Monitoring global carbon emissions in 2021

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Following record-level declines in 2020, near-real-time data indicate that global CO_2 emissions rebounded by 4.8% in 2021, reaching 34.9 $GtCO_2$. These 2021 emissions consumed 8.7% of the remaining carbon budget for limiting anthropogenic warming to 1.5 °C, which if current trajectories continue, might be used up in 9.5 years at 67% likelihood.

Global CO_2 emissions have exhibited a rapid increase (FIG. 1). However, embedded within this long-term trend are interannual fluctuations arising from global energy, finance and health crises. For example, during 2020, global lockdowns owing to the COVID-19 pandemic temporarily reduced CO_2 emissions[1,2]. The Carbon Monitor program[1,3] — which provides near-real-time daily global CO_2 emissions from power generation (29 countries), industry (73 countries), road transportation (406 cities), aviation and maritime transportation, and commercial and residential sectors (206 countries) — offers an opportunity to track the evolution of these CO_2 emissions, and in doing so, assess remaining carbon budgets and progress in reaching the Paris Agreement. Here, we document the status of CO_2 and fossil CH_4 emissions for 2021, revealing a rebound from COVID-related 2020 reductions and a corresponding decrease in the remaining CO_2 budget.

Status of CO_2 emissions in 2021

One of the key features of 2021 global CO_2 emissions is the rebound from 2020 levels (which exhibited a reduction from 2019 associated with COVID-19-related lockdowns[1,2]; FIG. 1). In particular, global annual emissions increased from 33.3 $GtCO_2$ in 2020 (with a range of 33.0–33.6 $GtCO_2$; including the leap day of February 29, 2020) to 34.9 $GtCO_2$ (with a range of 34.6–35.2 $GtCO_2$) in 2021, representing a 4.8% increase (3.8–5.7% range). Despite rising case numbers and new variants, the impact of the COVID-19 pandemic on CO_2 emissions therefore appears to be less in 2021 compared to 2020 owing to a reduction in restrictive policies.

These rebounds are apparent in most sectors and big emitting nations. For instance, 2021 emissions from power, industry and ground transport (the largest emitters) rebounded by 5.0% (657 $MtCO_2$), 2.6% (256 $MtCO_2$) and 8.9% (513 $MtCO_2$) from 2020 levels, respectively; collectively, these sectors contribute 89% (1.4 $GtCO_2$) of the total global rebound. However, the largest rebounds occurred in the aviation sector, including 25.8% (65 $MtCO_2$) and 18.1% (50 $MtCO_2$) increases from domestic and international aviation. At the country level, 2021 emissions in China, the USA, the 27 European Union countries (EU27) and the UK, India, and Russia, also rebounded by 5.7% (597 $MtCO_2$), 6.5% (296 $MtCO_2$), 6.7% (193 $MtCO_2$), 9.4% (212 $MtCO_2$), and 6% (91 $MtCO_2$) from 2020 levels, respectively. Among the top emitters, Japan was the only country not to exhibit a substantial rebound; here, emissions dropped 4.7% (51 $MtCO_2$) from 2019 levels in 2020, and 5% (54 $MtCO_2$) from 2019 levels in 2021.

Methane (CH_4) emissions, a short-lived climate forcer with larger comparative impact than CO_2, also exhibited substantial changes (FIG. 1). Similar to CO_2, fossil-related methane emissions dropped by 5.7% from 2019 to 2020, but then rebounded by 3.7% in 2021 owing to increased demand of natural gas and other fossil fuels[4].

Although the amplitude of CO_2 and CH_4 changes (the initial drop and subsequent rebound) are unprecedented, such crises and rebounds are not unique. Indeed, since the 1970s there have been global events in every decade that caused temporary negative growth in global CO_2 emissions[5]: the energy (oil) crises of 1974, 1980–1982 and 1992, and the financial crisis of 2008. In all cases, emissions rebounded substantially after the event, shifting the downward trend such that average decadal growth rates were 3%, 1%, 1%, 3% and 2% for each decade since the 1970s. Thus, while there was a record CO_2 decline in 2020, the rebound in 2021 could signal that history is being repeated, reducing confidence in global climate mitigation actions.

Countdown of the dwindling carbon budget

Carbon budgets estimate the maximum amount of cumulative net global anthropogenic CO_2 emissions that would limit warming to a given level with a given probability from a specified date, taking into account other anthropogenic climate forcers. Starting from 2020, the IPCC estimates that the global carbon budget for 1.5 °C and 2 °C warming is 400 $GtCO_2$ and 1,150 $GtCO_2$ with 67% likelihood, respectively, or 300 $GtCO_2$ and 900 $GtCO_2$ with 83% likelihood[6]. The observed variability in

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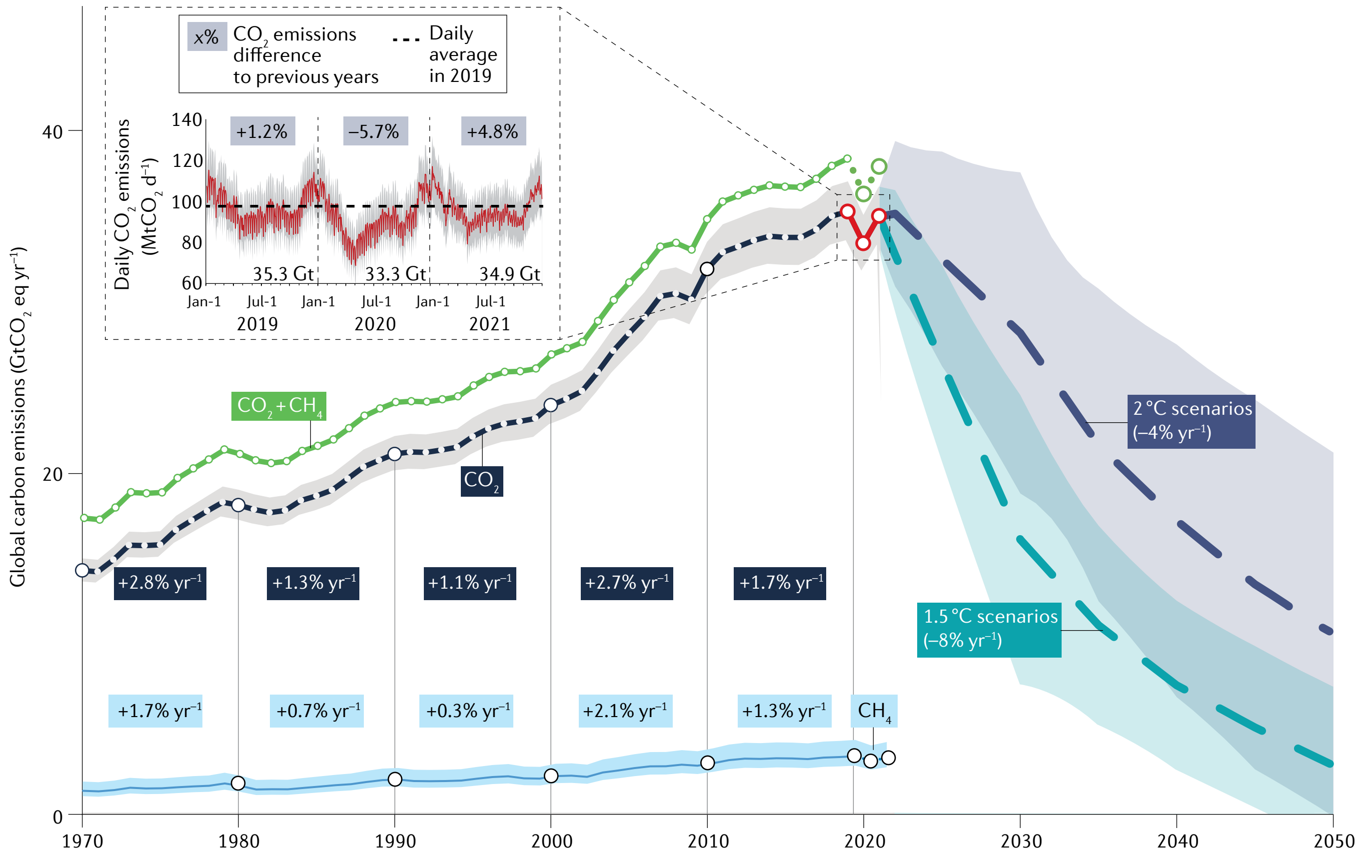

Fig. 1 | **Global CO_2 and CH_4 emission trends.** Temporal evolution of historical CO_2 emissions[5] (navy; including emissions from fossil fuel combustion and the process of cement production), near-real-time CO_2 emissions[1,3] (red), projected CO_2 emission mitigation pathways[10] (dark blue and aqua), and historical fossil CH_4 emissions[41] (light blue; 1970–2018 data from EDGARv6.0, scaled to 2021 with IEA data). Solid/dashed lines and shading represent the median and range, respectively. The inset depicts daily near-real-time CO_2 data over 2019 to 2021, and the corresponding year-on-year changes in annual CO_2 emissions. Current emission trends will use up the allowed future emissions for limiting anthropogenic warming to 1.5 °C (the remaining carbon budgets) within 10 years.

CO_2 emissions have clear implications for this budget, and thus achievement of the Paris Agreement.

For example, despite dramatic reductions in 2020, emissions for that year still consumed 8.3 ± 0.07% of the remaining 1.5 °C budget, or 2.9 ± 0.02% of the remaining 2 °C budget with 67% likelihood. In accordance with the rebound and enhanced emissions, budget use increased further in 2021. Specifically, 2021 emissions used 8.7 ± 0.1% of the 1.5 °C budget and 3.0 ± 0.03% of the 2 °C budget with 67% likelihood. As of the end of 2021, 332 $GtCO_2$ and 1,082 $GtCO_2$ remain for the 1.5 °C and 2 °C budgets with 67% likelihood, respectively.

Assuming that emissions continue at 2021 levels without immediate reduction strategies, these values permit quantification of the timescale at which the remaining CO_2 budget might be used, and thus when limits to constrain warming to Paris Agreement levels might be exceeded (at least based on the IPCC remaining CO_2 budgets). To stay within only 1.5 °C warming, it is estimated that the remaining CO_2 budget might be used within 9.5 ± 0.1 years (in 2031) at 67% likelihood, or 6.6 ± 0.1 years (in 2028) with 83% likelihood. For 2 °C warming, budgets could be used within 31.0 ± 0.3 years (in 2052) or 23.8 ± 0.2 years (in 2045) with 67% and 83% likelihood, respectively.

National countdown to net-zero emissions

The impacts of 2020 and 2021 on the carbon budget highlight an immediate necessity for more stringent actions towards carbon neutrality. Indeed, even ignoring the rebound effects, the 6% temporary decrease in CO_2 emissions arising from global COVID-related lockdowns is lower than the required 8% reductions needed per year to limit anthropogenic warming to 1.5 °C by 2100 with 67% likelihood.

Currently, the USA, EU and UK plan to reach net zero by 2050, China and Russia by 2060, and India by 2070, leaving limited time to meet emission targets. Assuming that each country's emissions continuously decline by the same amount per year to achieve net zero by the target, the US and the EU27 and UK would need to reduce their emissions from the current 2021 levels by 167 $MtCO_2$ per year and 105 $MtCO_2$ per year, respectively. China would further have to reduce their emissions by 286 $MtCO_2$ per year, and Russia by 41 $MtCO_2$ per year to achieve targets of net zero by 2060 (REF.[7]). With plans for net zero by 2070, India's reductions would need to be 51 $MtCO_2$ per year. Yet, even if these minimum annual emission reduction targets were achieved, these nations alone would emit over 400 $GtCO_2$ cumulatively from 2020 to 2045, using up all of the remaining 1.5 °C budget (67% likelihood) by 2045.

Even if nations were on track to achieve their Nationally Determined Contributions, global greenhouse gas emissions have not yet peaked[8]. Indeed, preliminary Carbon Monitor data already suggest a further increase of global emissions in early 2022. More costly and aggressive emission reduction actions are therefore needed to curb the emissions growth trend and contribute to the achievement of the 1.5 °C, or at least 2 °C, Paris Agreement goals. Doing so requires continuous monitoring, documentation and evaluation[9] of national carbon emissions.

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Competing interests
The authors declare no competing interests.

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