Earth Systems and Climate Change Hub

National Environmental Science Programme

Global and regional carbon budgets

Carbon budgets track sources and sinks of carbon dioxide and their transfer between the atmosphere, ocean and land.

Carbon budgets

Tracking emissions of carbon dioxide over time through carbon budgets allows us to quantify and explain how human activities and natural processes add to and subtract emissions from the atmosphere. This can help to identify where the biggest opportunities for mitigation exist, and how carbon-climate feedbacks might help or hinder efforts to achieve global targets for reducing greenhouse gas emissions.

What are carbon budgets?

Over the past 200 years, human activities have created an imbalance in the global budgets of atmospheric carbon dioxide (CO_2) by transferring carbon between pools of the Earth system.

For example, the combustion of fossil fuels (coal, oil and gas) has transferred carbon, as CO_2, from stores underground to the atmosphere. Other transfers have moved CO_2 from the atmosphere into the oceans and into terrestrial ecosystems through, for example, enhanced plant uptake.

With rising atmospheric CO_2 concentrations driving human-induced climate change, it is critically important to track the sources and sinks of CO_2. The tracking of atmospheric CO_2 sources and sinks and the net balance between all sources and sinks is called the 'carbon budget'.

The Earth Systems and Climate Change (ESCC) Hub supports and provides leadership to the Global Carbon Project (GCP). The GCP is an international collaboration which provides an assessment of human-caused CO_2 sources and sinks. The GCP's annual Global Carbon Budget provides information, data and communication products to inform and raise awareness about how the world is tracking against the carbon budget to limit global warming. In addition to CO_2, other greenhouse gas budgets are also tracked, including methane and nitrous oxide. These greenhouse gas emission budgets provide a transparent and traceable method of assessing global greenhouse gas emissions.

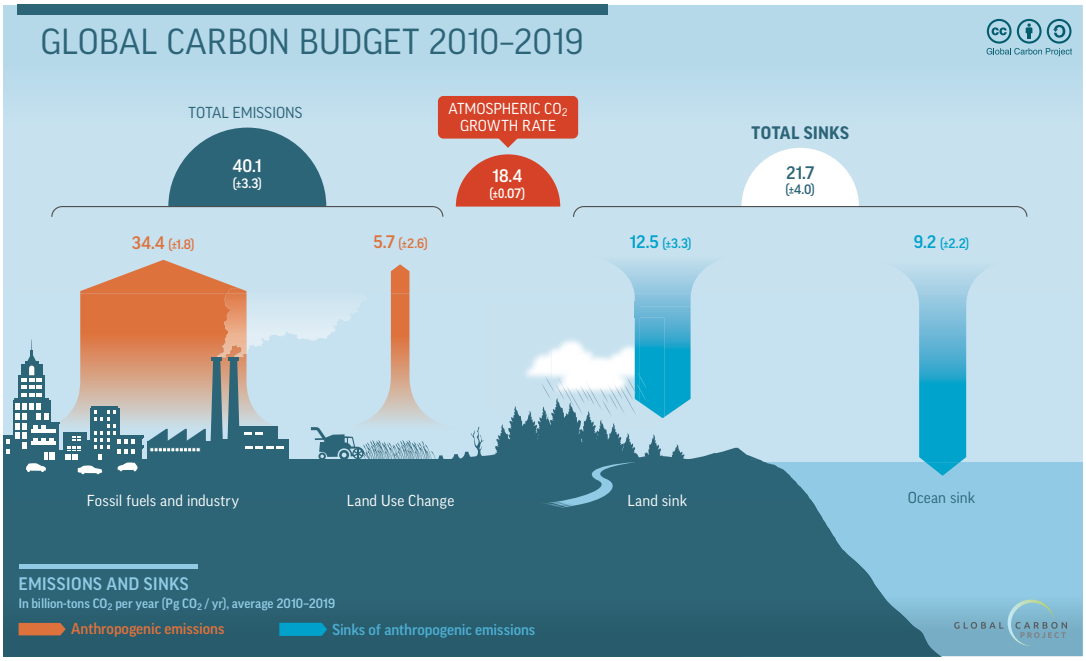

Figure 1: **The global carbon budget, including all major human-caused sources and sinks of CO_2 (and their net effect in the atmosphere).** Arrows show the annual flux averaged over 2010-2019. Note that 'Gt' (gigatons, or billion tons) and 'Pg' (petagrams, or 10^{15} grams) are equivalent.
Source: *Global Carbon Project*

Understanding land and ocean carbon sinks

The land and ocean draw down atmospheric CO_2 and act as sinks to slow the accumulation of human-caused CO_2 emissions, thereby slowing the progression of climate change. Combined, land and ocean sinks remove an annual average of 54 per cent of all CO_2 from human activities – with land sinks removing about 31 per cent of all annual emissions and ocean sinks about 23 per cent. These natural sinks therefore play an important service in mitigating climate change.

Although CO_2 has continued to accumulate in the atmosphere, the proportion of emissions removed by land and ocean sinks has remained constant over the past 60 years. This suggests that strong self-regulating feedbacks have led the sinks to increase their carbon sequestration capacity over time. However, there is large interannual variability of both the land and ocean sink strength in response to climate variability (e.g. El Niño) and extremes. This suggests likely sensitivity of the sinks to future changes in climate and variability.

Tracking land and ocean sinks and how they may change under a warming and variable climate is vital for understanding the climate change mitigation challenge faced by the international community.

Carbon dioxide emission trends and the impacts of COVID-19

Global fossil CO_2 emissions (from fossil fuels and land use change) have increased every decade since the 1960s, from an average of 16±1 billion tons (Gt) of CO_2 per year to 40±3 $GtCO_2$ per year during 2010-2019.

Fossil fuel emissions reached a new high of 36.4 $GtCO_2$ in 2019, but dropped in 2020 by an unprecedented 7 per cent (when compared to 2019) due to the economic slowdown brought about by the COVID-19 pandemic. This drop was primarily attributed to a lack of road and air travel and a downturn in industrial activity during the pandemic in 2020. To put this drop into perspective, the Global Financial Crisis in 2008 saw a 1.5 per cent drop in global emissions compared to 2007.

Although a full rebound of emissions could be reached within 2021, the repercussions of the pandemic could further slow growth in the coming years. Before the fall in CO_2 emissions due to the COVID-19 pandemic, the rate of growth in emissions was already slowing down, with an average increase just below 1% over 2010-2019 compared to an annual growth of 3% during the previous decade.

Behind the global slowing trend in emissions, there are 24 countries that had declining CO_2 emissions for at least one decade – even while their economies continued to grow. This included many European countries such as Denmark, the UK and Spain, as well as the USA, Mexico and Japan. For the rest of the world, emissions continued to grow until 2019.

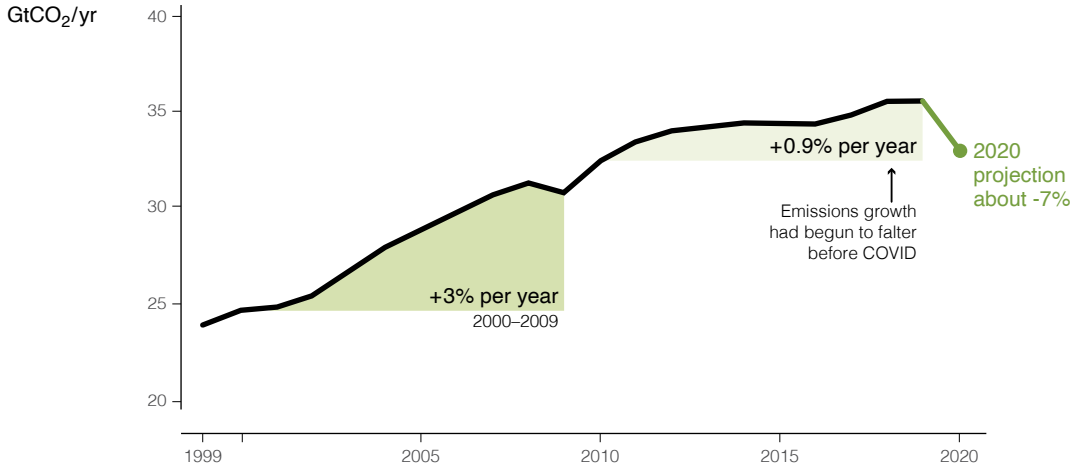

Figure 2: **Global fossil fuel emissions in billion tons of CO_2 ($GtCO_2$).**
Source: *Global Carbon Project*

The 'remaining carbon budget'

As warming is directly related to cumulative CO_2 emissions, the 'remaining carbon budget' can also be estimated.

This is the amount of CO_2 that can be emitted in the future and still limit warming to a given target, such as +1.5 °C or +2 °C global warming above pre-industrial levels. This is possible by constructing the total CO_2 budget allowed for a temperature target and then subtracting the historical cumulative emissions to date.

Cumulative CO_2 emissions can be directly linked to global average temperature change due to the long lifespan of CO_2 in the atmosphere (hundreds of thousands of years). This also implies that net CO_2 emissions need to reach zero (that is, emissions are balanced by removals) in order to stabilise the climate at any given warming level. Shorter-lived greenhouse gases, such as methane and nitrous oxide, are linked to the remaining budget in a more complex way. However, emissions reductions of non-CO_2 greenhouse gases would increase the remaining CO_2 budget because these gases contribute to shorter-term warming.

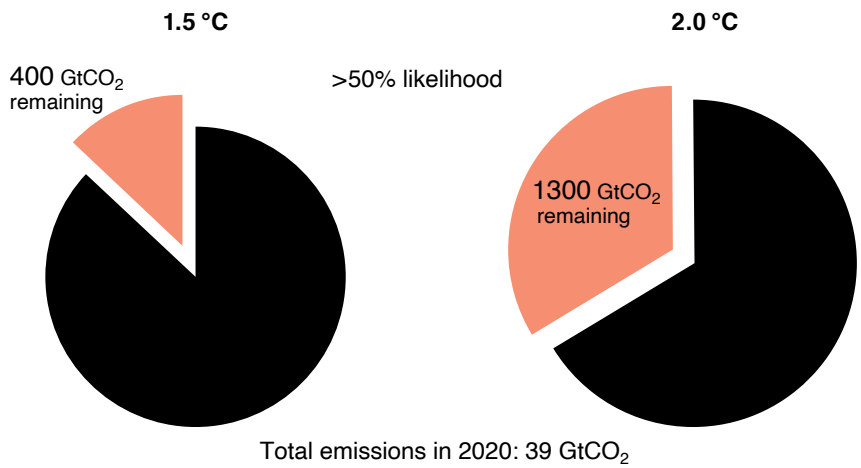

Figure 3: **The remaining carbon budget for 1.5 °C and 2 °C temperature targets with a more than 50% probability, starting in 2020.** Budget uncertainties are ±250 $GtCO_2$. Gt is gigatons, Tt is trillion tons.

Australia's carbon budget

As well as contributing data and leadership towards the development of the annual global carbon budget, the Earth Systems and Climate Change Hub has also developed a CO_2 budget for Australia.

As with the global budget, the Australian budget is made up of the multiple sources and sinks of CO_2 from human activities and natural processes.

The budget shows that Australia's landscape removes, on average, about 700 million tons of CO_2 from the atmosphere each year, depending on annual climate and weather conditions. However, even with this large CO_2 uptake, the net balance of all human and natural sources and sinks results in the accumulation of CO_2 in the atmosphere.

Analysis by the ESCC Hub indicates that in 2019, Australian terrestrial ecosystems were a large net source of CO_2 because of the reduced uptake of CO_2 by plants caused by drought, high temperatures and large CO_2 emissions from bushfires.

> *Carbon budgets provide information and data to inform and raise awareness about how the world is tracking against the global climate change mitigation challenge.*

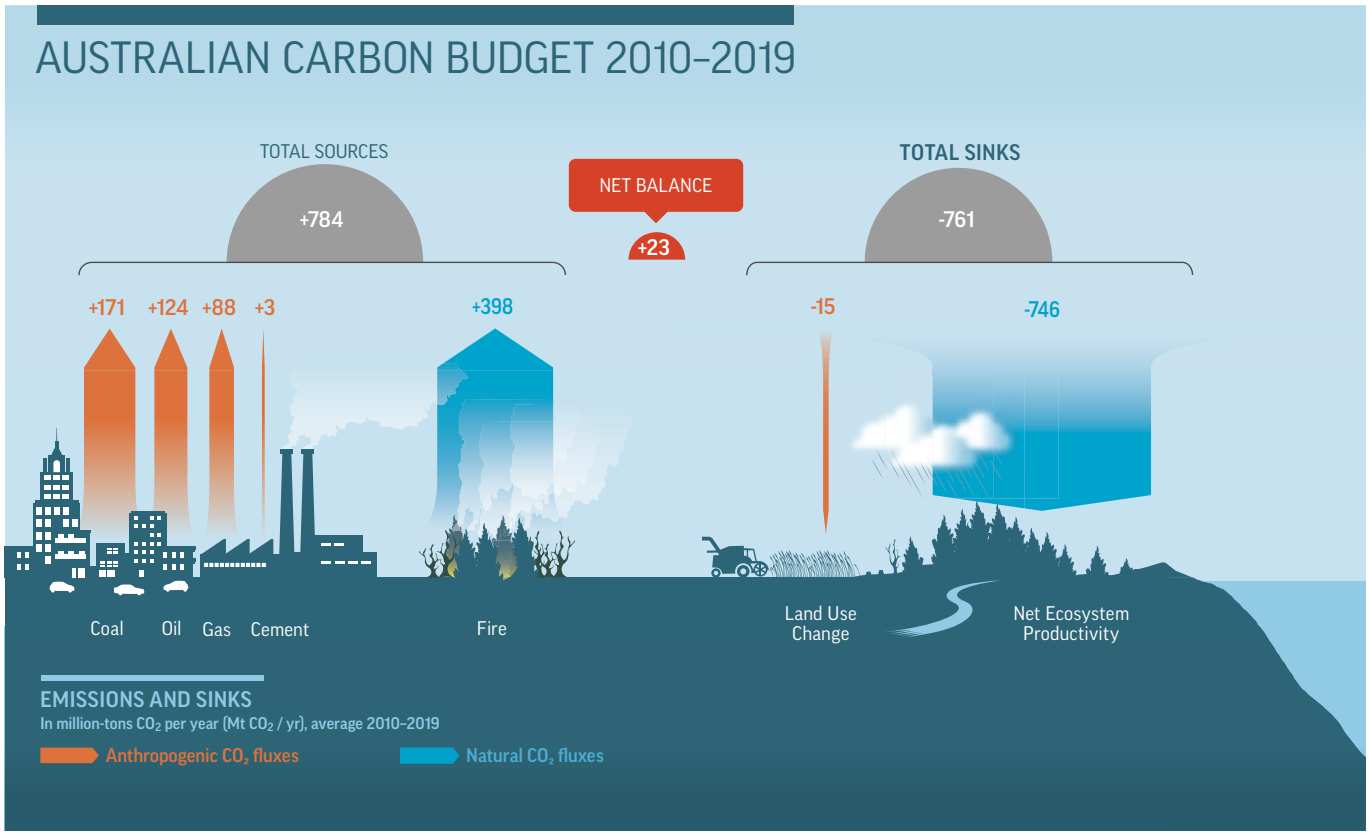

Figure 4: **The Australian carbon budget, including natural and human-caused CO_2 sources and sinks (and their net effect in the atmosphere).** Annual fluxes are the average for the 2010-2019 decade. Units are in million tons of CO_2.

>>> FURTHER INFORMATION

- Global Carbon Project: https://www.globalcarbonproject.org/
- Global Carbon Budget: https://www.globalcarbonproject.org/carbonbudget
- Global Carbon Atlas: http://www.globalcarbonatlas.org/
- Australian National Greenhouse Inventory: https://ageis.climatechange.gov.au/
- Haverd V, et al. 2018. A new version of the CABLE land surface model (Subversion revision r4601) incorporating land use and land cover change, woody vegetation demography, and a novel optimisation-based approach to plant coordination of photosynthesis. *Geoscientific Model Development* 11 (7), https://gmd.copernicus.org/articles/11/2995/2018/
- Villalobos Y, et al. 2021. Was Australia a sink or source of CO_2 in 2015? Data assimilation using OCO-2 satellite measurements. *Atmospheric Chemistry and Physics Discussions*. In review: https://doi.org/10.5194/acp-2021-16

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The Earth Systems and Climate Change Hub is funded by the Australian Government's National Environmental Science Program