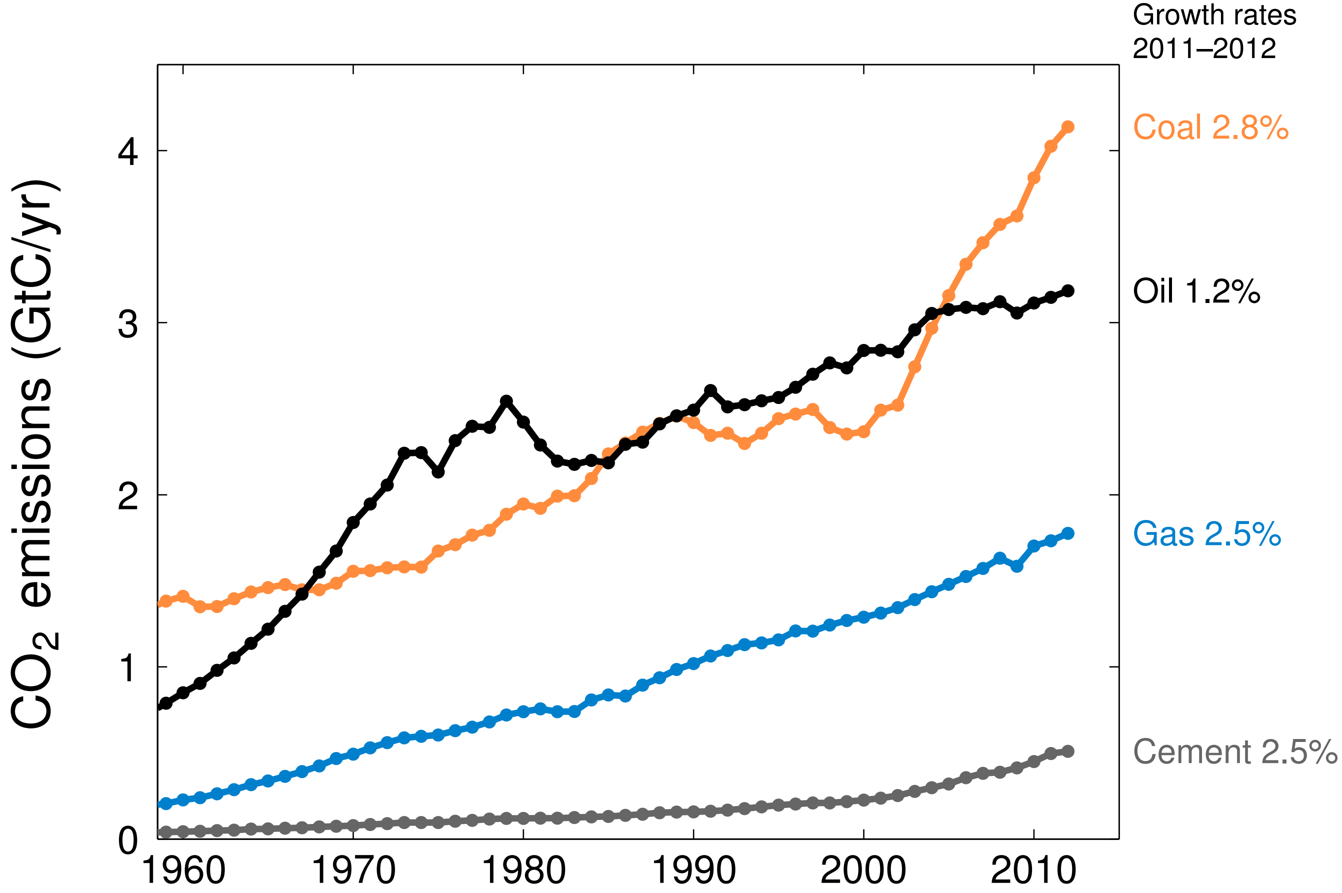
Uncertainty is ±5% for one standard deviation (IPCC "likely" range)

With leap year adjustment: 2012 growth rate is 1.9% and 2013 is 2.4%

Source: Le Quéré et al 2013; CDIAC Data; Global Carbon Project 2013

Emissions from Coal, Oil, Gas, Cement

Share of global emissions in 2012:
coal (43%), oil (33%), gas (18%), cement (5%), flaring (1%, not shown)

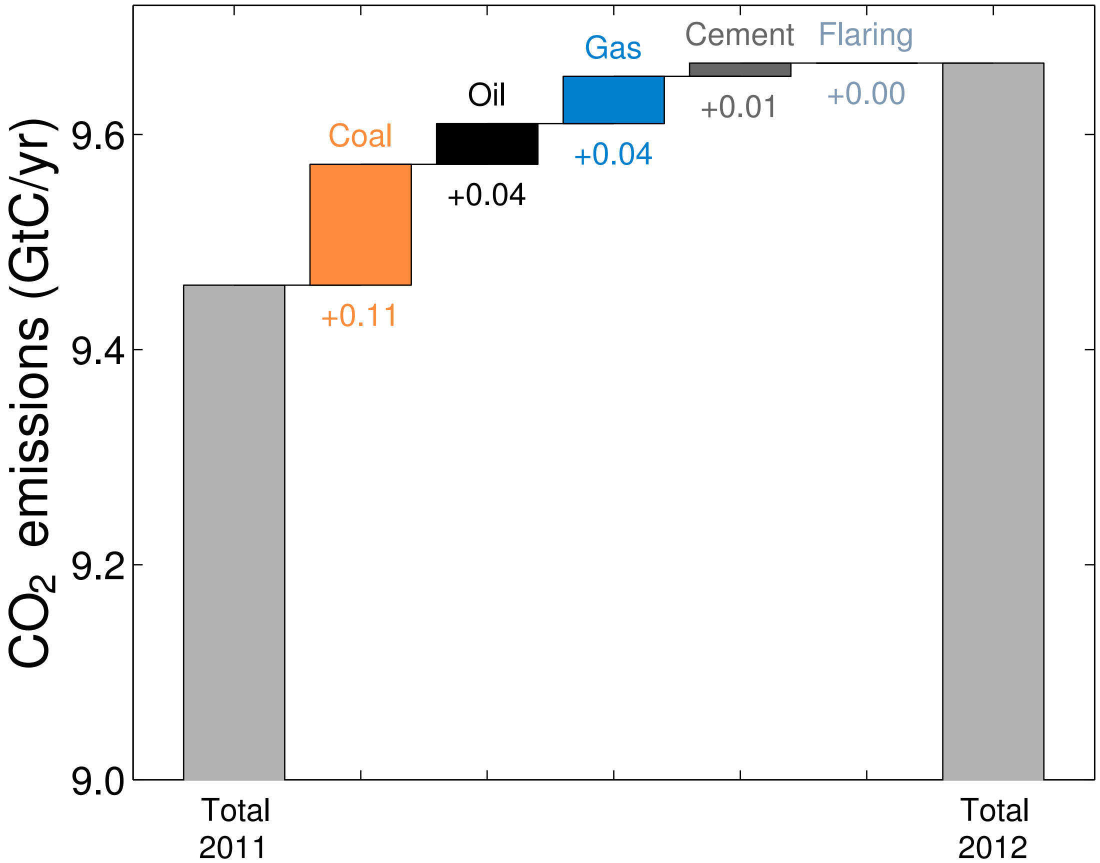


With leap year adjustment in 2012 growth rates are: coal 2.5%, oil 0.9%, gas 2.2%, cement 2.2%.

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Fossil Fuel and Cement Emissions Growth 2012

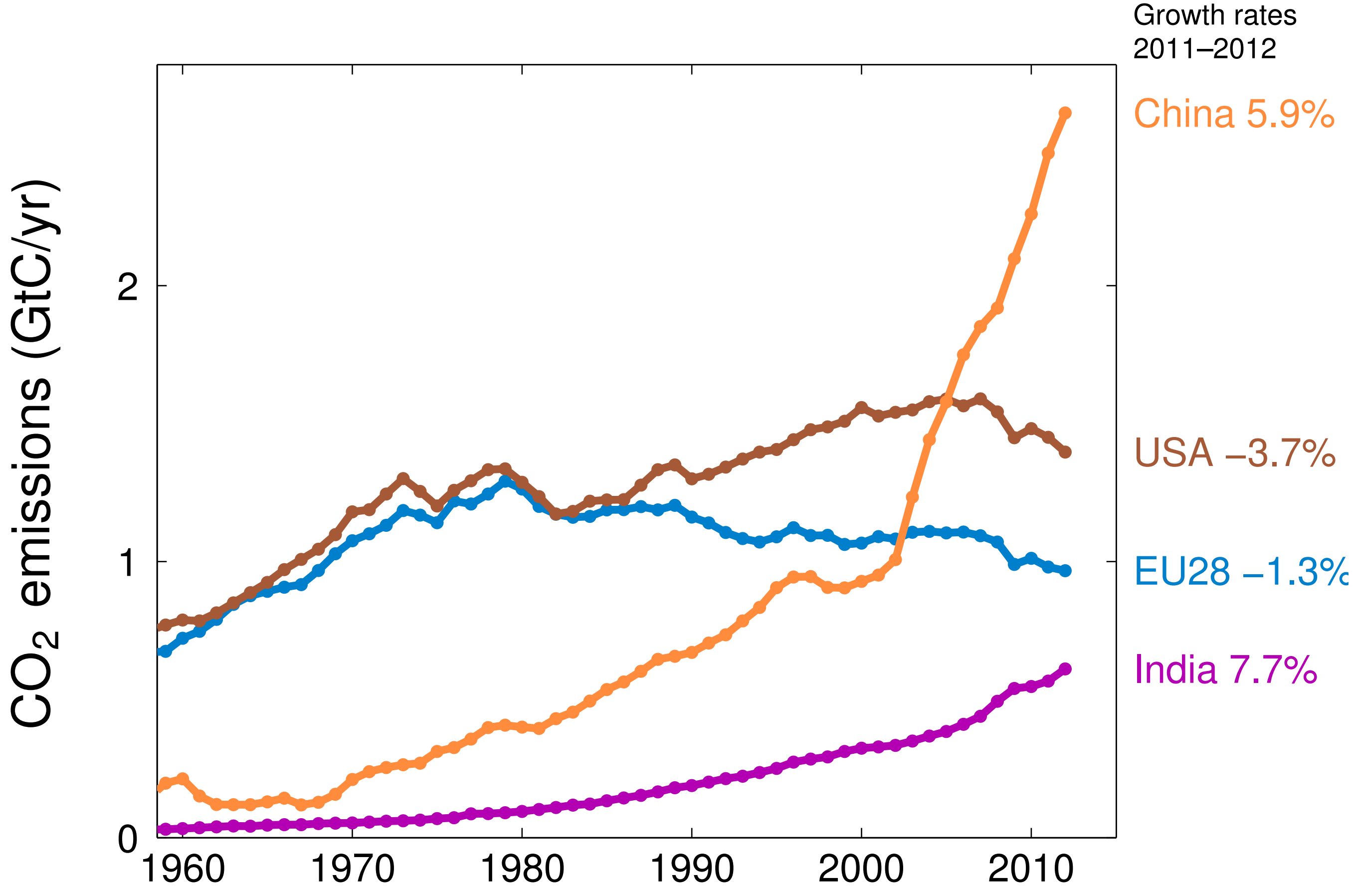
Coal accounted for 54% of the growth in global emissions in 2012,
oil (18%), gas (21%), and cement (6%).



Many countries increased dependence on coal in 2012:
Emissions from coal grew 4.2% in Germany, 5.6% in Japan, 3.0% in the EU28, 10.2% in India.
Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Top Fossil Fuel Emitters (Absolute)

Top four emitters in 2012 covered 58% of global emissions
China (27%), United States (14%), EU28 (10%), India (6%)



With leap year adjustment in 2012 growth rates are: China 5.6%, USA -4.0%, EU -1.6%, India 7.4%.

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Fossil Fuel and Cement Emissions Growth 2012

China accounted for 71% of the global emissions growth in 2012, India 21%, Japan 11%.

The USA contributed to a decrease in emissions.

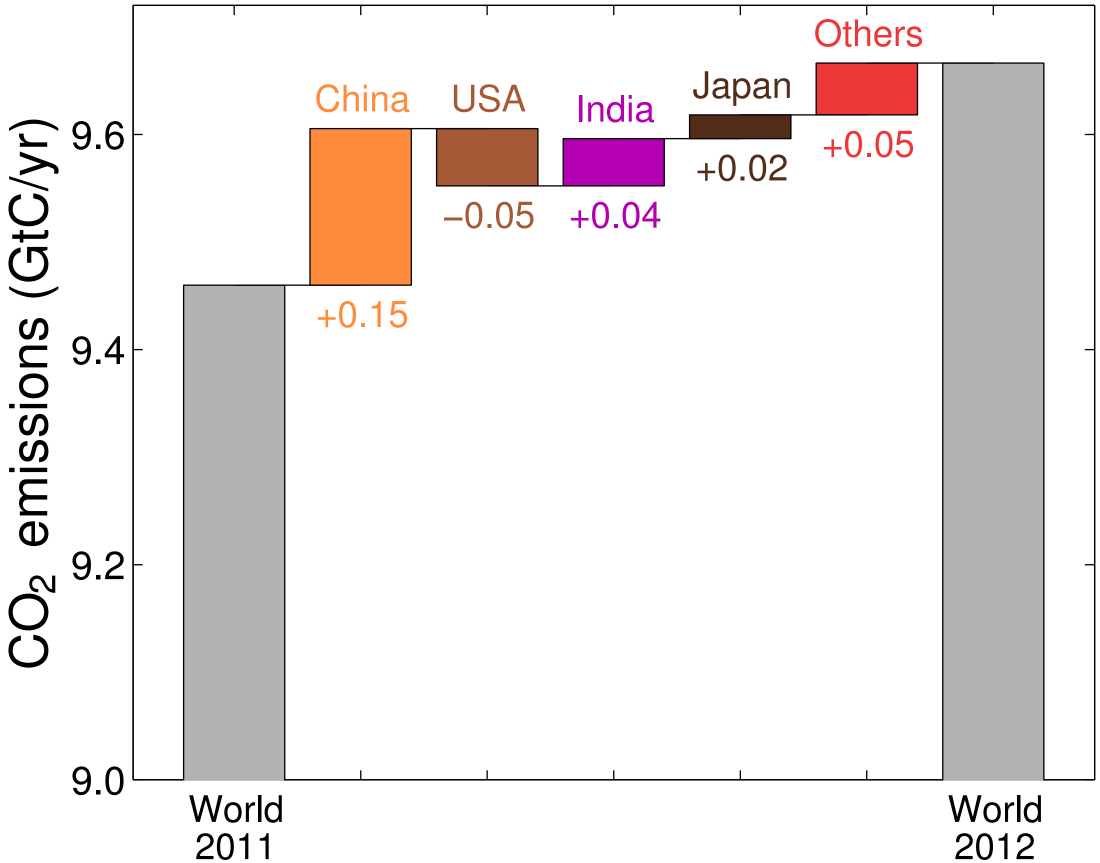
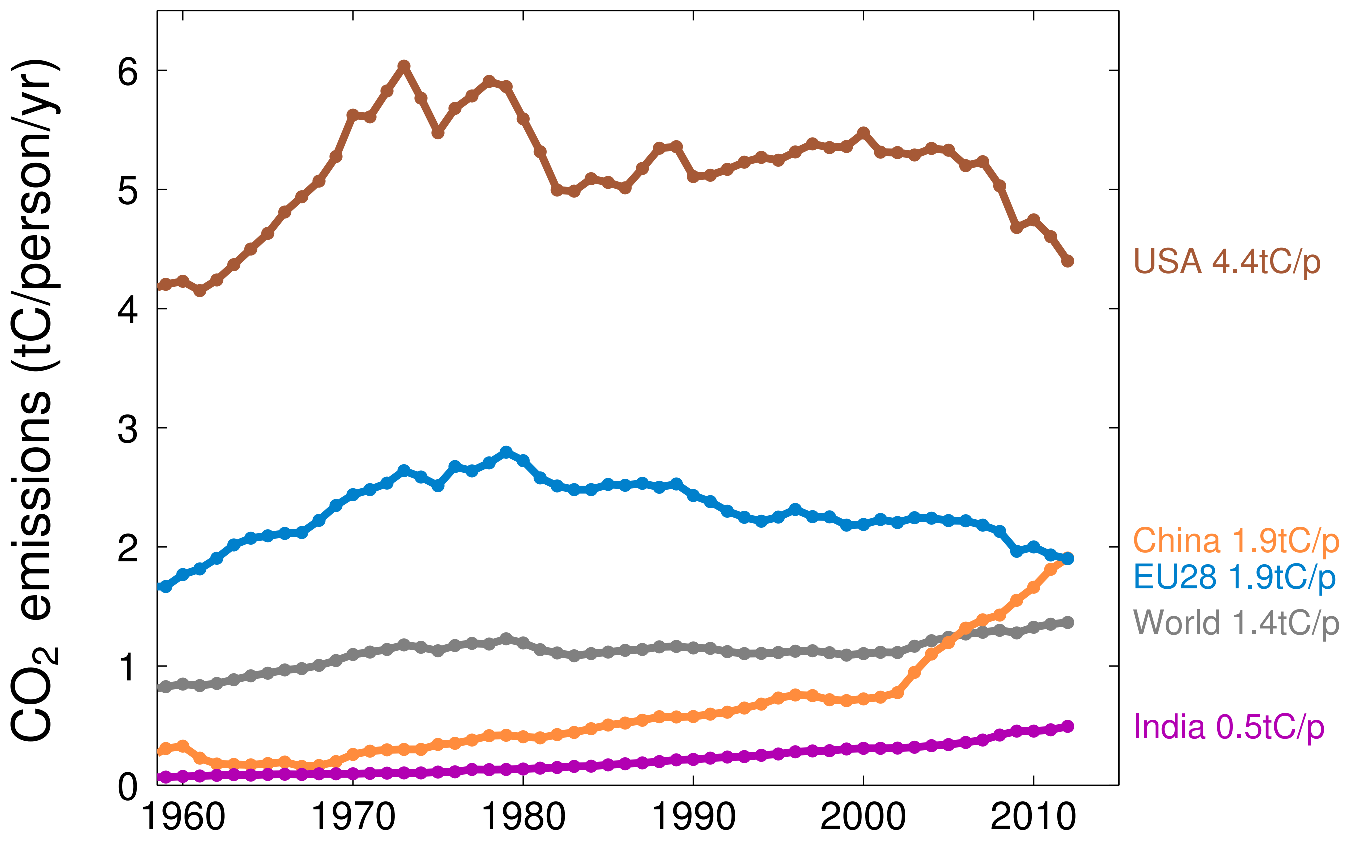


Figure shows the top four countries contributing to emissions changes in 2012

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Top Fossil Fuel Emitters (Per Capita)

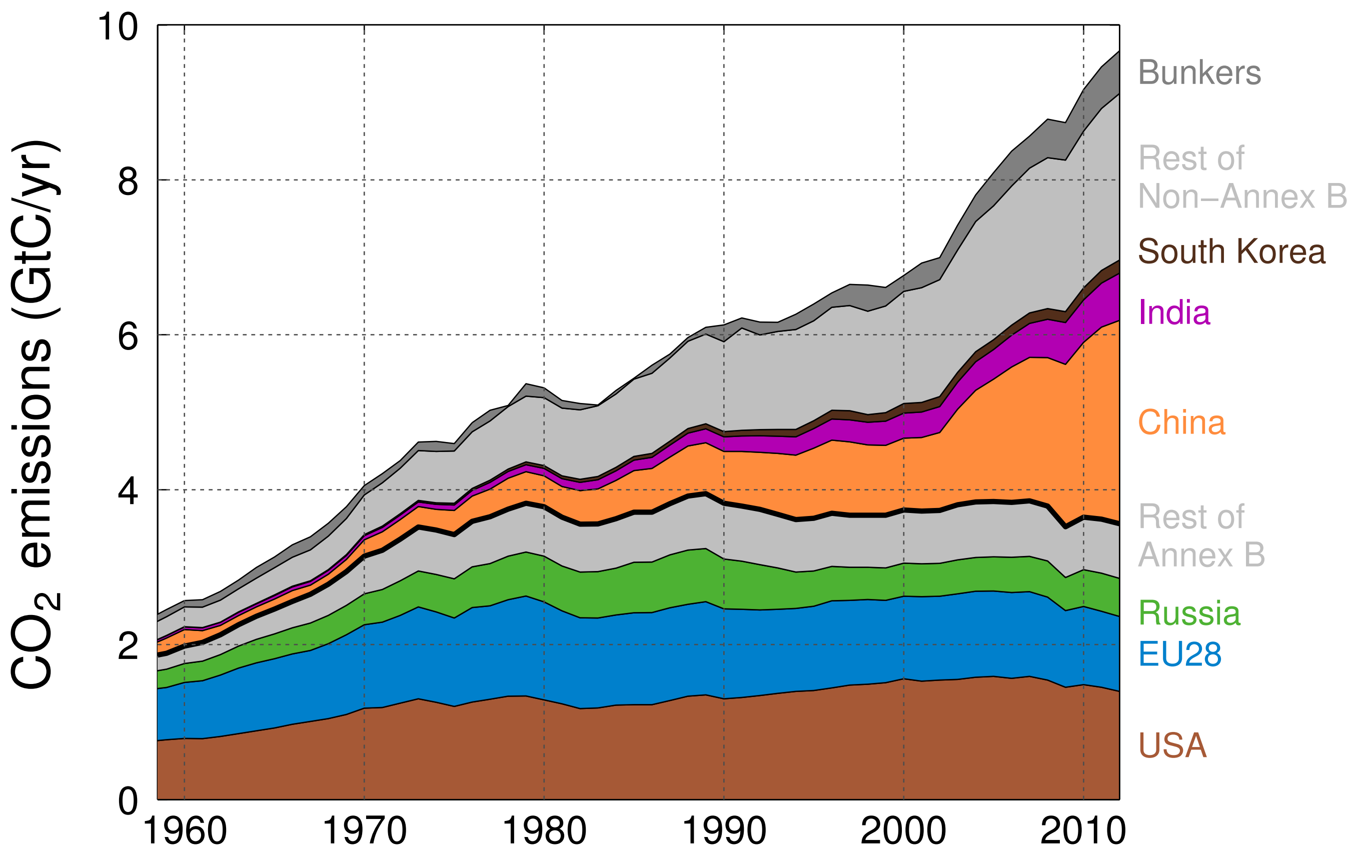
Average per capita emissions in 2012
China is growing rapidly and the US is declining fast



Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Breakdown of Global Emissions by Country

Emissions from Annex B countries have slightly declined
Emissions from non-Annex B countries have increased rapidly in recent years

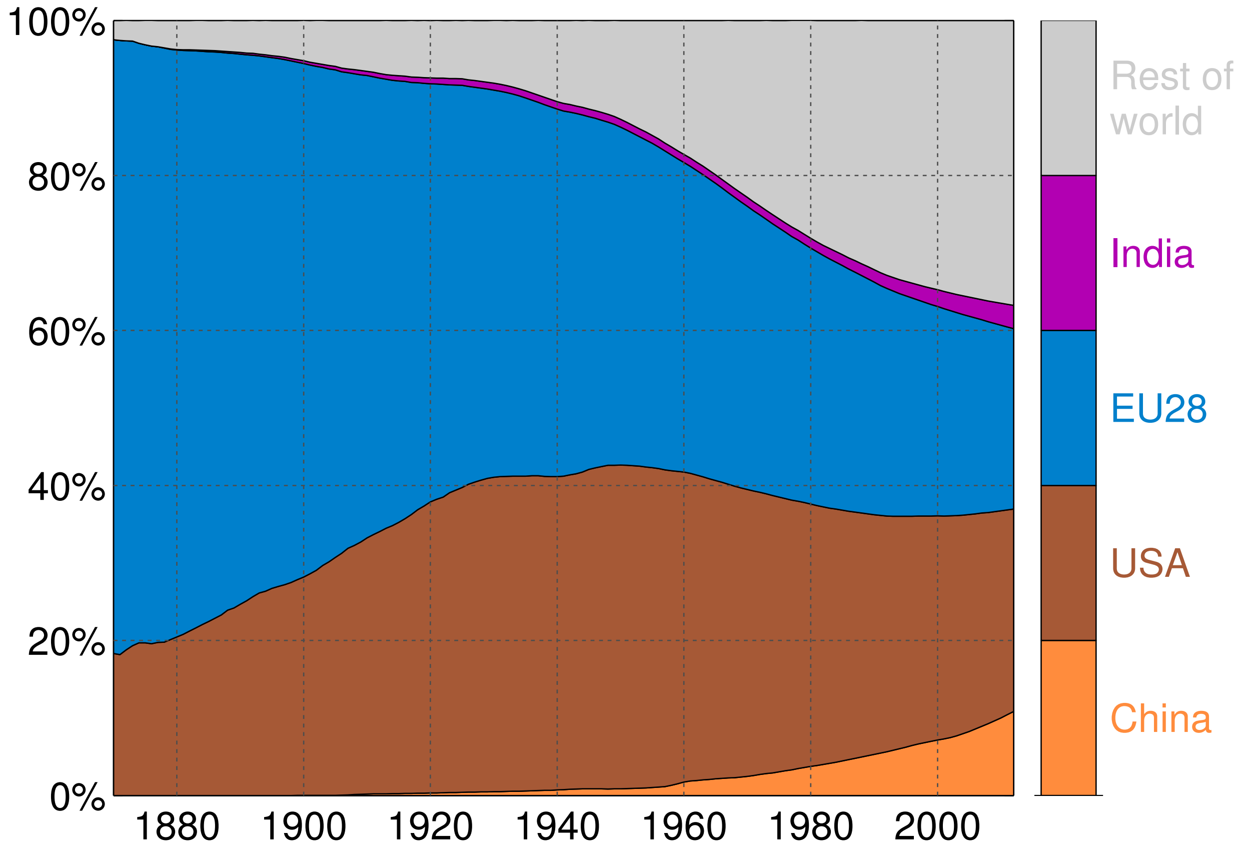


Annex B countries have emission commitments in the Kyoto Protocol

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Historical Cumulative Emissions by Country

Cumulative emissions from fossil-fuel and cement were distributed (1870–2012):
USA (26%), EU28 (23%), China (11%), and India (4%) covering 64% of the total share



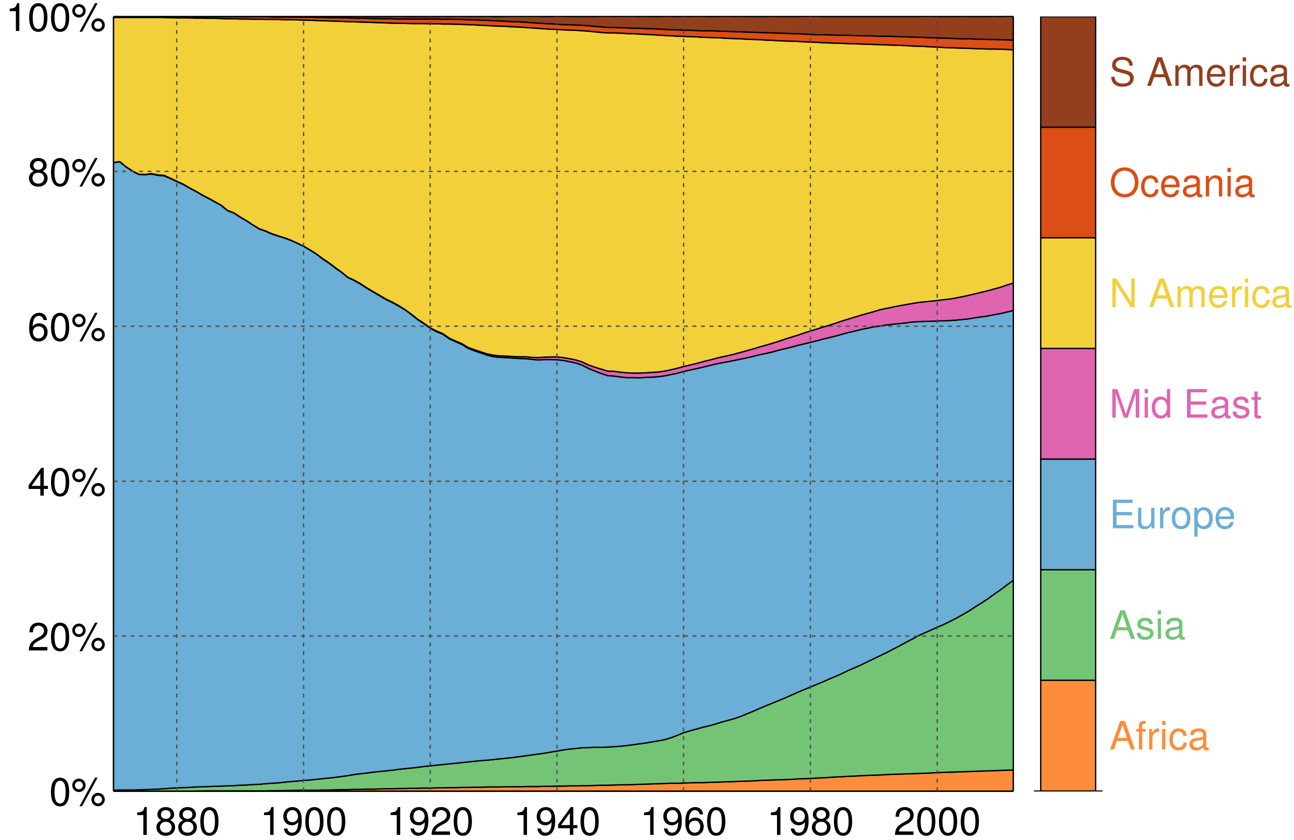
Cumulative emissions (1990–2012) were distributed USA (20%), EU28 (15%), China (18%), India (5%)

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Historical Cumulative Emissions by Region

Cumulative emissions from fossil-fuel and cement (1870–2012)

North America and Europe responsible for most cumulative emissions, but Asia growing fast

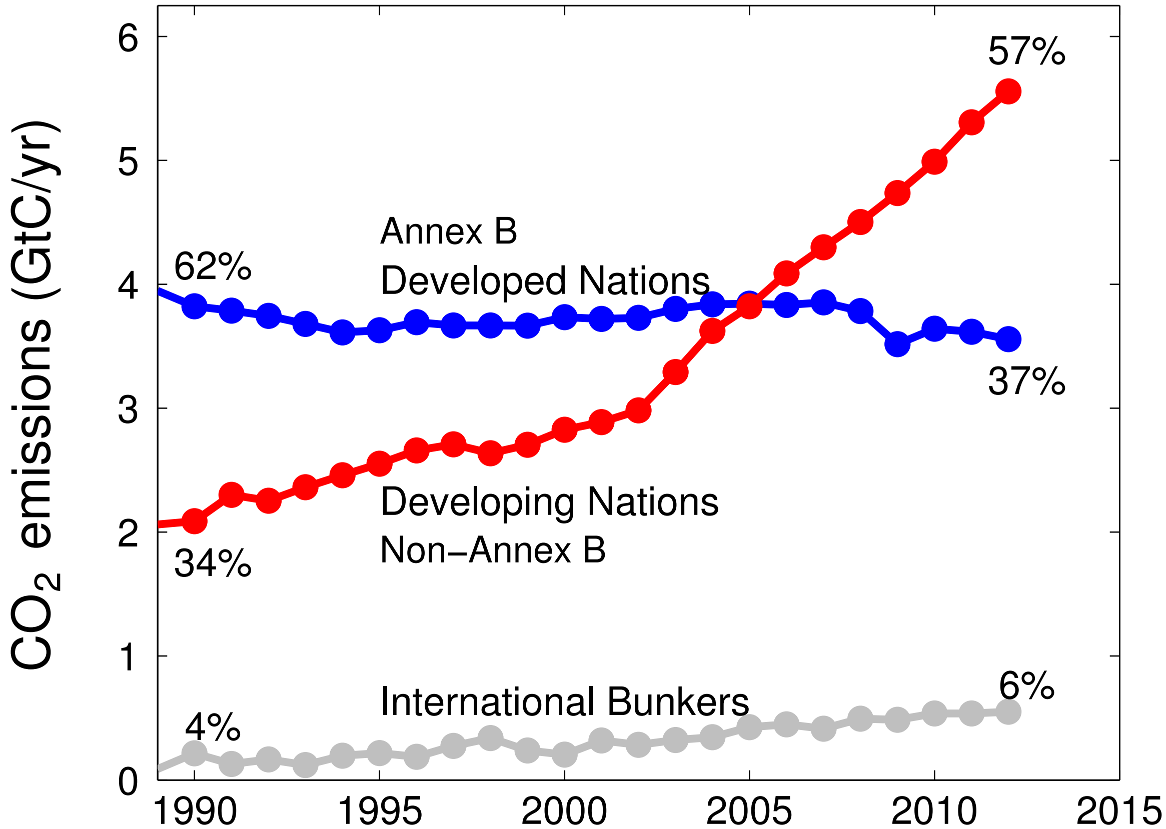


Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Territorial Emissions as per the Kyoto Protocol

The Kyoto Protocol was negotiated in the context of emissions in 1990

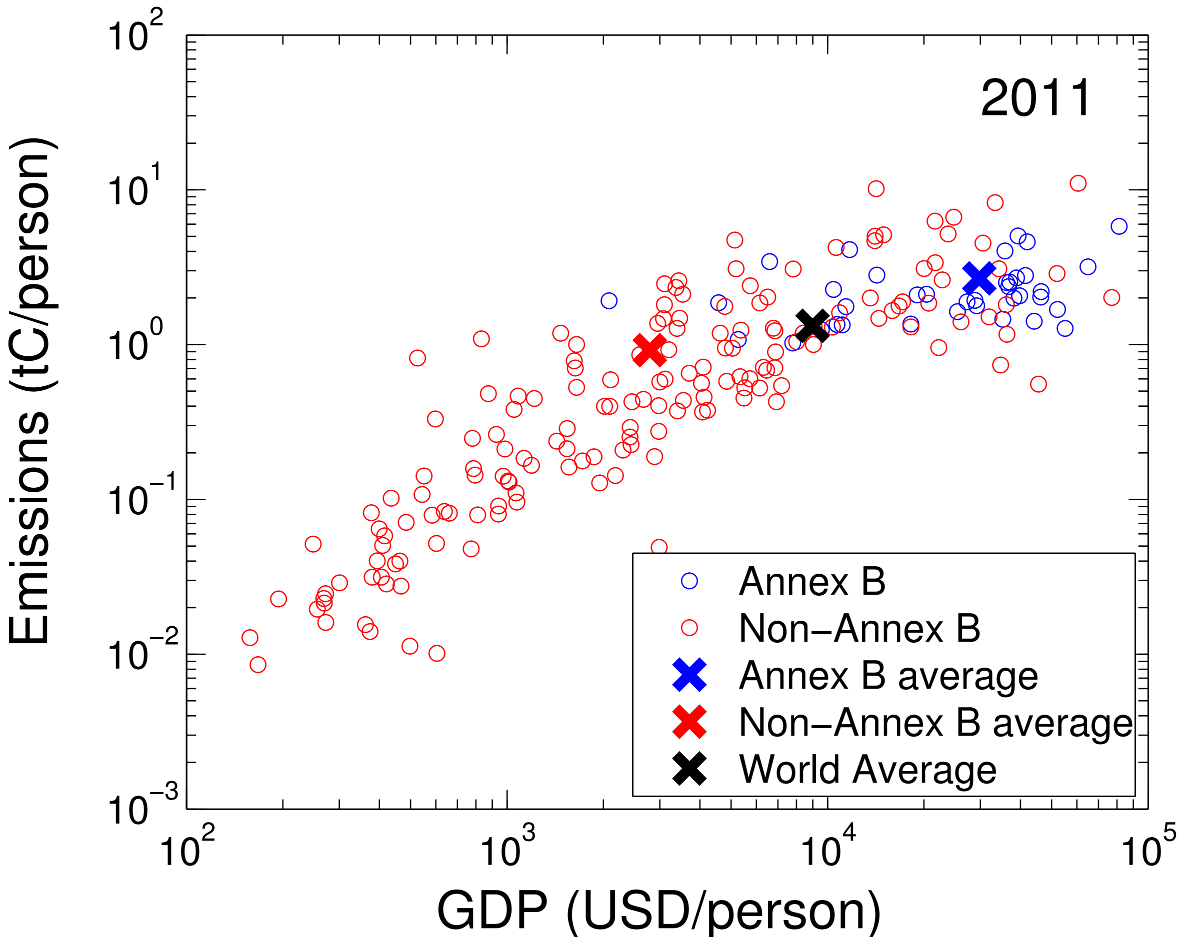
The global distribution of emissions is now starkly different



Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Annex B versus non-Annex B Countries

Annex B countries have emission reduction commitments in the Kyoto Protocol
Annex B countries do not necessarily have highest economic activity per capita

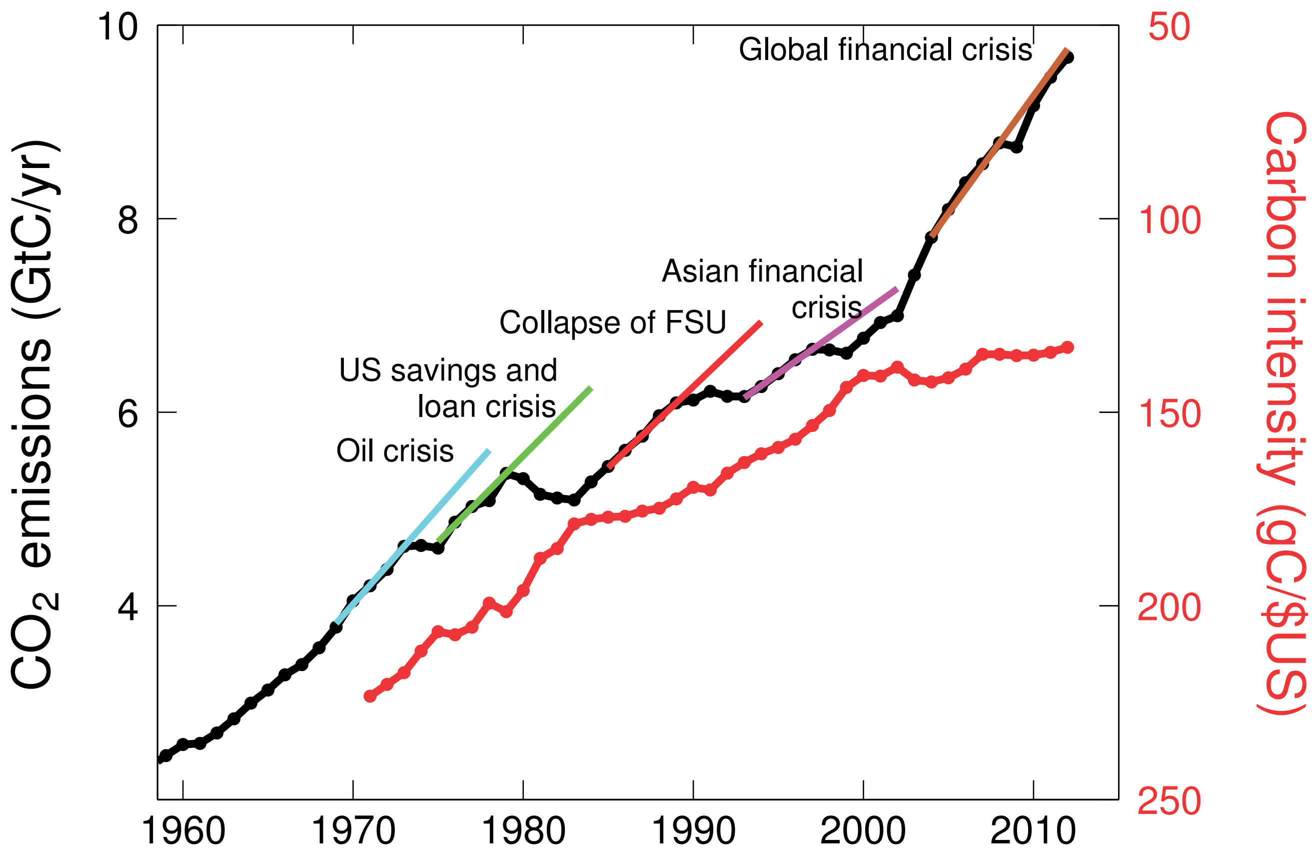


GDP is measured in Market Exchange Rates

Source: CDIAC Data; Unstats; Global Carbon Project 2013

Carbon Intensity of Economic Activity

The global financial crisis of 2008–2009 had no lasting effect on emissions
Carbon intensity has had minimal improvement with increased economic activity since 2005



Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Key Statistics

Region/Country	Emissions 2012: Per capita (tC per person)	Total (Gt C)	Total (%)	Growth 2012 (Gt C)	Growth 2012 (% per year)
Global (with bunkers)	1.4	9.67	100	0.207	2.2
Developed Countries (Annex B)					
Annex B	3.0	3.56	36.8	-0.047	-1.3
USA	4.6	1.40	14.4	-0.053	-3.7
Russian Federation	3.4	0.49	5.1	-0.001	-0.2
Japan	2.5	0.34	3.5	0.022	6.9
Germany	2.4	0.20	2.1	0.004	1.8
Canada	4.0	0.14	1.4	-0.001	-0.6
Developing Countries (Non-Annex B)					
Non-Annex B	0.9	5.56	57.5	0.251	4.7
China	1.8	2.63	27.2	0.146	5.9
India	0.5	0.61	6.3	0.044	7.7
South Korea	3.4	0.17	1.7	0.002	1.1
Iran	2.1	0.16	1.7	0.005	3.1
Saudi Arabia	4.6	0.14	1.4	0.008	5.9
International Bunkers					
Aviation and Shipping	-	0.55	5.7	0.002	0.5

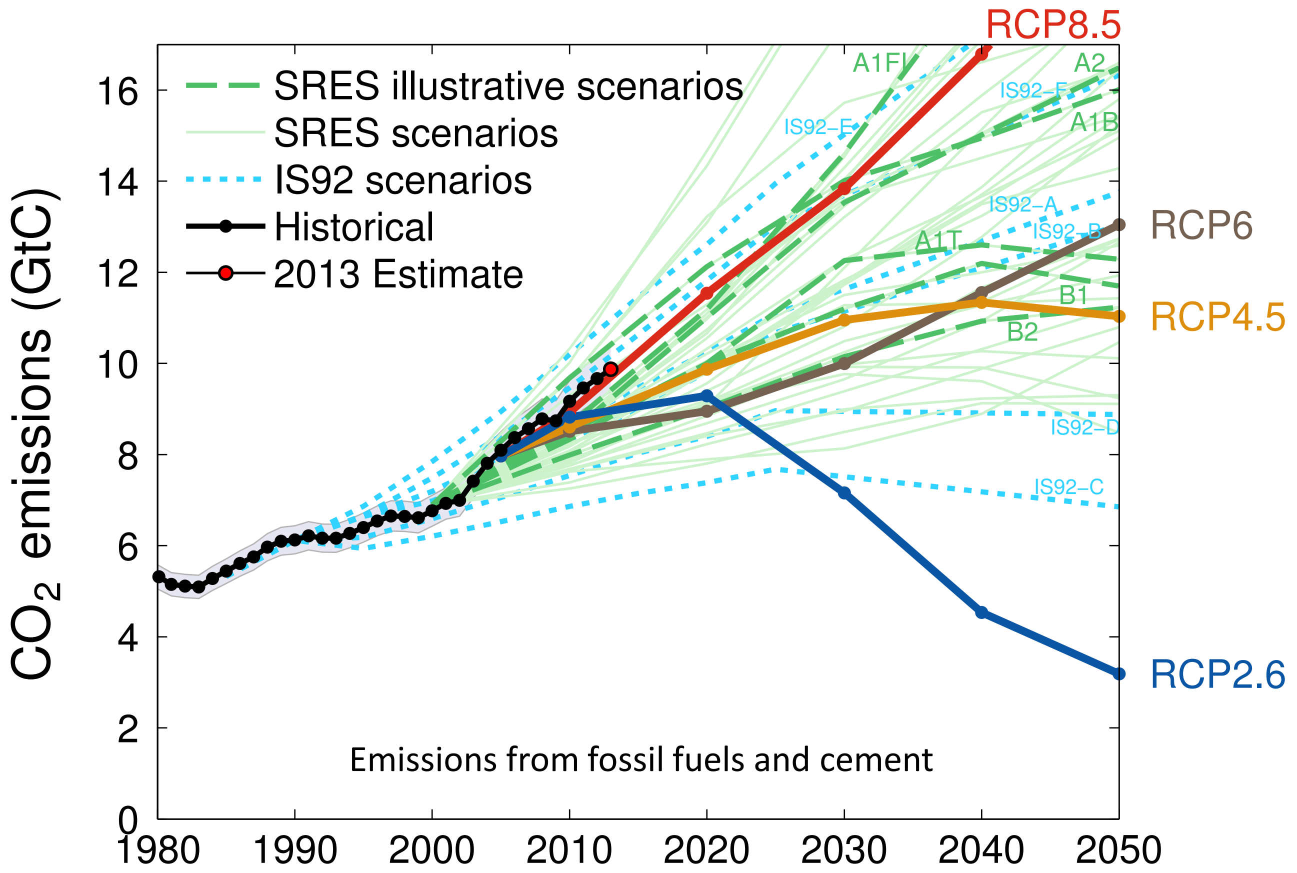
Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Observed Emissions versus Emissions Scenarios

Observed Emissions and Emissions Scenarios

The IPCC has been associated with four generations of emission scenarios

Emissions tracking the higher scenarios

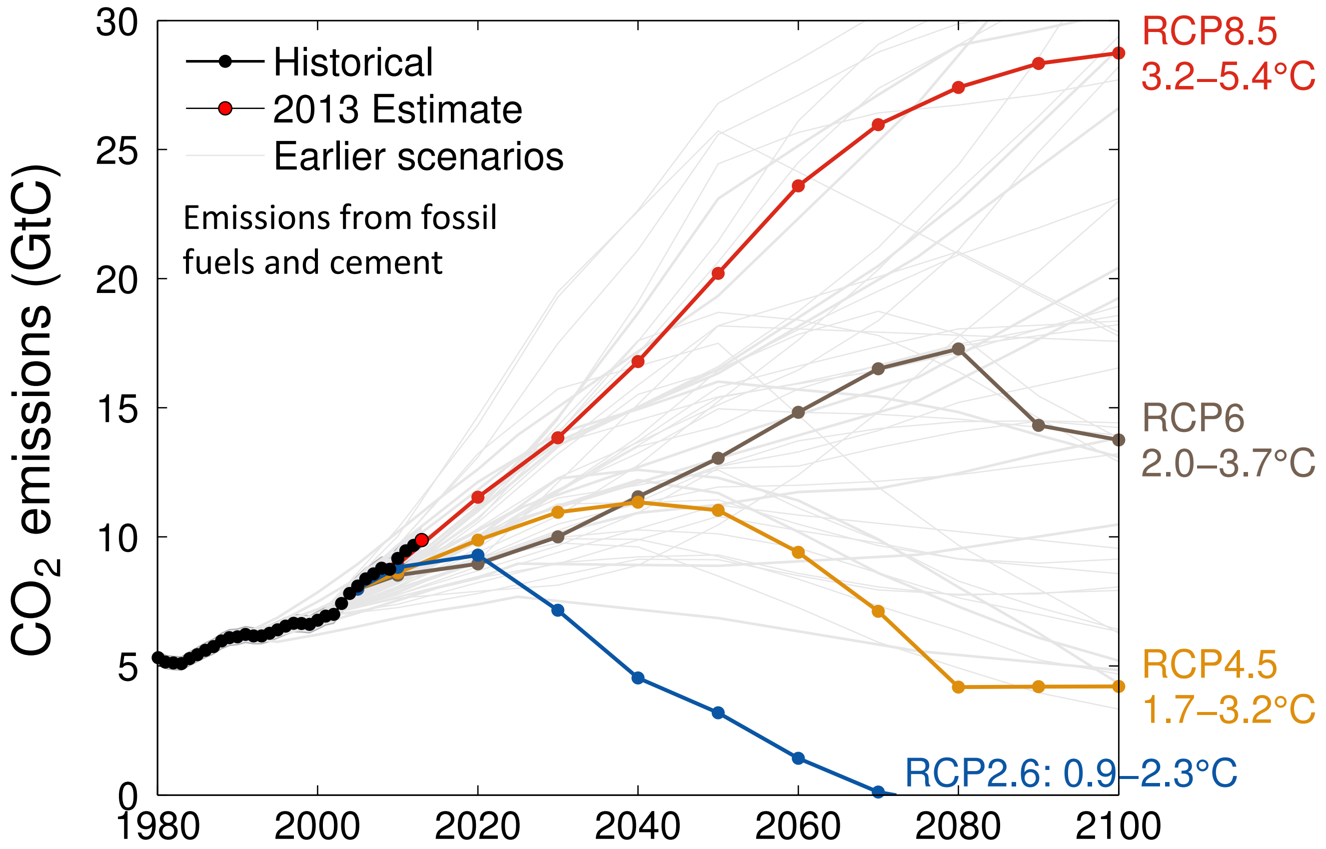


Main periods of use: SA90 (1990–1992, not shown), IS92 (1992–2000), SRES (2000–2012), RCPs (2012+)

Source: Peters et al. 2012a; CDIAC Data; Global Carbon Project 2013

Observed Emissions and Emissions Scenarios

Emissions are on track for 3.2–5.4ºC "likely" increase in temperature above pre-industrial
Large and sustained mitigation is required to keep below 2ºC

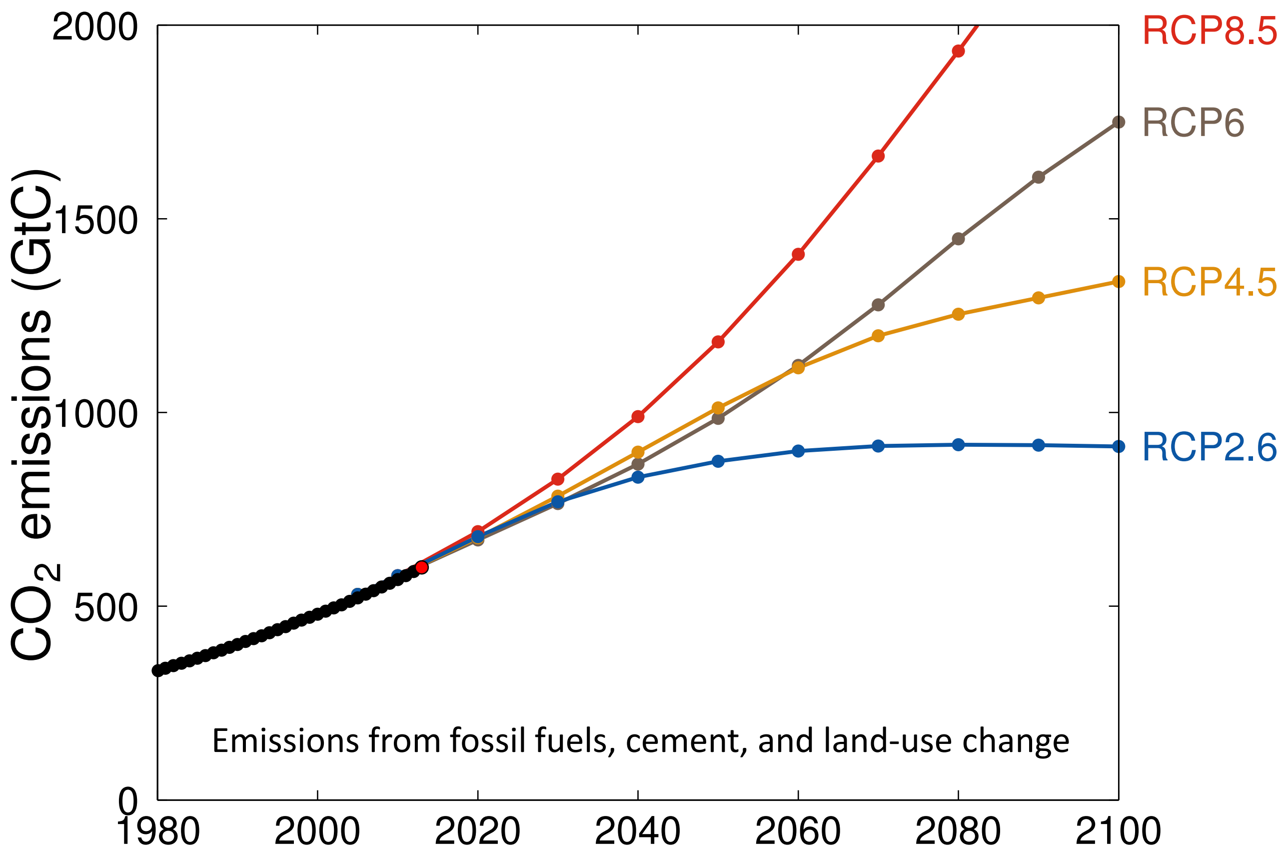


Linear interpolation is used between individual data points

Source: Peters et al. 2012a; CDIAC Data; Global Carbon Project 2013

Cumulative Emissions and Scenarios

For a "likely" chance to keep warming less than 2ºC since the period 1861–1880, requires cumulative CO_2 emissions to stay below 1000GtC, or 790GtC when allowing for non-CO_2



Cumulative emissions 1870–2013 are 550 ±60 GtC; 70% from fossil fuels and cement, 30% from land-use change

Cumulative emissions from 1750–1870 are highly uncertain, with about 50 GtC with 90% from land-use change

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

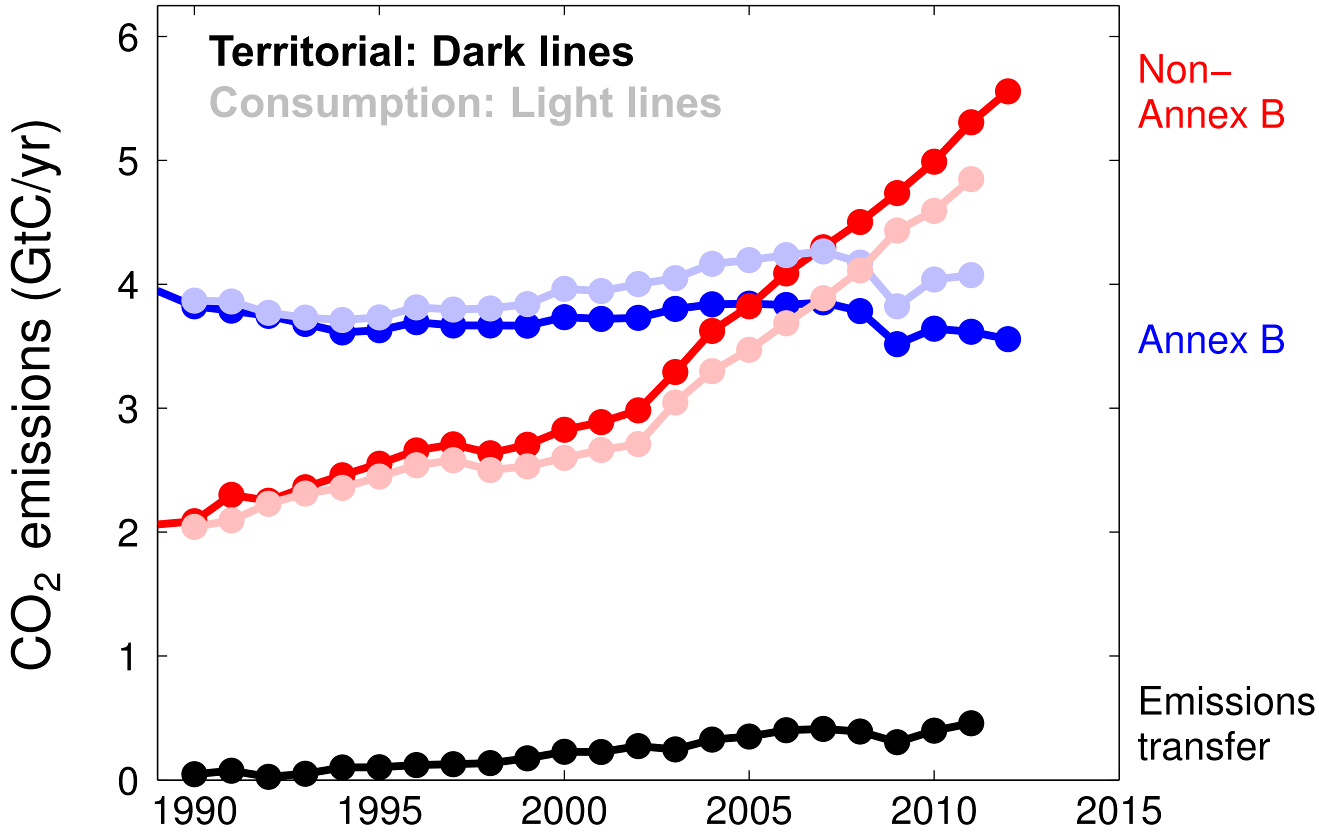
Consumption-based Emissions

Consumption–based emissions allocate emissions to the location that goods and services are consumed

Consumption-based emissions = Production/Territorial-based emissions minus emissions embodied in exports plus the emissions embodied in imports

Consumption Emissions per the Kyoto Protocol

The net emissions transfers into Annex B countries (black line) more than offsets the Annex B emission reductions achieved within the Kyoto Protocol

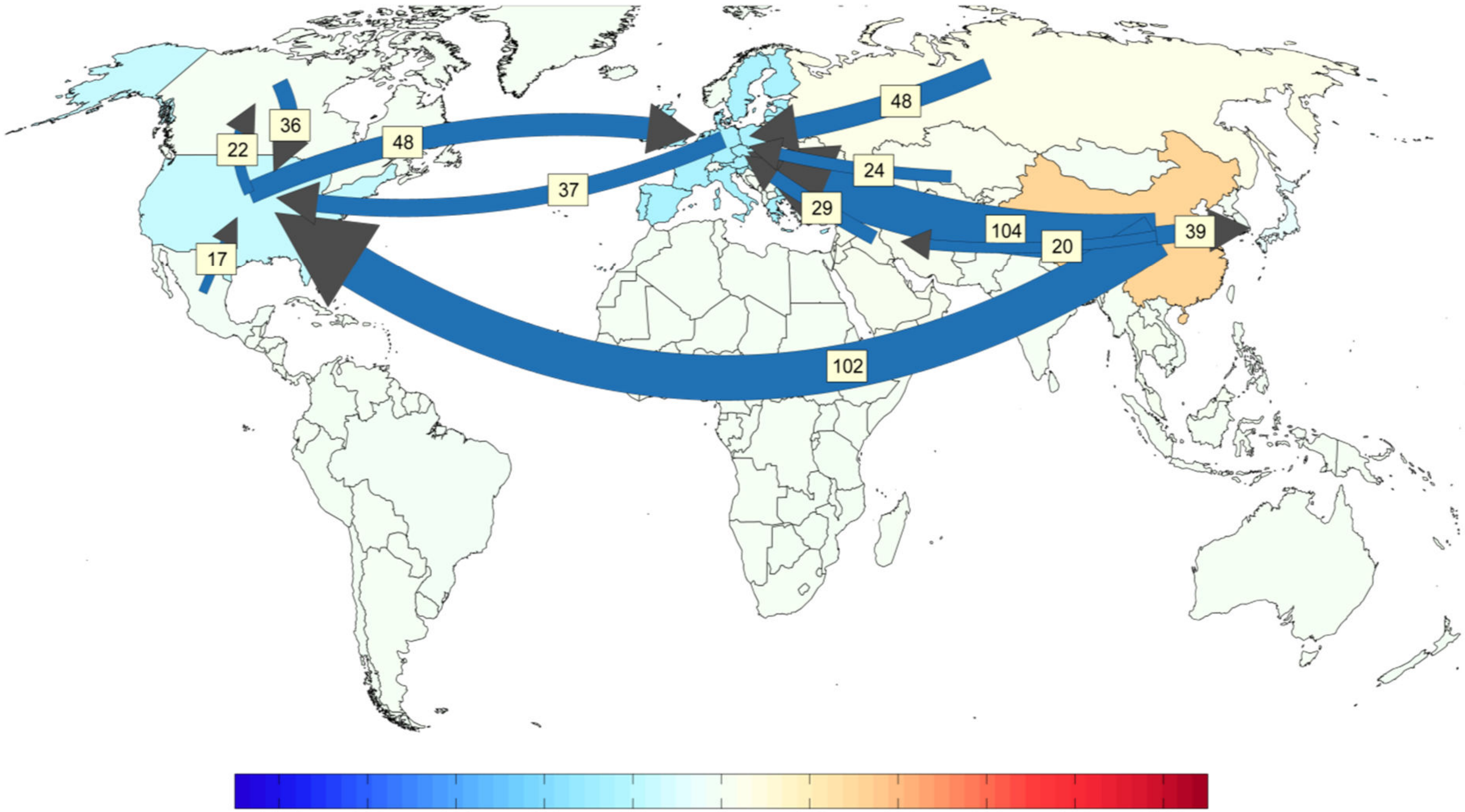


In Annex B, production-based emissions have had a slight decrease.
Consumption-based emissions have grown at 0.5% per year, and emission transfers have grown at 12% per year

Source: Le Quéré et al 2013; Peters et al 2011;Global Carbon Project 2013

Major Flows from Production to Consumption

Start of Arrow: fossil-fuel combustion
End of arrow: goods and services consumption

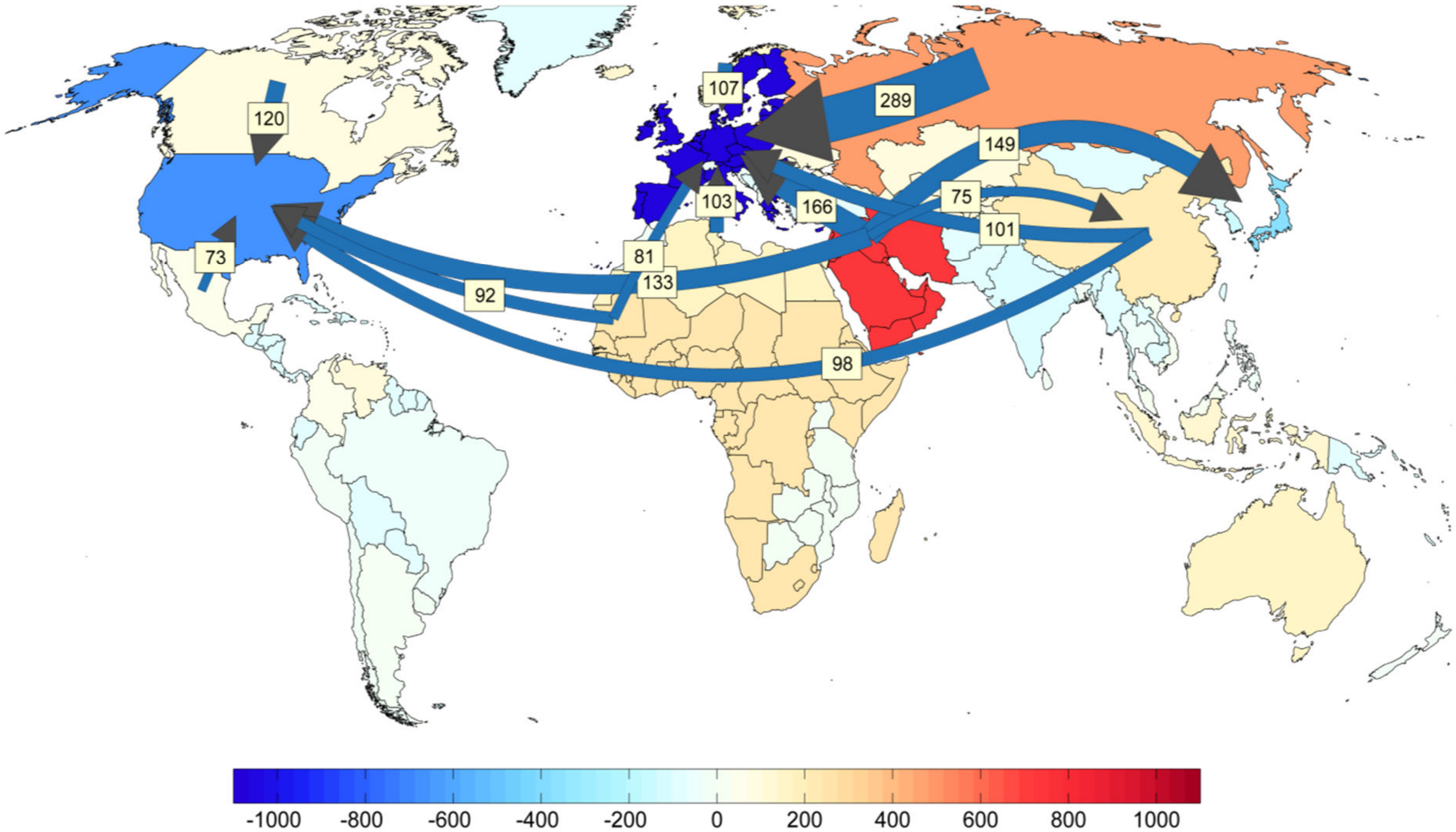


Values for 2007. EU27 is treated as one region. Units: TgC=GtC/1000

Source: [Peters et al 2012b]

Major Flows from Extraction to Consumption

Start of Arrow: fossil-fuel extraction
End of arrow: goods and services consumption

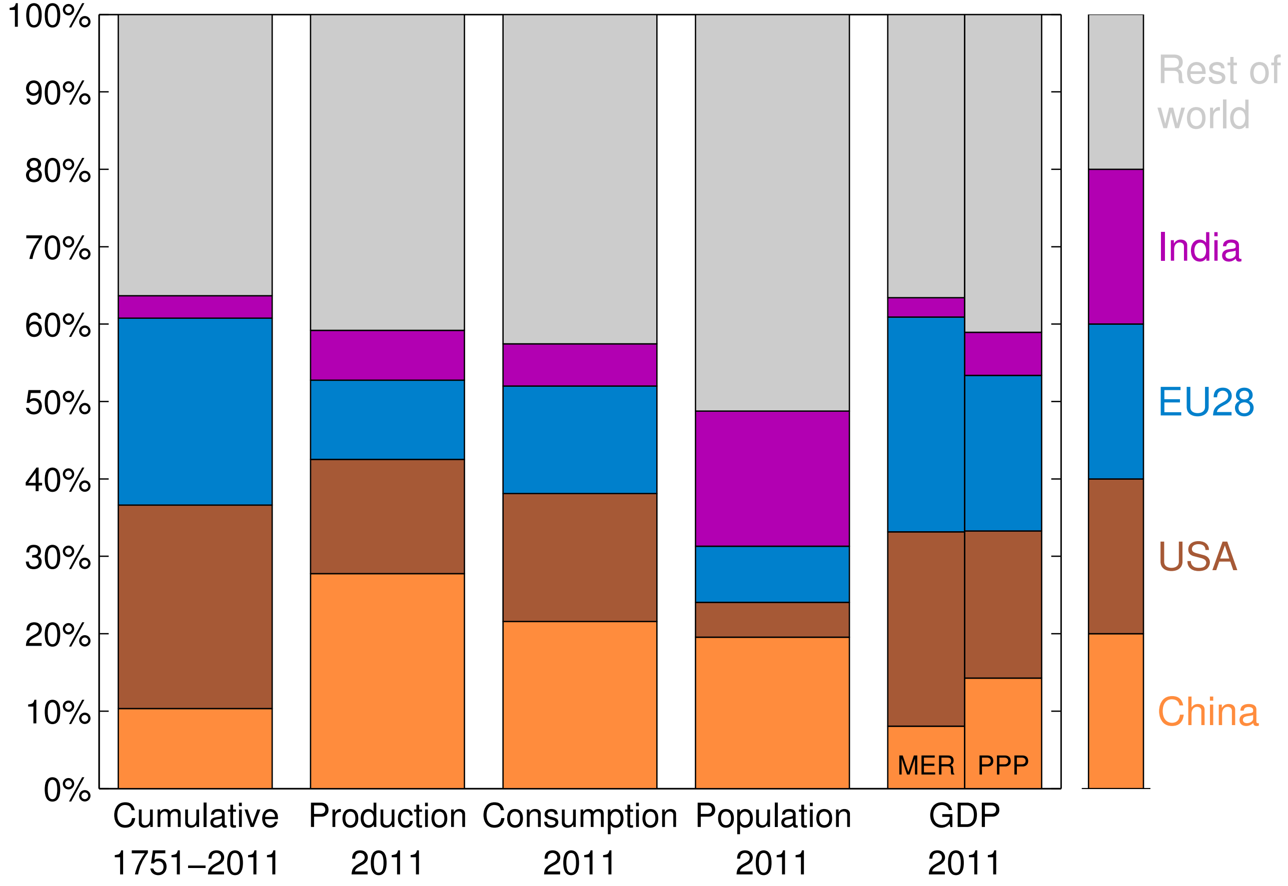


Values for 2007. EU27 is treated as one region. Units: TgC=GtC/1000

Source: Peters et al 2012b

Alternative Ranking of Countries

Depending on perspective, the importance of individual countries changes



GDP: Gross Domestic Product in Market Exchange Rates (MER) and Purchasing Power Parity (PPP)

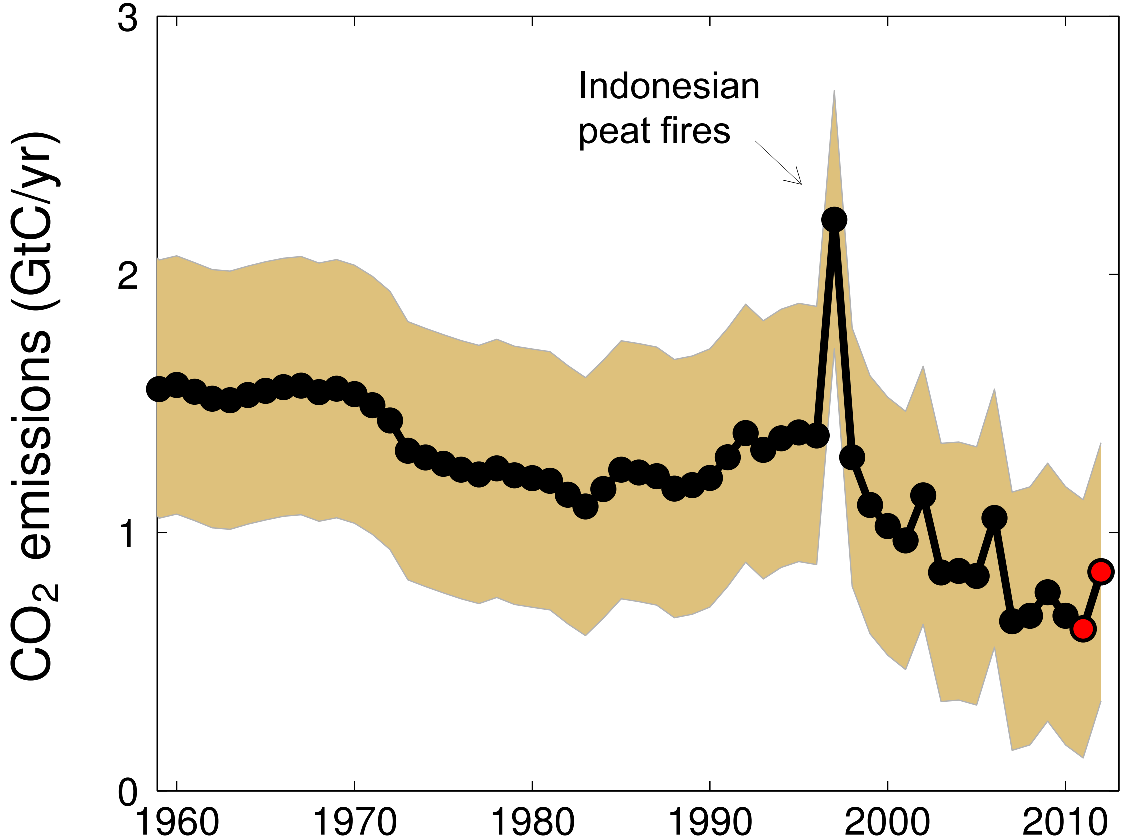
Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

Land-Use Change Emissions

Land-Use Change Emissions

Global land-use change emissions are estimated 0.8 ± 0.5 GtC during 2003–2012

The data suggests a general decrease in emissions since 1990

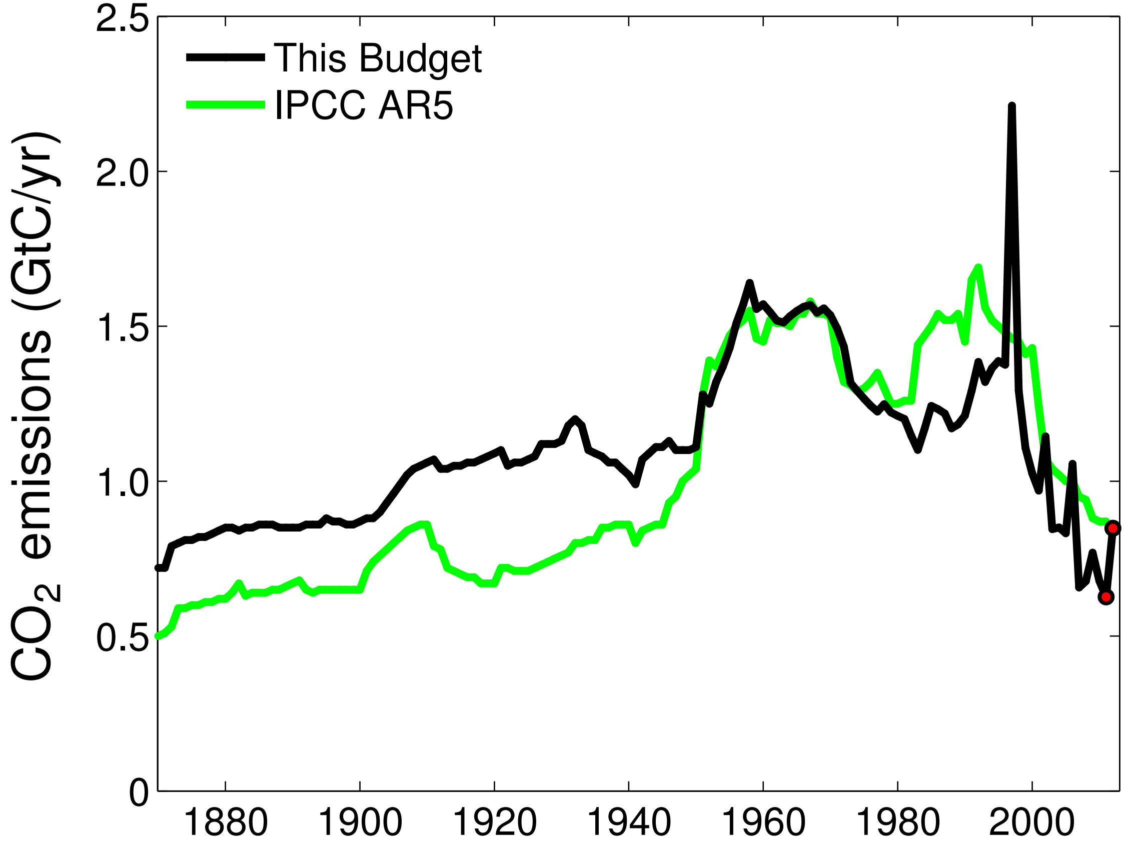


2011 and 2012 are extrapolated estimates

Source: Le Quéré et al 2013; Houghton & Hackler (in review); Global Carbon Project 2013

Uncertainty in Land-Use Change Emissions

Uncertainty in land-use change is large, particularly in early years.
This budget uses updated estimates, and has higher cumulative emissions than the IPCC AR5.



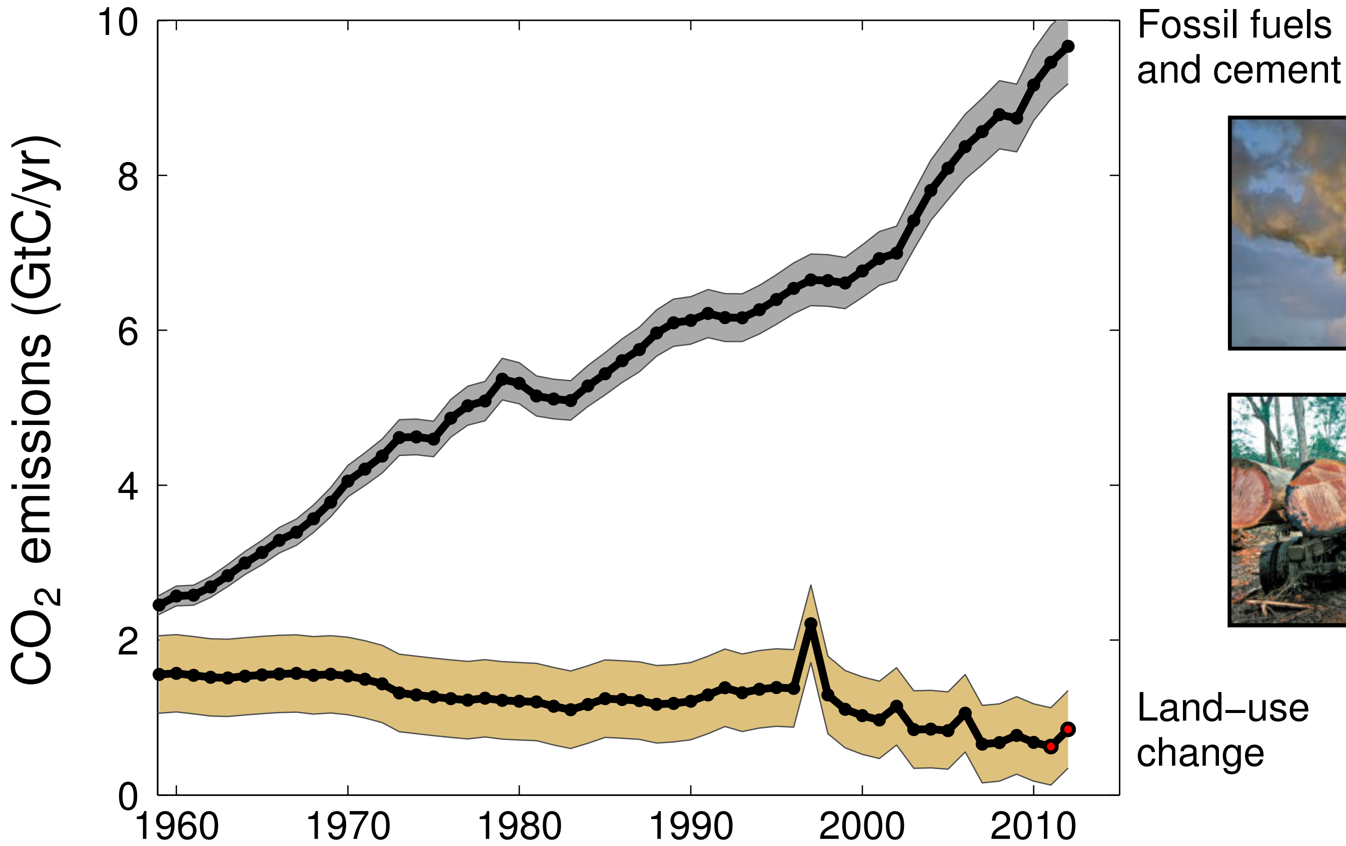
Cumulative emissions 1870–2011: 155 ± 55 GtC (this budget), 145 ± 60 GtC (IPCC)

Source: Le Quéré et al 2013; Houghton & Hackler (in review); Global Carbon Project 2013

Total Global Emissions

Total global emissions: 10.5 ± 0.7 GtC in 2012, 43% over 1990

Percentage land-use change: 38% in 1960, 17% in 1990, 8% in 2012

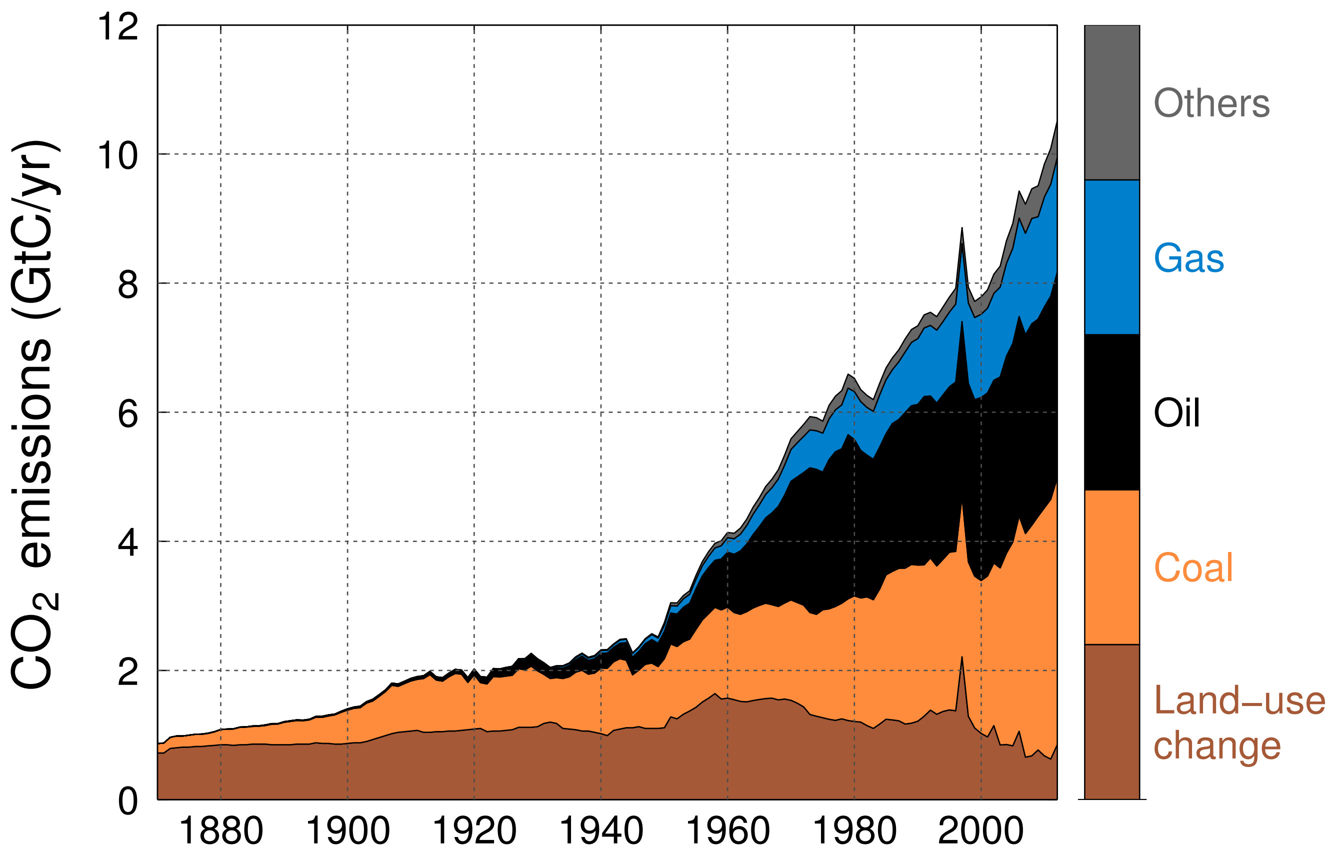


Land use emissions in 2011 and 2012 are extrapolated estimates

Source: Le Quéré et al 2013; CDIAC Data; Houghton & Hackler (in review); Global Carbon Project 2013

Total Global Emissions by Source

Land-use change was the dominant source of annual emissions until around 1950
Coal consumption continues to grow strongly

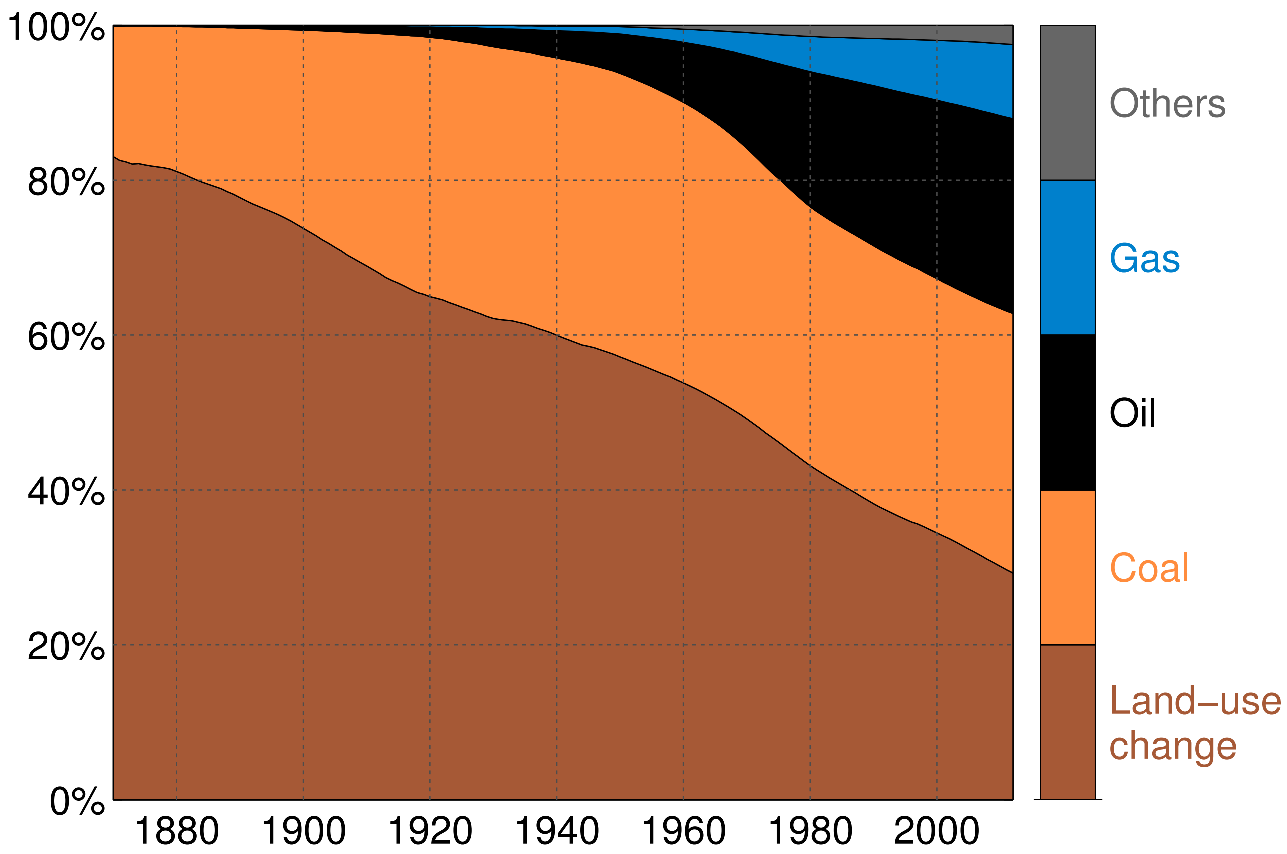


Others: Emissions from cement production and gas flaring.

Source: CDIAC Data; Houghton & Hackler (in review); Global Carbon Project 2013

Historical Cumulative Emissions by Source

Despite reductions in land-use change, it represents about 29% of cumulative emissions in 2012
Coal represents about 34%, oil 25%, gas 10%, and others 2%



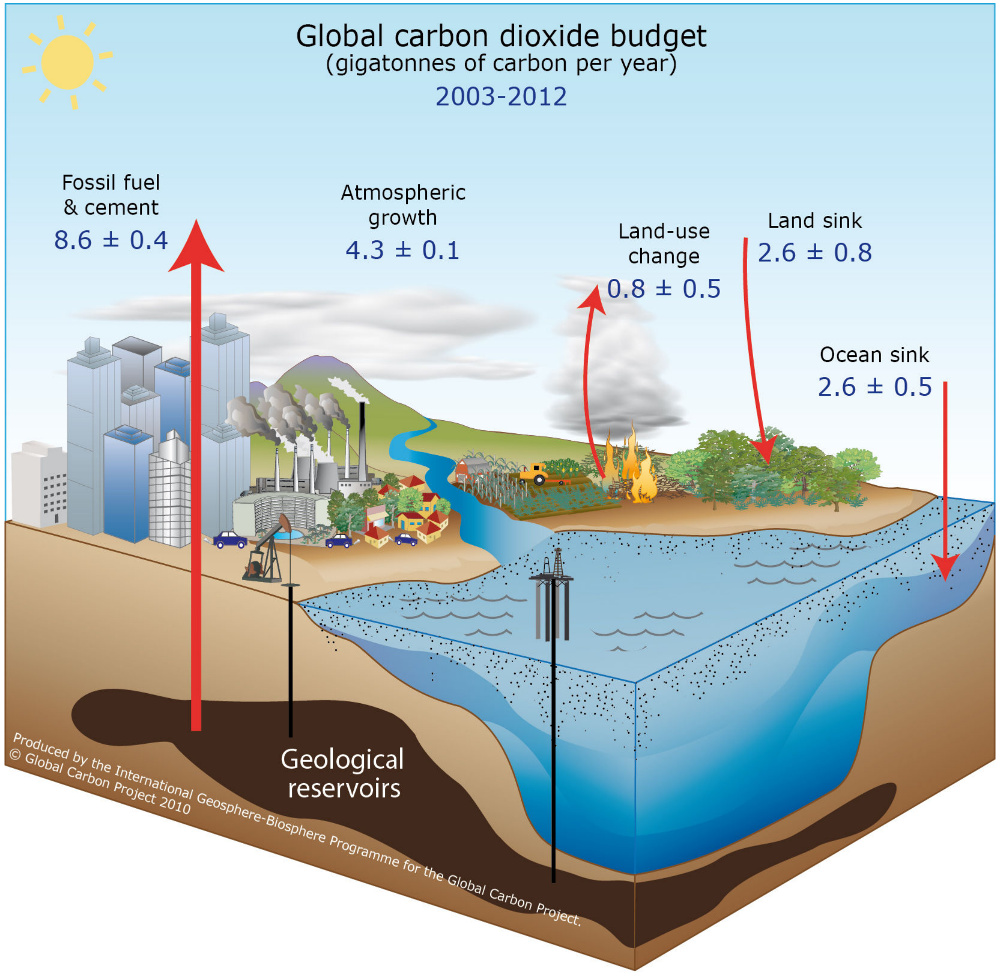
Others: Emissions from cement production and gas flaring.

Source: CDIAC Data; Houghton & Hackler (in review); Global Carbon Project 2013

Closing the Carbon Budget

Anthropogenic Perturbation of the Global Carbon Cycle

Perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2003–2012 (GtC/yr)



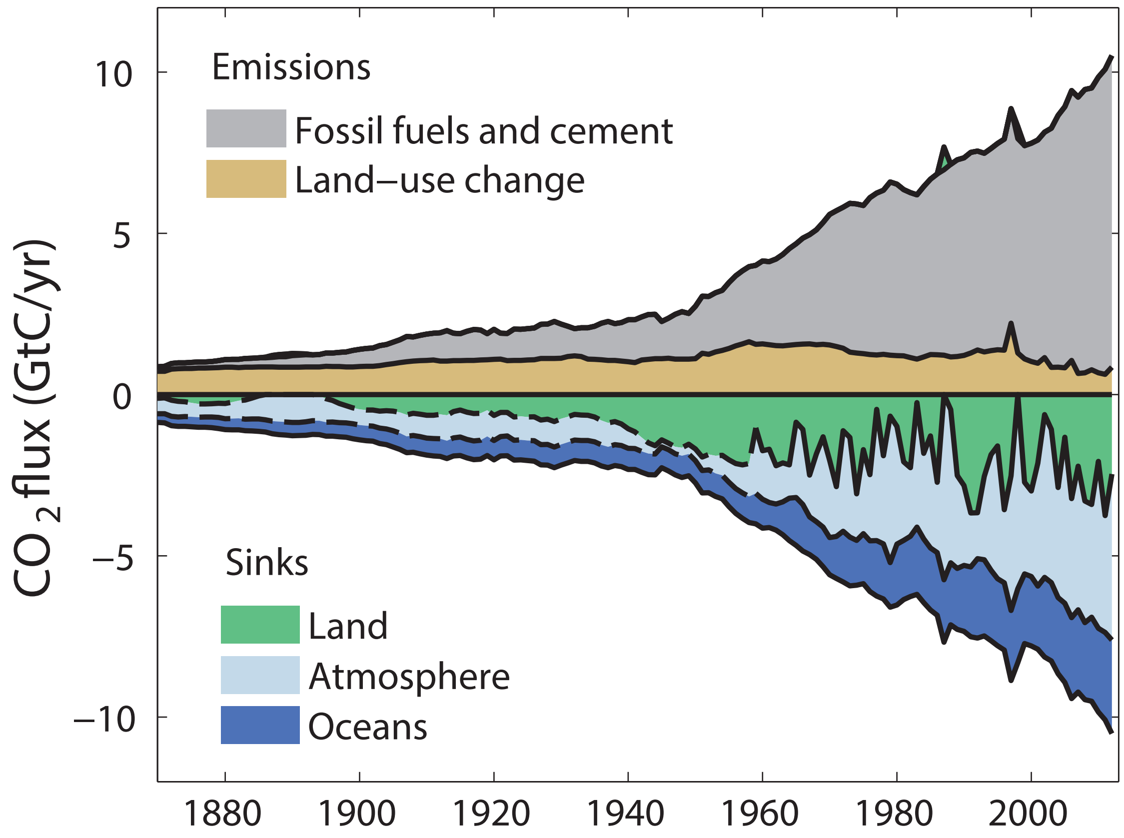
Source: Le Quéré et al 2013; CDIAC Data; NOAA/ESRL Data; Global Carbon Project 2013

Global Carbon Budget

Emissions to the atmosphere are balanced by the sinks

Average sinks since 1870: 41% atmosphere, 31% land, 28% ocean

Average sinks since 1959: 45% atmosphere, 28% land, 27% ocean



Source: CDIAC Data; Houghton & Hackler (in review); NOAA/ESRL Data; Joos et al 2013; Khatiwala et al 2013; Le Quéré et al 2013; Global Carbon Project 2013

Global Carbon Budget

The cumulative contributions to the Global Carbon Budget from 1750
Contributions are shown in parts per million (ppm)

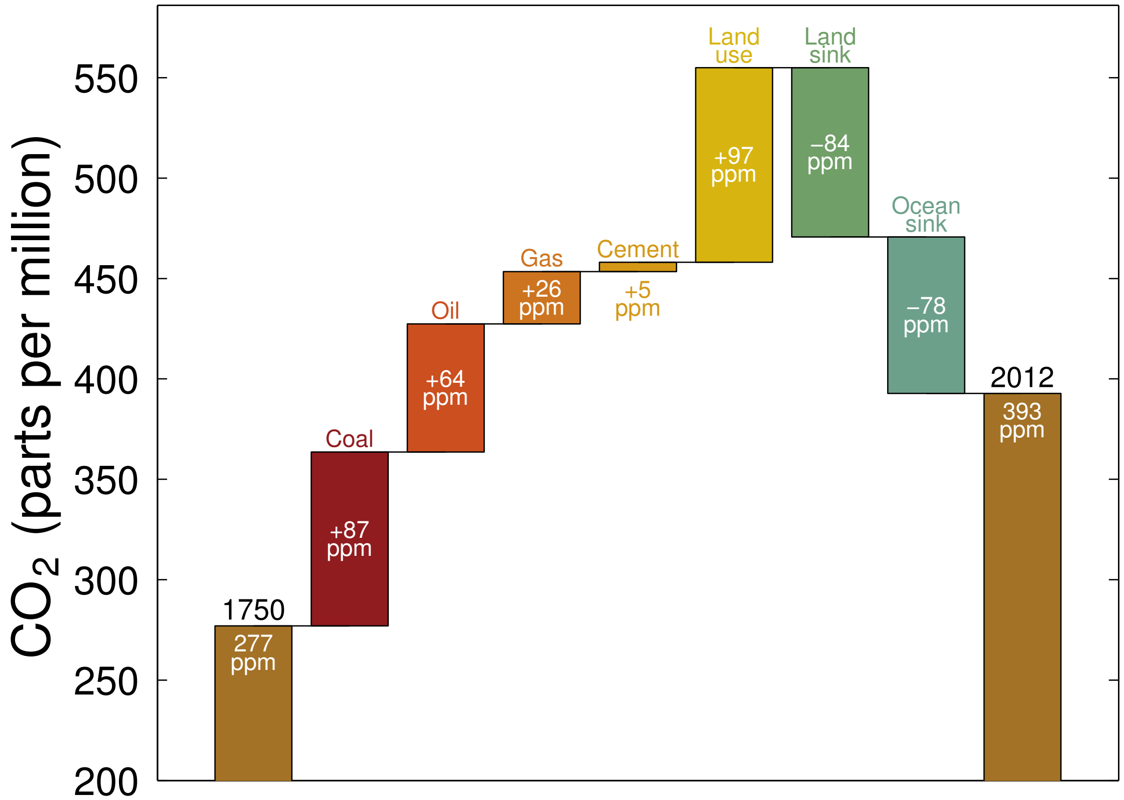


Figure concept from Shrink That Footprint

Source: Le Quéré et al 2013; NOAA/ESRL Data; CDIAC Data; Houghton & Hackler (in review);Global Carbon Project 2013

Fate of Anthropogenic CO_2 Emissions (2003-2012 average)

8.6 ± 0.4 GtC/yr 92%

0.8 ± 0.5 GtC/yr 8%

+

4.3±0.1 GtC/yr
45%

2.6 ± 0.5 GtC/yr
27%

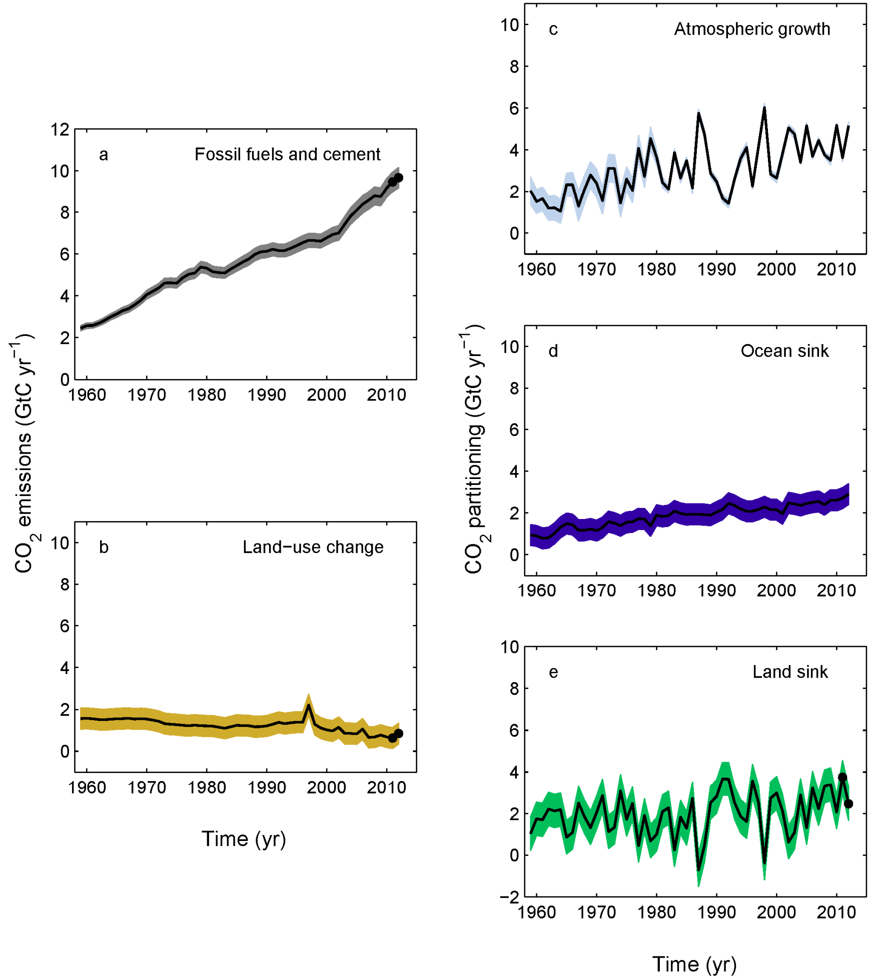
2.6 ± 0.8 GtC/yr
27%

Calculated as the residual
of all other flux components

Source: Le Quéré et al 2013; CDIAC Data; Global Carbon Project 2013

Changes in the Budget over Time

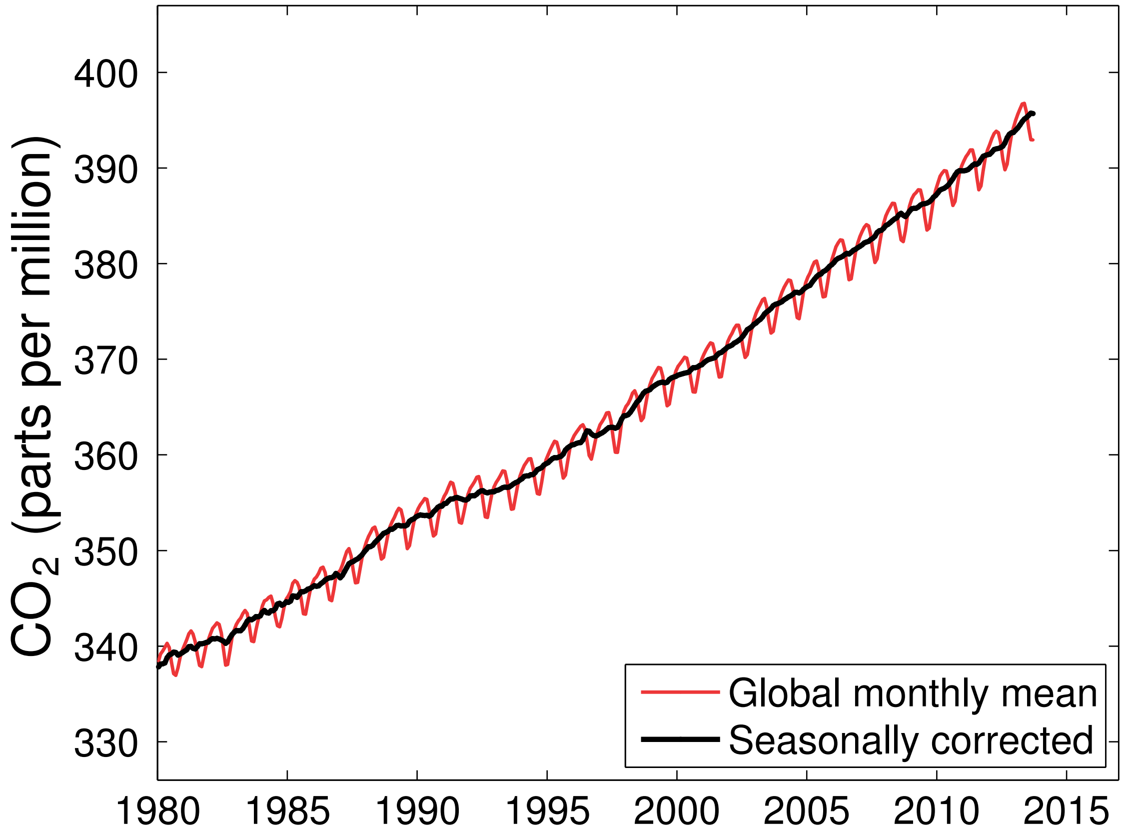
The sinks have continued to grow with increasing emissions, but climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO_2 in the atmosphere



Source: [Le Quéré et al 2013](); [CDIAC Data](); [NOAA/ESRL Data](); [Global Carbon Project 2013]()

Atmospheric Concentration

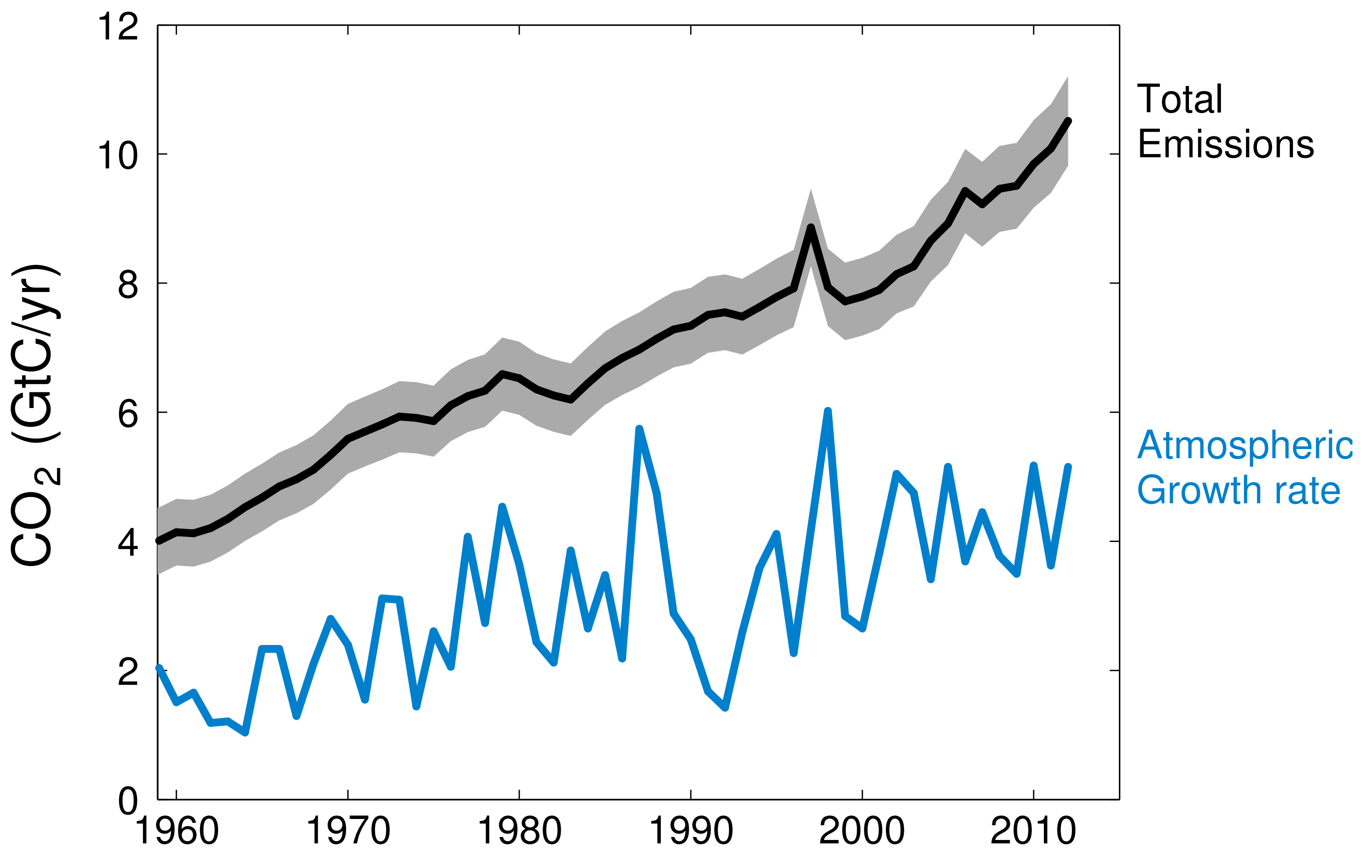
The pre-industrial (1750) atmospheric concentration was around 277ppm
This increased to 393ppm in 2012, a 42% increase



Source: NOAA/ESRL Data; Global Carbon Project 2013

Atmospheric Growth Rate

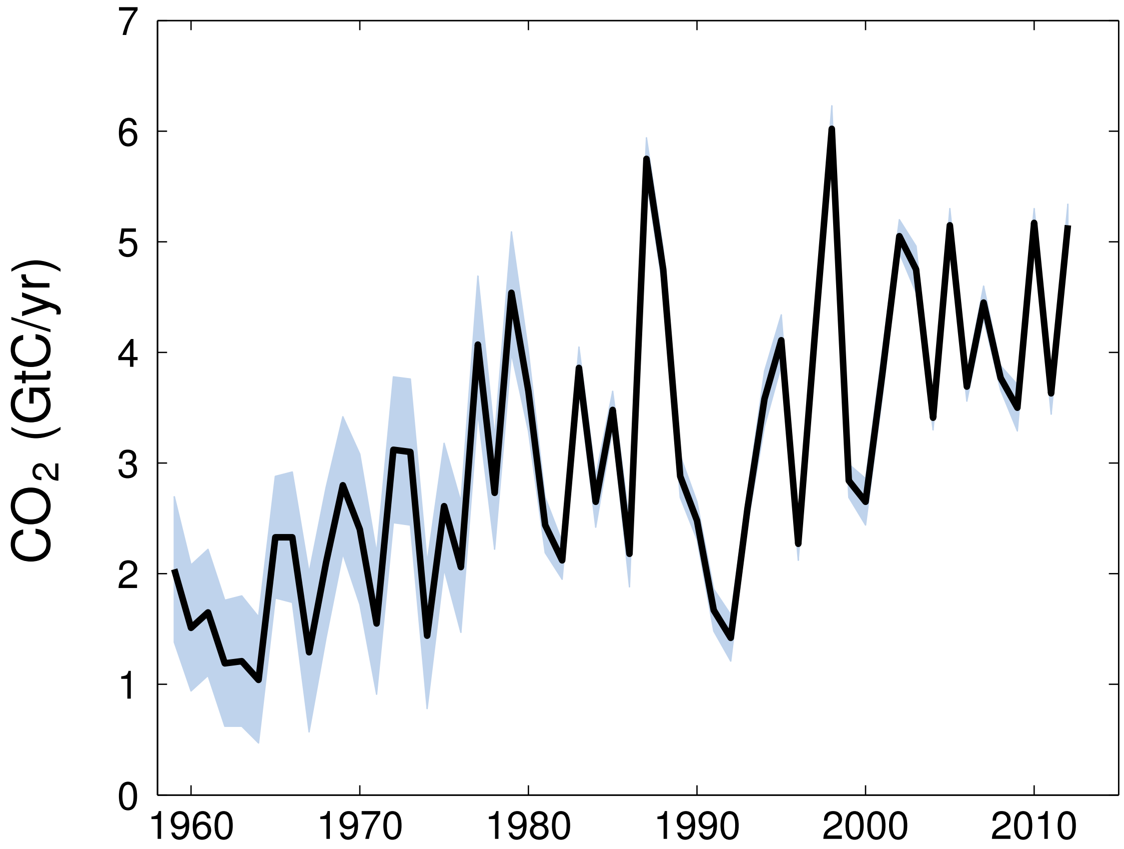
The atmospheric concentration growth rate has had a steady increase



Source: CDIAC Data; NOAA/ESRL Data; Le Quéré et al 2013; Global Carbon Project 2013

Atmospheric Growth Rate

The atmospheric concentration growth rate has had a steady increase
4.3±0.1 GtC/yr for 2003–2012, 5.2±0.1 GtC/yr in 2012

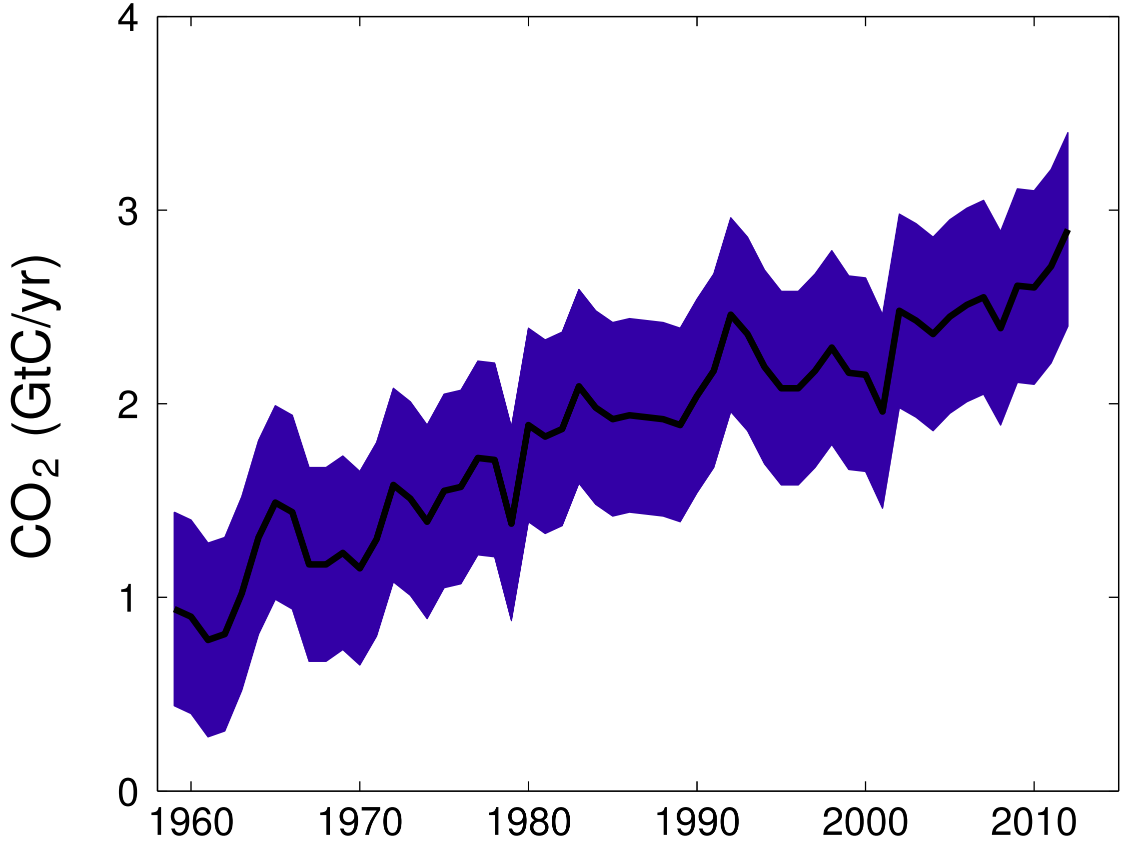


Source: NOAA/ESRL Data; Le Quéré et al 2013; Global Carbon Project 2013

Ocean Sink

Ocean carbon sink continues to increase

2.6±0.5 GtC/yr for 2003–2012, 2.9±0.5 GtC/yr in 2012

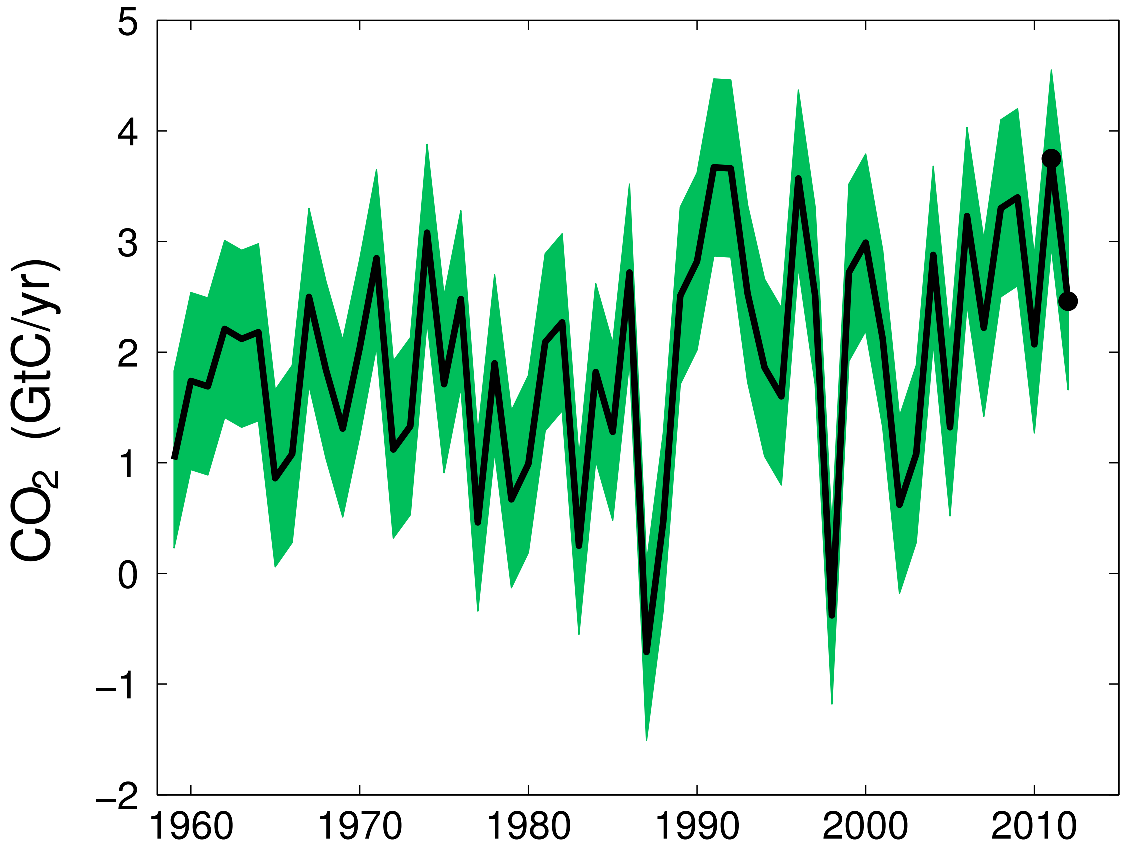


Source: Le Quéré et al 2013; Global Carbon Project 2013

Terrestrial Sink: Residual

Residual sink is increasing with time. Large interannual variability

2.6±0.8 GtC/yr for 2003–2012, 2.5±0.9 GtC/yr in 2012

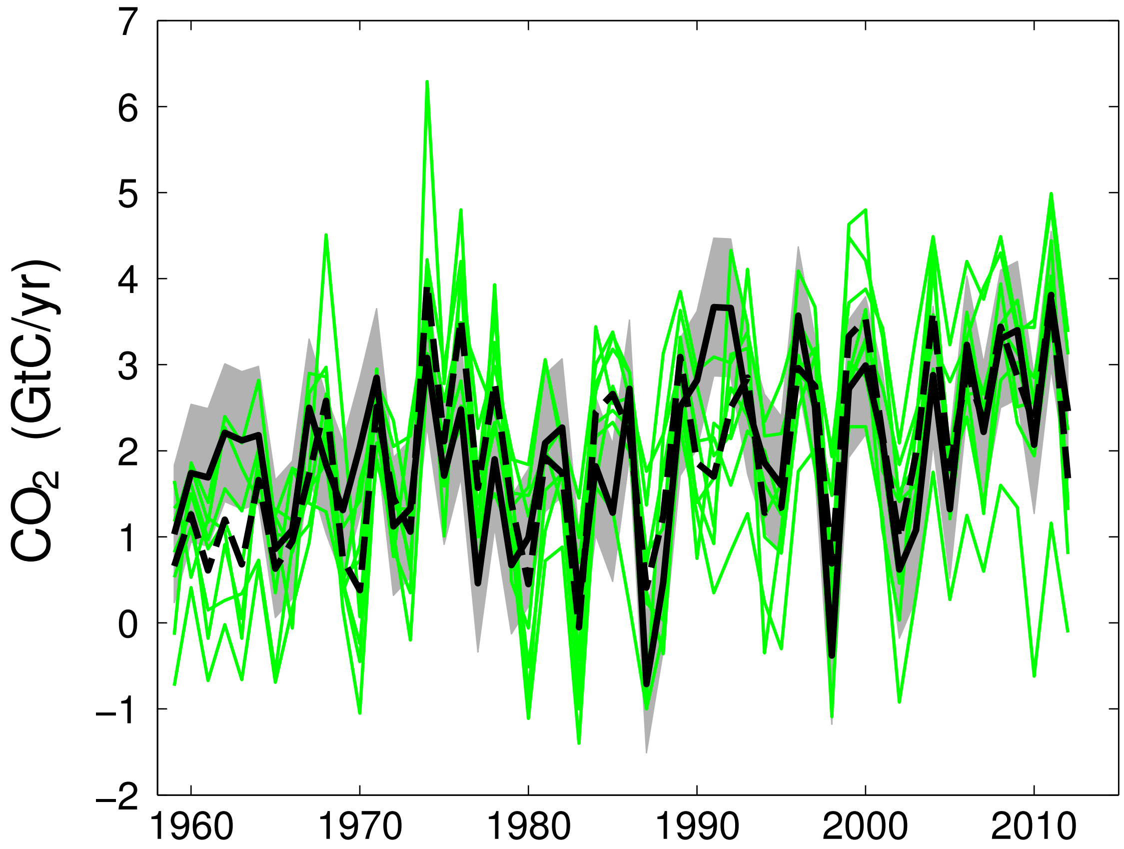


2011 and 2012 are extrapolated estimates

Source: Le Quéré et al 2013; Global Carbon Project 2013

Terrestrial Sink: DGVMs

Terrestrial sink from DGVMs is consistent with the residual sink estimated from the carbon budget
2.7±1.0 GtC/yr for 2003–2012, 1.7±1.2 GtC/yr in 2012



DGVM: Dynamic Global Vegetation Model

Source: Le Quéré et al 2013; Global Carbon Project 2013

References Used in this Presentation

Global Carbon Project (2013) More information, data sources and data files at www.globalcarbonproject.org

C. Le Quéré, G. Peters, R. Andres, R. Andrew, T. Boden, P. Ciais, P. Friedlingstein, R. Houghton, G. Marland, R. Moriarty, S. Sitch, P. Tans, A. Arneth, A. Arvanitis, D. Bakker, L. Bopp, J. G. Canadell, Y. Chao, L. P. Chini, S. Doney, A. Harper, I. Harris, J. House, A. Jain, S. Jones, E. Kato, R. Keeling, K. Klein Goldewijk, A. Körtzinger, C. Koven, N. Lefèvre, A. Omar, T. Ono, G.-H. Park, B. Pfeil, B. Poulter, M. Raupach, P. Regnier, C. Rödenbeck, S. Saito, J. Schwinger, J. Segschneider, B. Stocker, B. Tilbrook, S. van Heuven, N. Viovy, R. Wanninkhof, A. Wiltshire, C. Yue, S. Zaehle (2013) "Global Carbon Budget 20123", *Earth System Science Data Discussions* (in review), http://www.earth-syst-sci-data-discuss.net/6/689/2013, DOI:10.5194/essdd-6-689-2013

T. Boden, G. Marland, R. Andres (2013) "Global, Regional, and National Fossil-Fuel CO_2 Emissions in Trends", Carbon Dioxide Information Analysis Center **(CDIAC)**, http://cdiac.ornl.gov/trends/emis/meth_reg.html, DOI:10.3334/CDIAC/00001_V2013

UN (2013) United Nations Statistics Division http://unstats.un.org/unsd/default.htm

G. Peters, R. Andrew, T. Boden, J. Canadell, P. Ciais, C. Le Quéré, G. Marland, M. Raupach, C. Wilson (2012a) "The challenge to keep global warming below 2ºC" *Nature Climate Change*, http://dx.doi.org/10.1038/nclimate1783, DOI:10.1038/nclimate1783

G. Peters, J, Minx, C. Weber, O. Edenhofer, O (2011) "Growth in emission transfers via international trade from 1990 to 2008", *Proceedings of the National Academy of Sciences*, www.pnas.org/content/108/21/8903 DOI:10.1073/pnas.1006388108

G. Peters, S. Davis, R. Andrew (2012b) "A synthesis of carbon in international trade", *Biogeosciences*, http://www.biogeosciences.net/9/3247/2012/bg-9-3247-2012.html, DOI:10.5194/bg-9-3247-2012

F. Joos, R. Roth, J.Fuglestvedt, G. Peters, I. Enting, W. von Bloh, V. Brovkin, E. Burke, M. Eby, N. Edwards, T. Friedrich, T. Frölicher, P. Halloran, P. Holden, C. Jones, T. Kleinen, F. Mackenzie, K. Matsumoto, M. Meinshausen, G.-K. Plattner, A. Reisinger, J. Segschneider, G. Shaffer, M. Steinacher, K. Strassmann, K. Tanaka, A. Timmermann, and A. Weaver (2013) "Carbon dioxide and climate impulse response functions for the computation of greenhouse gas metrics: a multi-model analysis", *Atmospheric Chemistry and Physics*, http://www.atmos-chem-phys.net/13/2793/2013/acp-13-2793-2013.html, DOI: 0.5194/acp-13-2793-2013

S. Khatiwala, T. Tanhua, S. Mikaloff Fletcher, M. Gerber, S. Doney, H. Graven, N. Gruber, G. McKinley, A. Murata, A. Rios, C. Sabine (2013), "Global ocean storage of anthropogenic carbon", *Biogeosciences*, http://www.biogeosciences.net/10/2169/2013/bg-10-2169-2013.html, doi:10.5194/bg-10-2169-2013

R. Houghton and J. Hackler (in review) "Annual Flux of Carbon from Land Use and Land-Cover Change 1850 to 2010", *Global Biogeochemical Cycles*

E. Dlugokencky and P. Tans (2013) "Trends in Atmospheric Carbon Dioxide", National Oceanic & Atmosphere Administration, Earth System Research Laboratory **(NOAA/ESRL)**, http://www.esrl.noaa.gov/gmd/ccgg/trends/

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GLOBAL IGBP CHANGE International Geosphere-Biosphere Programme
IHDP International Human Dimensions Programme on Global Environmental Change
WCRP World Climate Research Programme
DIVERSITAS an international programme of biodiversity science
Australian Climate Change Science Programme
NIES
The Research Council of Norway
Department of Energy & Climate Change
Department for Environment Food & Rural Affairs
NATURAL ENVIRONMENT RESEARCH COUNCIL
LSCE

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