Publication Date: Thursday, 11th July 2019

Global Carbon Budgets:

Determining limits on fossil fuel emissions

Climate Science Communications Group Committee

Briefing paper: Issue 9

Acknowledgements

The Royal Meteorological Society would like to thank Pierre Friedlingstein, Caroline Coch and the members of the Climate Science Communications Group, for their effort and hard work in writing and editing this paper.

Also, thank you to Kasia Tokarska, Kirsten Zickfeld and Joeri Rogelj for reviewing the paper.

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How much CO_2 can the world emit and still avoid dangerous climate change?

Carbon dioxide (CO_2) from fossil fuels burning and land-use change is accumulating in the atmosphere. Current levels are over 40 % higher than in the pre-industrial era and a continued increase of atmospheric CO_2 will lead to further warming of the planet. In the Paris Agreement, countries set out to "hold the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C". There is an upper limit to CO_2 emissions compatible with these objectives. Current knowledge from climate models indicate that the relationship between total or "cumulative" CO_2 emissions and surface warming is broadly linear, meaning that if we double the total amount of CO_2 emissions, we would see a doubling of the warming. From this relationship, one can estimate the remaining carbon budget that could be emitted to the atmosphere in order to remain below 1.5 °C or 2 °C. These carbon budgets were first assessed in the IPCC 5th Assessment Report in 2013, but were revisited in recent publications and in the IPCC Special Report on global warming of 1.5 °C released in October 2018. These newer estimates better account for the historical CO_2 emissions and level of warming already observed.

Given a present-day warming of about 1 °C above pre-industrial levels and historical emissions of about 2200 $GtCO_2$, these studies broadly agree that the 1.5 °C and 2 °C limits would impose a remaining budget of less than about 580 $GtCO_2$ and 1500 $GtCO_2$ respectively. These remaining carbon budgets would be used up in less than about 15 years and 35 years respectively at current rate of global CO_2 emissions.

How are these carbon budgets developed?

Models that simulate both the climate and the land and ocean carbon cycle response to CO_2 emissions are the main tools used to quantify the carbon budget. In general, these models start from "pre-industrial" and run all the way to 2100, using historical CO_2 emissions for the past and scenarios of CO_2 and non-CO_2 emissions for the 21st century. From these simulations, one can diagnose the CO_2 emissions by the time the simulated global warming reaches 1.5 °C or 2 °C. Knowing the historical warming and associated CO_2 emissions, one can infer the remaining budget compatible with these climate targets. Alternatively, remaining carbon budgets can be estimated from the linear relationship between cumulative CO_2 emissions and surface warming diagnosed from models, accounting for the historical warming and the future warming expected from non-CO_2 greenhouse gases and aerosols.

What are the uncertainties?

In current carbon budget estimates, there are three major uncertainties: (1) climate sensitivity, (2) carbon cycle feedbacks, and (3) contribution from non-CO_2 emissions. (1) Climate sensitivity refers to the amount of warming that goes along with an increase in atmospheric CO_2 concentration. There is a large range of plausible estimates of climate sensitivity, due to uncertainty in physical feedbacks, such as cloud feedbacks; briefing paper issue 1 dealt with this topic in depth. (2) Carbon cycle feedbacks refer to the effects of increased atmospheric CO_2 on the land and ocean carbon system. With higher concentrations of atmospheric CO_2, land and ocean CO_2 uptake increases, hence slowing the growth of atmospheric CO_2. At the same time, atmospheric CO_2 increase also induces climate change that tends to reduce the global land and ocean CO_2 uptake, hence accelerating the growth of atmospheric CO_2. Uncertainties on both the climate sensitivity and the carbon cycle feedbacks have direct implication on the size of the remaining carbon budget. (3) Greenhouse gases such as methane (CH_4), nitrous oxide (N_2O) and aerosols also play a role in current and future warming. The quantification of the remaining carbon budget consistent with a climate target needs to make assumptions on the level of future non-CO_2 emissions as well as their associated warming.

Furthermore, there are additional processes that are currently not represented in climate models which could also affect the size of the remaining carbon budget, such as thawing of permafrost. Because of these uncertainties, remaining carbon budgets are usually given in probabilistic terms. Nevertheless, it is crystal clear that the world will need to reduce emissions urgently and become carbon neutral well within this century if we wish to achieve the Paris Agreement target.

Notes, further reading and references:

RMetS Climate Science Briefing Paper Issue 1, Climate Sensitivity: How much warming results from increases in atmospheric carbon dioxide (CO_2)?
RMetS Climate Science Briefing Paper Issue 6, Climate Modelling: How is Earth's climate modelled and how does modelling help our understanding?
IPCC AR5 Working Group 1, Climate Change 2013: The Physical Science Basis
IPCC AR6 Special Report Global Warming of 1.5 °C