The increase in CO_2-induced global warming will only stop when humans stop adding CO_2 to the atmosphere

Science Summary

August 2021

Climate-Carbon Interactions in the Current Century

- **The global average temperature is projected to remain roughly constant after human-induced CO_2 emissions reach zero.**
- ***Why will the temperature remain constant?* If CO_2 emissions stop, the atmospheric CO_2 concentration will decrease as CO_2 is taken up by the ocean and land, which has a cooling effect. As the CO_2 concentration declines, the ocean takes up less heat, leading to additional warming, which offsets the cooling. These two effects largely balance, resulting in a stable global temperature.**
- **Emissions of other greenhouse gases, such as methane, contribute to additional warming.**
- ***Urgent action is needed* to stabilise the temperature increase and the climate system. This would require the world to stop burning fossil fuels and stop deforestation. CO_2 removal can also play a small role in balancing any remaining CO_2 emissions or warming from non-CO_2 emissions.**

CARBON BUDGET

The Paris Agreement sets the goal to keep global warming well below 2˚C and to pursue efforts to limit it to 1.5˚C.

The 'carbon budget' is an important concept developed a decade ago to assess how much additional carbon dioxide (CO_2) can be emitted by human activities before a temperature target will be reached with a given probability. It has been a powerful concept in the last decade, providing critical knowledge to policymakers for formulating appropriate mitigation plans and motivating increased climate ambition.

The carbon budget concept builts on the near-linear relationship between CO_2-induced global warming and total cumulative CO_2 emissions, which implies that additional global warming will stop when CO_2 emissions are zero (Figure 1).

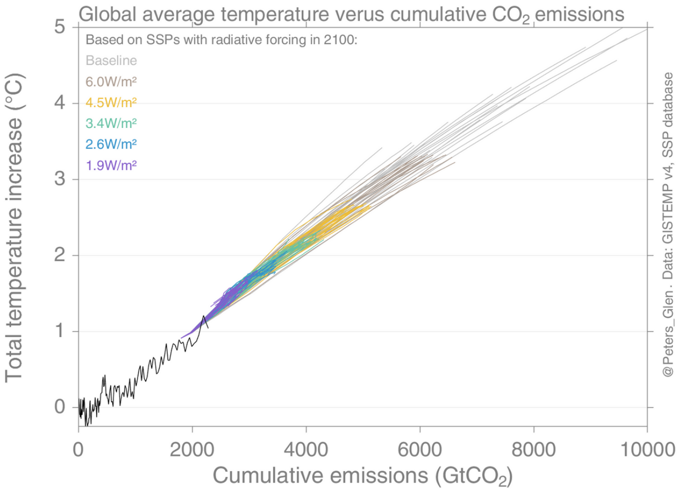

Figure 1. Observed (black line) and projected (coloured lines) increase in temperature (vertical axis) and cumulative CO_2 emissions from human activities since pre-industrial levels in 1870 (horizontal axis). Each line is a different scenario [1,2], coloured by the forcing level in 2100, which corresponds to different levels of warming (1.9 W/m² is 1.5°C, 2.6 W/m² is 1.5-2°C, and so on).

STUDYING THE RESPONSE TO NET-ZERO EMISSIONS

The relationship between the temperature increase and cumulative emissions varies slightly by model. Some models have different behaviour when emissions reach net zero.

To understand these variations, an experiment was set up to determine how the global mean temperature will change after emissions reach zero, which is known as the Zero Emissions Commitment (ZEC).

The ZEC Model Intercomparison Project (ZEC-MIP) brought together 18 climate models to compare how they behave under different emission pathways and thus different atmospheric CO_2 levels reached before net-zero emissions are achieved (e.g. 750, 1,000 or 2,000 billion tonnes of carbon) (Figure 2).

The climate models included in the simulations used these emission pathways, and the results showed the evolution in CO_2 concentrations and global average temperature over time [3].

Changes in atmospheric CO_2 concentration

After anthropogenic CO_2 emissions stop, the additional carbon already added to the atmosphere is gradually redistributed over the next centuries among the atmosphere, ocean and land.

All models project a decay in atmospheric CO_2 concentrations as the natural land and ocean sinks continue to take up CO_2 as they strive to reach equilibrium (Figure 3a) [3].

Changes in temperature

Despite the drop in atmospheric CO_2 concentrations, the average temperature response across simulations shows a small increase in the first 10 years after reaching zero CO_2 emissions, followed by a small gradual decline over the next 90 years across the different model simulations, although a wide range is seen in the model responses (Figure 3b).

Across the 18 climate models, the temperature response after zero CO_2 emissions leads to a slight decline of ~0.1˚C over 100 years, but there is a large spread across models, with some showing slight warming and others slight cooling [3].

Ocean heat uptake

It is evident that the temperature response does not follow the same pathway as that of CO_2 concentrations (Figure 3b). The elevated CO_2 concentration in the atmosphere traps additional energy from the sun, and most (~90%) of this additional energy enters the ocean.

However, as the atmospheric CO_2 concentration decreases after zero emissions, less of the energy (heat) is taken up by the ocean and more stays in the atmosphere. This decline in ocean heat uptake leads to a warming of the atmosphere. This warming effect counterbalances the cooling effect from the decreasing atmospheric CO_2.

As a result, the atmospheric temperature remains roughly constant after zero CO_2 emissions [3].

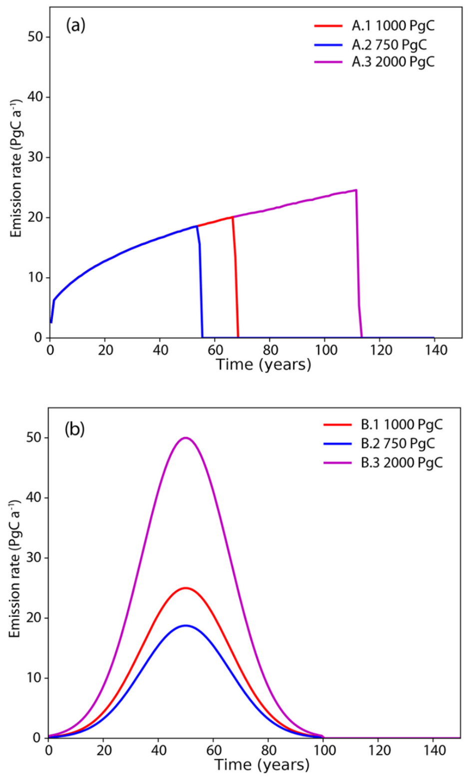

Figure 2. CO_2 emissions in different experiments, all ending with zero emissions. Figure from: MacDougall et al (2020)

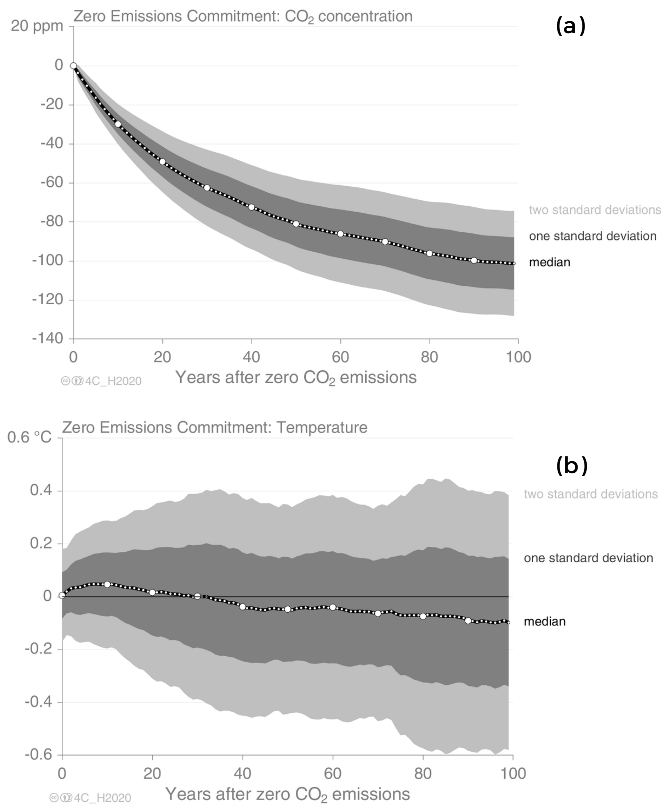

Figure 3. Change in CO_2 concentration (left) and global average temperature (right) after each model reached zero CO_2 emissions. Figure adapted from: MacDougall et al (2020)

Differences between models

The different climate models all show the same processes at play, but the relative proportions of the ocean heat uptake, and the ocean and land carbon sinks vary across models. To compare these effects, they need to be translated into a unit that is comparable with the energy balance, and Watts per square meter is used here. Each model has a different climate response, scale and speed, and so the energy balance can lead to a different temperature response across models (Figure 4) [3].

The Zero Emission Commitment, where CO_2 emissions reach zero, is a different concept to the 'committed warming' when CO_2 concentrations are held constant. Constant CO_2 concentrations require continued, but falling, CO_2 emissions that offset the uptake of the natural carbon sinks [4].

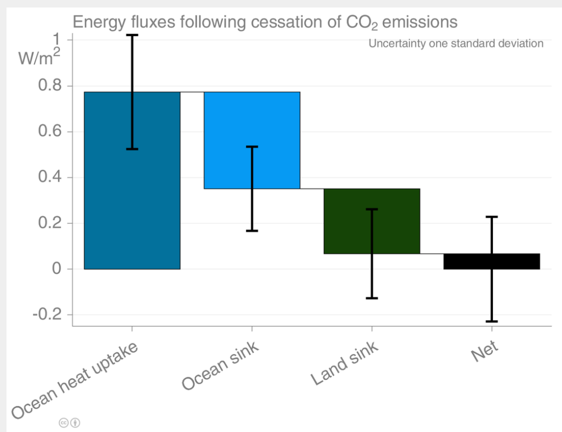

Figure 4. Energy fluxes after CO_2 emissions cease, showing the warming effect of the reduced ocean heat uptake (first bar), and the cooling effect of carbon uptake in the ocean (second bar) and land (third bar), leading to the net cooling effect (last bar). The black lines (whiskers) indicate the distribution across different models of the ZEC-MIP. Figure adapted from: MacDougall et al. (2020).

ZERO OR NET-ZERO EMISSIONS: IMPORTANCE FOR POLICY MAKING

The concepts of carbon budgets and net zero emissions have both become powerful framings for climate action. Whilst some prefer carbon budgets and others prefer net-zero emissions, the two concepts result from the same physical mechanism.

Since the publication of the IPCC Special Report on Global Warming of 1.5˚C [5], the concept of 'net zero' emissions has become prevalent. The 'net' term means that CO_2 emissions (e.g. burning fossil fuels) are balanced by CO_2 removals (e.g. growing new forests).

Some have argued that the 'net' has given an excuse for companies or countries to continue CO_2 emissions, in the hope of large-scale CO_2 removal coming at a later date [6]. Even worse, some incorrectly use 'offsets' (the purchase of reductions by a third-party, often not verified) as a type of CO_2 removal.

It is important to separate the physical use of net zero, the balance of emissions and removals, with the misuse of the term by some actors.

EMISSIONS BEYOND CO_2

The focus in this Science Summary is on the role of CO_2 emissions in climate warming. Other greenhouse gases also have climate impacts.

Most notably, methane has a shorter lifetime than CO_2 (about 10 years), and thus when methane emissions decline sufficiently fast, the methane-induced warming also declines. Other components, like nitrous oxide, are long lived (about 100 year lifetime) and the behaviour is more like that of CO_2 emissions. Complicating matters further are sulphur emissions, with an extremely short lifetime (weeks) but a strong cooling effect. If current sulphur emissions are stopped, motivated by reducing local air pollution, the climate may warm a few tenths of a degree.

However, these different non-CO_2 emissions are often coupled through technology, so reducing one will likely reduce the other.

CONCLUSION

To stabilise the climate system at a given temperature requires zero CO_2 emissions, a balance of anthropogenic CO_2 emissions and anthropogenic CO_2 removals, with sufficient declines in non-CO_2 emissions. This requires stopping the burning of fossil fuels and deforestation, with a potential small role of CO_2 removal to balance any remaining CO_2 or non-CO_2 emissions.

References

1. Riahi K., van Vuuren D.P., Kriegler E., et al., (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Global Environmental Change 42: 153-168. doi.org/10.1016/j.gloenvcha.2016.05.009
2. Rogelj J., Popp A., Calvin K.V., et al. (2018). Scenarios towards limiting global mean temperature increase below 1.5 ˚C. Nature Clim Change 8: 325-332. doi.org/10.1038/s41558-018-0091-3
3. MacDougall A.H., Frölicher T.L., Jones C.D., et al. (2020). Is there warming in the pipeline? A multi-model analysis of the Zero Emissions Commitment from CO_2. Biogeosciences 17: 2987-3016. doi.org/10.5194/bg-17-2987-2020
4. Hausfather Z. (2021). Explainer: Will global warming 'stop' as soon as net-zero emissions are reached? Carbon Brief. carbonbrief.org/explainer-will-global-warming-stop-as-soon-as-net-zero-emissions-are-reached
5. IPCC (2018). Global warming of 1.5˚C. Masson-Delmotte V. et al. (eds.). www.ipcc.ch/sr15/
6. Dyke J., Watson R. and Knorr W. (2021). Climate scientists: concept of net zero is a dangerous trap. The Conversation (article). theconversation.com/climate-scientists-concept-of-net-zero-is-a-dangerous-trap-157368

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