Global Carbon Budget

2017
# Acknowledgements

The work presented here has been possible thanks to the enormous observational and modelling efforts of the institutions and networks below.

## Atmospheric CO₂ datasets
- NOAA/ESRL (Dlugokencky and Tans 2017)
- Scripps (Keeling et al. 1976)

## Fossil Fuels and Industry
- CDIAC (Boden et al. 2017)
- USGS, 2017
- UNFCCC, 2017
- BP, 2017

## Consumption Emissions
- Peters et al. 2011
- GTAP (Narayanan et al. 2015)

## Land-Use Change
- Houghton and Nassikas 2017
- Hansis et al. 2015
- GFED4 (van der Werf et al. 2017)
- FAO-FRA and FAOSTAT
- HYDE (Klein Goldewijk et al. 2017)
- LUH2 (Hurtt et al. 2011)

## Atmospheric inversions
- CarbonTracker Europe (van der Laan-Luijkx et al. 2017)
- Jena CarboScope (Rödenbeck et al. 2003)
- CAMS (Chevallier et al. 2005)

## Land models
- CABLE | CLASS-CTEM | CLM4.5(BGC) | DLEM | ISAM | JSBACH | JULES | LPJ-GUESS | LPJ | LPX-Bern | OCN | ORCHIDEE | ORCHIDEE-MICT | SDGVM | VISIT
- CRU (Harris et al. 2014)

## Ocean models
- CCSM-BEC | CSIRO | MITgem-REcoM2 | MPIOM-HAMOCC | MOCOM-HAMOCC | NEMO-PISCES (CNRM) | NEMO-PISCES(IPSL) | NEMO-PlankTOM5 | NorESM-OC

## pCO₂-based ocean flux products
- Jena CarboScope (Rödenbeck et al. 2014)
- Landschützer et al. 2016
- SOCATv5 (Bakker et al. 2016)

Full references provided in [Le Quéré et al 2017](https://doi.org/10.1038/s41586-017-0005-1)
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Towards real-time verification of CO₂ emissions

The Paris Agreement has increased the incentives to verify anthropogenic carbon dioxide emissions with independent Earth system observations. Reliable verification requires a step change in our understanding of carbon cycle variability.

Glen P. Peters, Carine Le Quéré, Robbie M. Andrew, Josep G. Canadell, Pierre Friedlingstein, Tatiana Lyams, Robert B. Jackson, Fortunat Joos, Jan Ivar Korsbakken, Sakan A. McGuire, Stephen Stich and Peter Tans

Emissions of CO₂ from fossil fuels and industry did not change from 2015 to 2016, yet there was a record increase in CO₂ concentrations in the atmosphere. The difference between the increase in atmospheric CO₂ concentrations and the increase in emissions is often referred to as the carbon budget. Important questions about our ability to detect a meaningful change in emissions from the atmospheric record include: (1) whether the observed changes in the atmospheric record are significant; (2) whether they are real or due to uncertainty in the atmospheric record; (3) how robust are the conclusions drawn from the results; and (4) what is the best way to detect such changes. These questions can be addressed using a model-based approach that involves the use of a model to simulate the atmospheric CO₂ concentration.

Original source:
https://doi.org/10.5194/essdd-2017-123

Abstract
Carbon dioxide (CO₂) emissions from fossil fuels and industry comprise ~90% of all CO₂ emissions from human activities. For the last three years, such emissions were stable, despite continuing growth in the global economy. Many positive trends contributed to this unique hiatus, including reduced coal use in China and elsewhere, continuing gains in energy efficiency, and a boom in low-carbon renewables such as wind and solar. However, the temporary hiatus appears to have ended in 2017. For 2017, we project CO₂ emissions growth of 2.0% (range 0.8%–2.9%) from 2016 levels (3-year average adjusted, reaching a record 36.8 Gt CO₂). Economic projections suggest further emissions growth in 2018 is likely. Time is running out on our ability to keep global average temperature increases below 2°C and, even more immediately, anything close to 1.5°C.
Data Access and Additional Resources

GCP Website

More information, data sources and data files:
http://www.globalcarbonproject.org/carbonbudget
Contact: c.lequere@uea.ac.uk

Global Carbon Atlas

More information, data sources and data files:
www.globalcarbonatlas.org
(co-funded in part by BNP Paribas Foundation)
Contact: philippe.ciais@lsce.ipsl.fr
All the data is shown in billion tonnes CO$_2$ (GtCO$_2$)

1 Gigatonne (Gt) = 1 billion tonnes = \(1 \times 10^{15}\) 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$_2$

(Figures in units of GtC and GtCO$_2$ are available from http://globalcarbonbudget.org/carbonbudget)

Most figures in this presentation are available for download as PDF or PNG from tinyurl.com/GCB17figs along with the data required to produce them.

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.
Anthropogenic perturbation of the global carbon cycle

Perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2007–2016 (GtCO\(_2\)/yr)

The budget imbalance is the difference between the estimated emissions and sinks.

Source: CDIAC; NOAA-ESRL; Le Quéré et al 2017; Global Carbon Budget 2017
Fossil Fuel and Industry Emissions
Global emissions from fossil fuel and industry: 36.2 ± 2 GtCO₂ in 2016, 62% over 1990

- Projection for 2017: 36.8 ± 2 GtCO₂, 2.0% higher than 2016

Estimates for 2015 and 2016 are preliminary. Growth rate is adjusted for the leap year in 2016.

Source: CDIAC; Le Quéré et al 2017; Global Carbon Budget 2017
The top four emitters in 2016 covered 59% of global emissions:
- China (28%)
- United States (15%)
- EU28 (10%)
- India (7%)

Bunker fuels used for international transport is 3.1% of global emissions.

Statistical differences between the global estimates and sum of national totals are 0.6% of global emissions.

Source: CDIAC; Le Quéré et al 2017; Global Carbon Budget 2017
Global emissions from fossil fuels and industry are projected to rise by 2.0% in 2017. The global projection has a large uncertainty, ranging from +0.8% to +3.0%.

Source: CDIAC; Jackson et al 2017; Le Quéré et al 2017; Global Carbon Budget 2017
Countries have a broad range of per capita emissions reflecting their national circumstances.

Source: CDIAC; Le Quéré et al 2017; Global Carbon Budget 2017
Emissions per unit economic output (emissions intensities) generally decline over time.
China’s intensity is declining rapidly, but is still much higher than the world average.

GDP is measured in purchasing power parity (PPP) terms in 2010 US dollars.

Source: CDIAC; IEA 2016 GDP to 2014, IMF 2017 growth rates to 2016; Le Quéré et al 2017; Global Carbon Budget 2017
Emissions by country from 2000 to 2016, with growth rates indicated for the more recent period of 2011 to 2016

Source: CDIAC; Le Quéré et al 2017; Global Carbon Budget 2017
Alternative rankings of countries

Depending on perspective, the significance of individual countries changes.
Emissions from fossil fuels and industry.

Data: CDIAC/GCP/IMF

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

Source: CDIAC; United Nations; Le Quéré et al 2017; Global Carbon Budget 2017
Fossil fuel and industry emissions growth

Emissions in the US, Russia and Brazil declined in 2016
Emissions in India and all other countries combined increased

Data: CDIAC/GCP

Figure shows the top four countries contributing to emissions changes in 2016
Source: CDIAC; Le Quéré et al 2017; Global Carbon Budget 2017
Breakdown of global emissions by country

Emissions from OECD countries are about the same as in 1990
Emissions from non-OECD countries have increased rapidly in the last decade

Source: CDIAC; Le Quéré et al 2017; Global Carbon Budget 2017
Historical cumulative emissions by country

Cumulative emissions from fossil-fuel and industry were distributed (1870–2016):
USA 26%, EU28 22%, China 13%, Russia 7%, Japan 4% and India 3%

Cumulative emissions (1990–2016) were distributed China 20%, USA 20%, EU28 14%, Russia 6%, India 5%, Japan 4%
‘All others’ includes all other countries along with bunker fuels and statistical differences
Source: CDIAC; Le Quéré et al 2017; Global Carbon Budget 2017
Historical cumulative emissions by continent

Cumulative emissions from fossil-fuel and industry (1870–2016)
North America and Europe responsible for most cumulative emissions, but Asia growing fast

Data: CDIAC/GCP

The figure excludes bunker fuels and statistical differences
Source: CDIAC; Le Quéré et al 2017; Global Carbon Budget 2017
Emissions from coal, oil, gas, cement

Share of global emissions in 2016:
coal (40%), oil (34%), gas (19%), cement (6%), flaring (1%, not shown)

Source: CDIAC; Le Quéré et al 2017; Global Carbon Budget 2017
Emissions by category from 2000 to 2016, with growth rates indicated for the more recent period of 2011 to 2016

Source: CDIAC; Jackson et al 2017; Global Carbon Budget 2017
Energy consumption by energy type

Energy consumption by fuel source from 2000 to 2016, with growth rates indicated for the more recent period of 2011 to 2016

Source: BP 2017; Jackson et al 2017; Global Carbon Budget 2017
The biggest changes in emissions were from a decline in coal and an increase in oil.

Data: CDIAC/GCP

Source: CDIAC; Le Quéré et al 2017; Global Carbon Budget 2017
Global emissions growth has generally recovered quickly from previous financial crises. It is unclear if the recent slowdown in global emissions is related to the Global Financial Crisis.

Economic activity is measured in purchasing power parity (PPP) terms in 2010 US dollars.

Source: CDIAC; Peters et al 2012; Le Quéré et al 2017; Global Carbon Budget 2017
The 10 largest economies have a wide range of emissions intensity of economic production.

Emission intensity: CO$_2$ emissions from fossil fuel and industry divided by Gross Domestic Product

Source: Global Carbon Budget 2017
New generation of emissions scenarios

In the lead up to the IPCC’s Sixth Assessment Report new scenarios have been developed to more systematically explore key uncertainties in future socioeconomic developments.

Five Shared Socioeconomic Pathways (SSPs) have been developed to explore challenges to adaptation and mitigation. Shared Policy Assumptions (SPAs) are used to achieve target forcing levels (W/m²). Marker Scenarios are indicated.

Source: Riahi et al. 2016; IIASA SSP Database; Global Carbon Budget 2017
New generation of emissions scenarios

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Source: Riahi et al. 2016; IIASA SSP Database; Global Carbon Budget 2017

Five Shared Socioeconomic Pathways (SSPs) have been developed to explore challenges to adaptation and mitigation. Shared Policy Assumptions (SPAs) are used to achieve target forcing levels (W/m²). Marker Scenarios are indicated.
According to the Shared Socioeconomic Pathways (SSP) that avoid 2°C of warming, global CO$_2$ emissions need to decline rapidly and cross zero emissions after 2050.
CO₂ emissions and economic activity

In recent years, CO₂ emissions have been almost flat despite continued economic growth.

Source: Jackson et al 2017; Global Carbon Budget 2017
The Kaya decomposition demonstrates the recent relative decoupling of economic growth from CO₂ emissions, driven by improved energy intensity.


Source: Jackson et al 2017; Global Carbon Budget 2017
The 10 most populous countries span a wide range of development and emissions per person.

Emission per capita: CO$_2$ emissions from fossil fuel and industry divided by population.

Source: Global Carbon Budget 2017
## Key statistics

### Emissions 2016

<table>
<thead>
<tr>
<th>Region/Country</th>
<th>Per capita tCO₂ per person</th>
<th>Total GtCO₂</th>
<th>%</th>
<th>Growth 2015-16 GtCO₂</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Global (with bunkers)</strong></td>
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<tr>
<td></td>
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<td>36.18</td>
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<td>Japan</td>
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<td>Canada</td>
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<tr>
<td><strong>Non-OECD</strong></td>
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<tr>
<td>Non-OECD</td>
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<td>China</td>
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<tr>
<td>India</td>
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<td>Russia</td>
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<td>Iran</td>
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<td>1.8</td>
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<td>Saudi Arabia</td>
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<td>1.8</td>
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<td><strong>International Bunkers</strong></td>
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<tr>
<td>Aviation and Shipping</td>
<td>-</td>
<td>1.37</td>
<td>3.8</td>
<td>0.053</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Source: [CDIAC](https://cdiac.ornl.gov/); [Le Quéré et al 2017](https://doi.org/10.1038/s41561-017-0048-9); [Global Carbon Budget 2017](https://doi.org/10.1038/s41561-017-0048-9)
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
Allocating fossil and industry emissions to the consumption of products provides an alternative perspective. USA and EU28 are net importers of embodied emissions, China and India are net exporters.

Consumption-based emissions are calculated by adjusting the standard production-based emissions to account for international trade.

Source: Peters et al 2011; Le Quéré et al 2017; Global Carbon Project 2017
Consumption-based emissions (carbon footprint)

Transfers of emissions embodied in trade from non-Annex B countries to Annex B countries grew at over 11% per year between 1990 and 2007, but have since declined at over 1% per year.

Source: CDIAC; Peters et al 2011; Le Quéré et al 2017; Global Carbon Budget 2017
Major flows from production to consumption

Flows from location of generation of emissions to location of consumption of goods and services

Values for 2011. EU is treated as one region. Units: MtCO$_2$

Source: Peters et al 2012
Major flows from extraction to consumption

Flows from location of fossil fuel extraction to location of consumption of goods and services

Values for 2011. EU is treated as one region. Units: MtCO₂

Source: Andrew et al 2013
Land-use Change Emissions
Land-use change emissions are highly uncertain. Higher emissions in 2016 are linked to increased fires during dry El Niño conditions in tropical Asia.

Estimates from two bookkeeping models, using fire-based variability from 1997.

Total global emissions: 40.8 ± 2.7 GtCO$_2$ in 2016, 52% over 1990
Percentage land-use change: 42% in 1960, 12% averaged 2007-2016

Land-use change estimates from two bookkeeping models, using fire-based variability from 1997

Source: CDIAC; Houghton and Nassikas 2017; Hansis et al 2015; van der Werf et al. 2017; Le Quéré et al 2017; Global Carbon Budget 2017
Total global emissions by source

Land-use change was the dominant source of annual CO₂ emissions until around 1950

Others: Emissions from cement production and gas flaring

Source: CDIAC; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2017; Global Carbon Budget 2017
Historical cumulative emissions by source

Land-use change represents about 31% of cumulative emissions over 1870–2016, coal 32%, oil 25%, gas 10%, and others 3%

Others: Emissions from cement production and gas flaring

Source: CDIAC; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2017; Global Carbon Budget 2017
Closing the Global Carbon Budget
Fate of anthropogenic CO$_2$ emissions (2007–2016)

Sources = Sinks

34.3 GtCO$_2$/yr
88%

17.3 GtCO$_2$/yr
47%

12%
4.9 GtCO$_2$/yr

30%
11.2 GtCO$_2$/yr

23%
8.7 GtCO$_2$/yr

Budget Imbalance:
(the difference between estimated sources & sinks)
6%
2.1 GtCO$_2$/yr

Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2017; Global Carbon Budget 2017
Carbon emissions are partitioned among the atmosphere and carbon sinks on land and in the ocean. The “imbalance” between total emissions and total sinks reflects the gap in our understanding.

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.

The budget imbalance is the total emissions minus the estimated growth in the atmosphere, land and ocean. It reflects the limits of our understanding of the carbon cycle.

Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2017; Global Carbon Budget 2017
The atmospheric concentration growth rate has shown a steady increase. The high growth in 1987, 1998, & 2015-16 reflect a strong El Niño, which weakens the land sink.

Source: NOAA-ESRL; Global Carbon Budget 2017
The ocean carbon sink continues to increase 8.7±2 GtCO$_2$/yr for 2007–2016 and 9.6±2 GtCO$_2$/yr in 2016.

**Source:** SOCAtv5; Bakker et al 2016; Le Quéré et al 2017; Global Carbon Budget 2017

Individual estimates from: Aumont and Bopp (2006); Buitenhuis et al. (2010); Doney et al. (2009); Hauck et al. (2016); Ilyina et al. (2013); Landschützer et al. (2016); Law et al. (2017); Rödenbeck et al. (2014). Séférian et al. (2013); Schwinger et al. (2016). Full references provided in Le Quéré et al. (2017).
Terrestrial sink

The land sink was 11.2±3 GtCO2/yr during 2007-2016 and 10±3 GtCO₂/yr in 2016. Total CO₂ fluxes on land (including land-use change) are constrained by atmospheric inversions.

Source: Le Quéré et al 2017; Global Carbon Budget 2017

Individual estimates from: Chevallier et al. (2005); Clarke et al. (2011); Guimberteau et al. (2017); Hansis et al. (2015); Haverd et al. (2017); Houghton and Nassikas (2017); Jain et al. (2013); Kato et al. (2013); Keller et al. (2017); Krinner et al. (2005); Melton and Arora (2016); Oleson et al. (2013); Reick et al. (2013); Rodenbeck et al. (2003); Sitch et al. (2003); Smith et al. (2014); Tian et al. (2015); van der Laan-Luijkx et al. (2017); Woodward et al. (1995); Zaehle and Friend (2010). Full references provided in Le Quéré et al. (2017).
Total land and ocean fluxes show more interannual variability in the tropics

Source: Le Quéré et al 2017; Global Carbon Budget 2017

Individual estimates from: Aumont and Bopp (2006); Buitenhuis et al. (2010); Chevallier et al. (2005); Clarke et al. (2011); ; Doney et al. (2009); Guimberteau et al. (2017); Hauck et al. (2016); Haverd et al. (2017); Ilyina et al. (2013); Jain et al. (2013); Kato et al. (2013); Keller et al. (2017); Krinner et al. (2005); Landschützer et al. (2016); Law et al. (2017); Melton and Arora (2016); Oleson et al. (2013); Reick et al. (2013); Rödenbeck et al. (2003); Rödenbeck et al. (2014); Séférian et al. (2013); Schwinger et al. (2016); Sitch et al. (2003); Smith et al. (2014); Tian et al. (2015); van der Laan-Luijkx et al. (2017); Woodward et al. (1995); Zaehle and Friend (2010). Full references provided in Le Quéré et al. (2017).
Remaining carbon budget imbalance

Large and unexplained variability in the global carbon balance caused by uncertainty and understanding hinder independent verification of reported \( \text{CO}_2 \) emissions.

The budget imbalance is the carbon left after adding independent estimates for total emissions, minus the atmospheric growth rate and estimates for the land and ocean carbon sinks using models constrained by observations.

Source: Le Quéré et al 2017; Global Carbon Budget 2017
The cumulative contributions to the global carbon budget from 1870
The carbon imbalance represents the gap in our current understanding of sources and sinks

Data: CDIAC/NOAA–ESRL/GCP/Joos et al 2013

The global CO$_2$ concentration increased from ~277ppm in 1750 to 403ppm in 2016 (up 45%). 2016 was the first full year with concentration above 400ppm.
Atmospheric CO\(_2\) concentration had record growth in 2015 & 2016 due to record high emissions and El Niño conditions, but growth is expected to reduce due to the end of El Niño.

Source: Peters et al. 2017; Global Carbon Budget 2017
Verification of a sustained change in CO$_2$ emissions

Our ability to detect changes in CO$_2$ emissions based on atmospheric observations is limited by our understanding of carbon cycle variability.

*Observations* show a large-interannual to decadal variability, which can only be partially *reconstructed* through the global carbon budget. The difference between observations and reconstructed is the “budget imbalance”.

Source: [Peters et al 2017; Global Carbon Budget 2017](#)
Seasonal variation of atmospheric CO₂ concentration

Weekly CO₂ concentration measured at Mauna Loa stayed above 400ppm throughout 2016 and is forecast to average 406.8 in 2017

Forecasts are an update of Betts et al 2016. The deviation from monthly observations is 0.24 ppm (RMSE). Updates of this figure are available, and another on the drivers of the atmospheric growth.

Source: Tans and Keeling (2017), NOAA-ESRL, Scripps Institution of Oceanography
End notes
Global Carbon Budget 2017

In 2017, CO₂ emissions from fossil fuels and industry are projected to grow by 2.0% (+0.8 to +3.0%). This follows three years of nearly no growth (2014-2016).

The plateau of last year was not peak emissions after all...

...we are changing trajectory...

Emissions decreased significantly in the presence of a growing GDP in 22 countries (representing 20% of global emissions) in the last decade (2007-2016). Other notable changes are also shown.

Japan: Emissions declined recently
India: Emissions grew 6% in the past decade but slowed in 2017

Boost: Emissions declining but probably due to economic crisis
China: Emissions declined for the past 3 years but are up again

...but atmospheric concentrations continue to rise

The carbon cycle has both emissions sources and carbon sinks, and their difference is the atmospheric growth (2007-2016).

Atmospheric growth increases in line with total CO₂ emissions, but has large variability. The 2015-2016 El Niño led to a record high growth due to lower CO₂ uptake by tropical forests.
The work presented in the Global Carbon Budget 2017 has been possible thanks to the contributions of hundreds of people involved in observational networks, modeling, and synthesis efforts.

We thank the institutions and agencies that provide support for individuals and funding that enable the collaborative effort of bringing all components together in the carbon budget effort.

We thank the sponsors of the GCP and GCP support and liaison offices.

We also want thank each of the many funding agencies that supported the individual components of this release. A full list in provided in Table B1 of Le Quéré et al. 2017. https://doi.org/10.5194/essd-2017-123

We also thanks the Fondation BNP Paribas for supporting the Global Carbon Atlas.

This presentation was created by Robbie Andrew with Pep Canadell, Glen Peters and Corinne Le Quéré in support of the international carbon research community.
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