Met Office

Understanding global carbon budgets

What is a carbon budget?

A carbon budget is the maximum amount of carbon that can be released into the atmosphere while maintaining a specified chance of staying below a given global average surface temperature rise.

Why are carbon budgets important?

Information on global carbon budgets enables policymakers to evaluate a range of mitigation options that are consistent with meeting long-term global temperature goals.

What do carbon budgets tell us?

All carbon budgets suggest stringent emission reductions will be necessary over the coming decades and net zero emissions in the medium to long term if we want to meet the "well-below 2 °C" goal.

Rapid and large reductions in emissions in the near term will limit the extent to which we have to rely on unproven negative emissions technologies.

If we exceed a carbon budget and subsequently overshoot a temperature goal we will require negative emissions to bring global temperature back down again in later years.

How are carbon budgets defined?

The size of the carbon budget is affected by how global temperature rise goals are interpreted. This interpretation depends on the following elements:

1. ***Probability levels of staying below a given temperature rise***
   (Usually either >66%, >50% or >33%)
2. ***Baselines against which the temperature rise is measured***
   (1861-1880 or 1850-1900)
3. ***Timing of when the temperature goal should be met***
   (E.g. In 2100, next century, or until peak warming which will depend on long-term feedbacks and could be many hundreds of years)
4. ***CO_2 only budgets and budgets that include non-CO_2 forcings such as methane emissions from permafrost, which tend to lower the available budget.***

For example, the latest IPCC report stated that the 2012-2100 carbon budget for a ≥66% chance of staying below 2 °C of warming from 1870 onwards is about 790 billion tonnes of carbon[1]. It rises to about 820 billion tonnes of carbon for a ≥50% chance.

[1] Here we discuss carbon budgets in terms of tonnes of carbon. Some budgets will use tonnes of carbon dioxide instead. To convert from carbon to carbon dioxide requires multiplying by 3.67 (so 790 billion tonnes of carbon is 2900 billion tonnes of CO_2).

Additional emissions from natural sources reduce carbon budgets

There are currently many processes, known as feedback mechanisms, that are not currently accounted for in carbon budgets and could produce additional emissions. Such feedback mechanisms include emissions from wetlands and permafrost regions, including Arctic tundra. These regions currently store vast quantities of carbon which could be released as carbon dioxide (CO_2) or methane (CH_4) if these regions warm further. This would result in amplifying the warming effect and drive a reduced global carbon budget for a given temperature goal.

Additional contributions from natural ecosystem processes may also reduce carbon budgets. For example as CO_2 concentrations increase, additional plant growth will be limited by the supply of nitrogen. Therefore the natural nitrogen cycle will act to reduce the effectiveness of carbon sinks (elements of the carbon system that absorb or store CO_2 such as the forests and oceans).However other factors could lead to an increase in the available global carbon budget, for example if the climate's sensitivity to carbon dioxide is lower than currently thought.

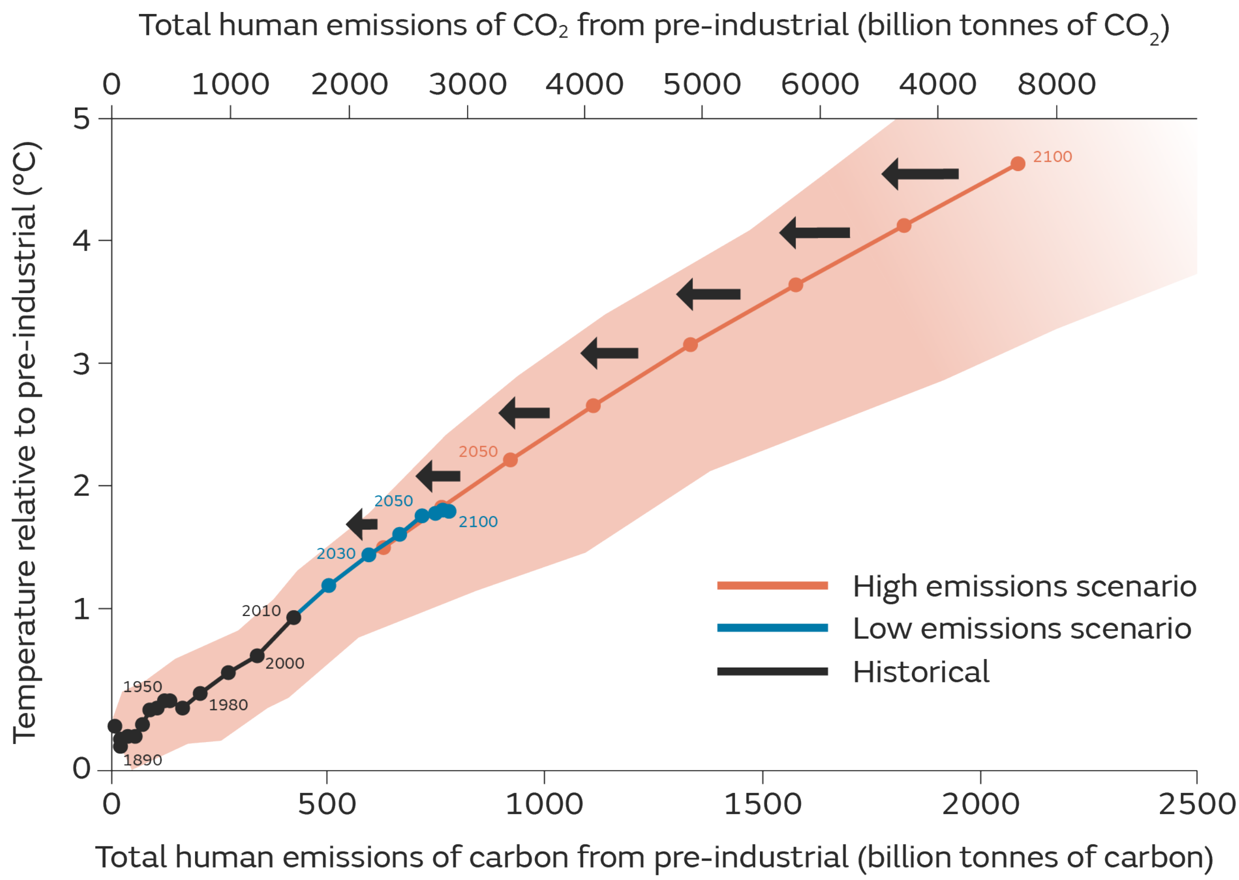
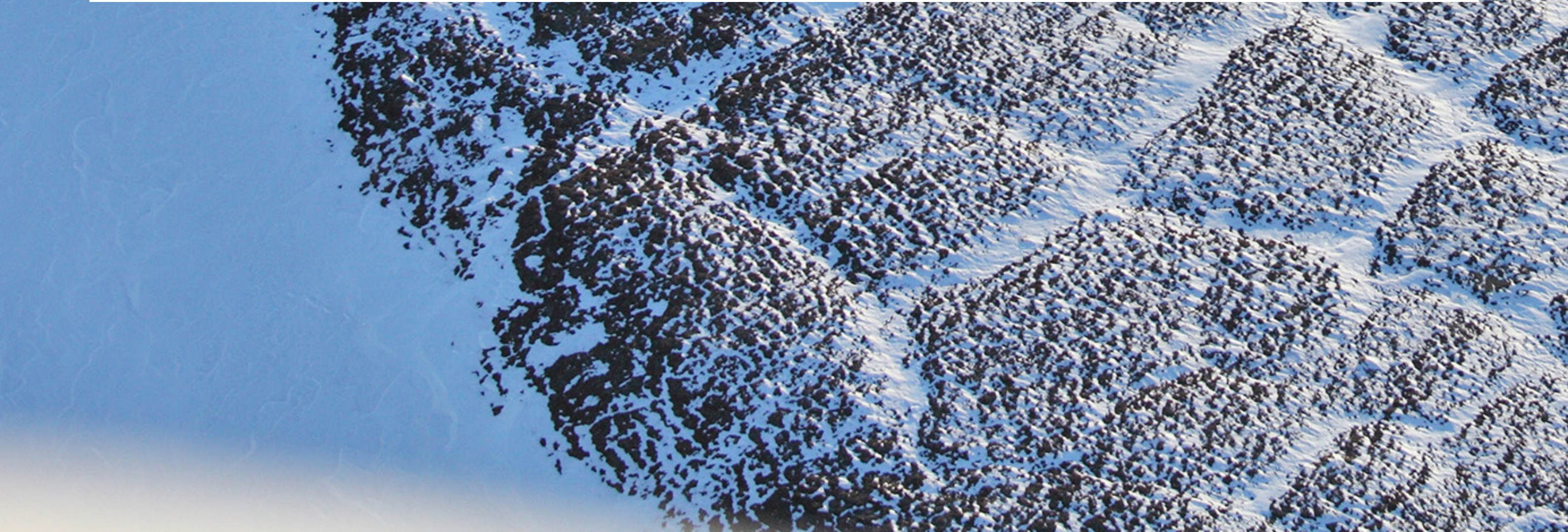


Figure 1: Shows global mean surface temperature increase as a function of cumulative total global carbon dioxide emissions from 1870. Multi-model results until 2100 are shown for the high emissions scenario RCP8.5 (orange), low emissions scenario RCP2.6 (blue) and historical period (black). The plume illustrates the multi-model spread over the RCP scenarios and the dots indicate decadal averages, with selected decades labelled. The black horizontal arrows show how additional natural greenhouse gas emissions reduce the allowable carbon emissions for any given temperature goal. Figure adapted from IPCC AR5 WG1 SPM-10.



How many years before the carbon budgets for 1.5 °C and 2 °C are used?

So far we've emitted 555 (±55) billion tonnes of carbon[2] which means that we may have as few as 5 years of emissions at current levels left (see figure 2) before we use up the carbon budget for a ≥66% chance of limiting temperature rises to 1.5 °C above pre-industrial levels. This rises to about 9 years for a ≥50% chance. For a ≥66% chance chance of staying below 2 °C we have about 20 years of current emissions left. This rises to about 28 years for a ≥50% chance, but there are uncertainties. As well as the inherent uncertainties in the relationship between emissions and temperature rises, and emissions' accounting more generally, this approach focuses on CO_2 emissions only: assumptions made about non-CO_2 GHGs will also impact likely temperature rises. The timescales referenced in figure 2 assume no future use of negative emissions technologies. Yet a significant proportion of IPCC 2 °C and 1.5 °C scenarios use some negative emissions, even if the technologies are uncertain (see next page).

Carbon budgets

How many years left?

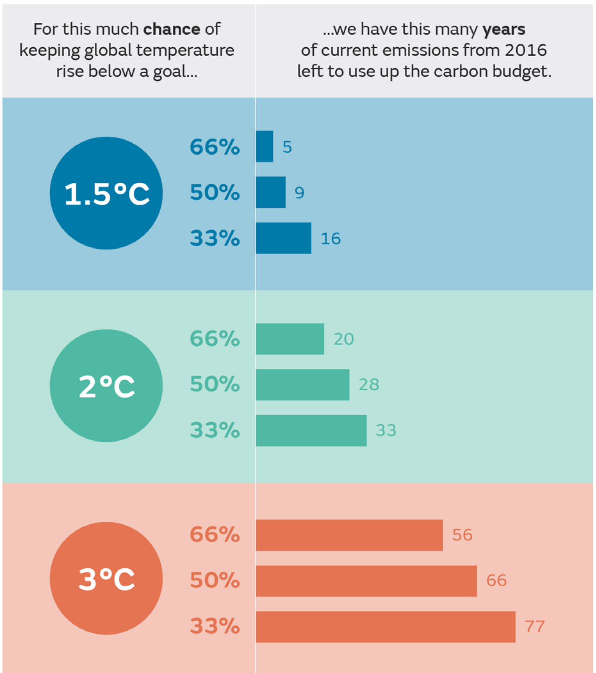


Figure 2: Shows how many years of current emissions from 2016 onwards would use up the IPCC's carbon budgets for different levels of warming. This is based on global carbon budgets as of 2011 from table 2.2 in the IPCC AR5 Synthesis Report combined with emissions data from 2011-2015 from the Global Carbon Project. This figure assumes no future negative emissions. The probabilities supplied here are not equivalent to the standard IPCC likelihood ratings, they instead refer to the percentage of climate model simulations that keep global temperature rise below a given level for a given amount of emissions. There are many ways to define carbon budgets and this is just one such representation in a quickly developing area of climate science.

What if we exceed a carbon budget?

If we exceed a carbon budget for any given temperature goal, we're more likely to see a higher level of warming. Without intervention, this warming would be prolonged due to slow natural climate recovery times. However, there is the possibility of reducing temperatures more rapidly by actively removing carbon from the atmosphere – a process known as 'negative emissions'. While this is an active area of research, there remains a lot of uncertainty surrounding the effectiveness and potential consequences of negative emissions. Techniques for negative emissions include:

- **Afforestation:** Planting trees where there were previously none.
- **BECCS (Bio-Energy Carbon Capture and Storage):** Farming bio energy crops which absorb carbon dioxide as they grow and then burning them for energy and storing the resulting emissions underground.
- **Direct air capture (DAC):** The use of chemicals to absorb CO_2 from the atmosphere before being stored in solid form or pumped into geological reservoirs.
- **Soil carbon sequestration storage:** Enhancing the storage of carbon in soils, e.g. by improved land management practices, or by adding biochar.

[2] Le Quere et al 2015, Global Carbon Budget 2015.

What are the limits to how much carbon we can remove from the atmosphere?

Research shows there are currently significant limitations to the widespread deployment of negative emissions technologies due to their high costs and impacts.[3] For example, BECCS requires converting forested land to bio energy crops which may result in extra greenhouse gas emissions. Including this offset and other factors means the net maximum contribution of negative emissions from BECCS over the 21st century is likely below the amount of negative emissions modelled to be consistent with meeting a 2 °C goal.[4] The conversion of land from agriculture could also impact global food prices and security.

How will negative emissions impact the Earth system?

Natural carbon sinks may become less effective depending on which emissions pathway we follow.[5] In a future scenario with considerable negative emissions, less CO_2 in the atmosphere means that the carbon absorbed by the land and ocean over the second half of the 21st century is less than half the present day value. In addition, planting trees would darken the Earth's surface at high latitudes leading to increased absorption of solar energy and thus potential warming of the land surface in those regions, offsetting some or all of the intended removal of carbon. These impacts may offset the effectiveness of negative emission technologies and therefore increase the amount required to achieve a given temperature goal.

[3] Smith et al 2015, Biophysical and economic limits to negative emissions. *Nature Climate Change*, doi:10.1038/nclimate2870

[4] AVOID2 report D2a. Planetary limits to BECCS negative emissions.

[5] Jones et al 2016. Simulating the Earth System response to negative emissions. Environ.Res.Lett. 11

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