Monitoring global carbon emissions in 2021

Zhu Liu1✉, Zhu Deng1, Steven J. Davis2, Clement Giron3 and Philippe Ciais4

Following record-level declines in 2020, near-real-time data indicate that global CO₂ emissions rebounded by 4.8% in 2021, reaching 34.9 GtCO₂. 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 CO₂ 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 CO₂ emissions1,2. The Carbon Monitor program3 — which provides near-real-time daily global CO₂ 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 CO₂ emissions, and in doing so, assess remaining carbon budgets and progress in reaching the Paris Agreement. Here, we document the status of CO₂ and fossil CH₄ emissions for 2021, revealing a rebound from COVID-related 2020 reductions and a corresponding decrease in the remaining CO₂ budget.

**Status of CO₂ emissions in 2021**

One of the key features of 2021 global CO₂ emissions is the rebound from 2020 levels (which exhibited a reduction from 2019 associated with COVID-19-related lockdowns1,2; Fig. 1). In particular, global annual emissions increased from 33.3 GtCO₂ in 2020 (with a range of 33.0–33.6 GtCO₂; including the leap day of February 29, 2020) to 34.9 GtCO₂ (with a range of 34.6–35.2 GtCO₂) 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 CO₂ 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 MtCO₂), 2.6% (256 MtCO₂) and 8.9% (513 MtCO₂) from 2020 levels, respectively; collectively, these sectors contribute 89% (1.4 GtCO₂) of the total global rebound. However, the largest rebounds occurred in the aviation sector, including 25.8% (65 MtCO₂) and 18.1% (50 MtCO₂) 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% (397 MtCO₂), 6.5% (296 MtCO₂), 6.7% (193 MtCO₂), 9.4% (212 MtCO₂), and 6% (91 MtCO₂) 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 MtCO₂) from 2019 levels in 2020, and 5% (34 MtCO₂) from 2019 levels in 2021.

Methane (CH₄) emissions, a short-lived climate forcer with larger comparative impact than CO₂, also exhibited substantial changes (Fig. 1). Similar to CO₂, 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 fuels4.

Although the amplitude of CO₂ and CH₄ 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 CO₂ emissions5: 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 CO₂ 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 CO₂ 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 GtCO₂ and 1,150 GtCO₂, with 67% likelihood, respectively, or 300 GtCO₂ and 900 GtCO₂ with 83% likelihood6. The observed variability in...
CO2 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% and 83% likelihood, respectively. As of the end of 2021, 332 GtCO2 and 1,082 GtCO2 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 CO2 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 CO2 budgets). To stay within only 1.5 °C warming, it is estimated that the remaining CO2 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 CO2 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 MtCO2 per year and 105 MtCO2 per year, respectively. China would further have to reduce their emissions by 286 MtCO2 per year, and Russia by 41 MtCO2 per year to achieve targets of net zero by 2060 [REF1]. With plans for net zero by 2070, India’s reductions would need to be 51 MtCO2 per year. Yet, even if these minimum annual emission reduction targets were achieved, these nations alone would emit over 400 GtCO2, 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 peaked8. 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 evaluation9 of national carbon emissions.

1. Liu, Z. et al. Near-real-time monitoring of global CO2 emissions reveals the effects of the COVID-19 pandemic. Nat. Commun. 11, 5172 (2020).
2. Le Quéré, C. et al. Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement. Nat. Clim. Change 10, 647–653 (2020).
3. Liu, Z. et al. Carbon Monitor, a near-real-time daily dataset of global CO2 emission from fossil fuel and cement production. Scientific Data 7, 392 (2020).
4. IEA. Global Methane Tracker 2022 (2022); https://www.iea.org/reports/global-methane-tracker-2022.
5. Crippa, M. et al. Fossil CO2 Emissions of All World Countries - 2020 Report (Publications Office of the European Union, 2020).
6. IPCC Climate Change 2021: The Physical Science Basis (eds Masson-Delmotte, V. et al.) (Cambridge Univ. Press, 2021).
7. Liu, Z. et al. Challenges and opportunities for carbon neutrality in China. Nat. Rev. Earth Environ. 3, 141–155 (2022).
8. Nationally Determined Contributions Under the Paris Agreement FCCC/PA/CMA/2021/8 (UNFCCC, 2021).
9. Deng, Z. et al. Comparing national greenhouse gas budgets reported in UNFCCC inventories against atmospheric inversions. Earth Syst. Sci. Data Discuss. https://doi.org/10.5194/essd-2021-235 (2021).
10. Huppmann, D. et al. IAMC 1.5°C Scenario Explorer and Data hosted by IIASA (Integrated Assessment Modeling Consortium & International Institute for Applied Systems Analysis, 2018).

Acknowledgements
The authors thank those that contributed to the 2020 and 2021 Carbon Monitor dataset. We acknowledge the National Natural Science Foundation of China (grant 41921005 and 71874097), Beijing Natural Science Foundation (JQ19032) and the Qiu Shi Science & Technologies Foundation.

Competing interests
The authors declare no competing interests.

RELATED LINKS
Carbon Monitor: https://carbonmonitor.org/