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Philippe Ciais, S Davis, Zhu Deng, Zhu Liu, et al.

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PERSPECTIVE • OPEN ACCESS

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ENVIRONMENTAL RESEARCH  
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## PERSPECTIVE

## Global fossil carbon emissions rebound near pre-COVID-19 levels

R B Jackson<sup>1,\*</sup>, P Friedlingstein<sup>2,3</sup>, C Le Quéré<sup>4</sup>, S Abernethy<sup>1</sup>, R M Andrew<sup>5</sup>, J G Canadell<sup>6</sup>, P Ciais<sup>7</sup>, S J Davis<sup>8</sup>, Zhu Deng<sup>9</sup>, Zhu Liu<sup>9</sup>, J I Korsbakken<sup>5</sup> and G P Peters<sup>5</sup><sup>1</sup> Department of Earth System Science, Woods Institute for the Environment, and Precourt Institute for Energy, Stanford University, Stanford, CA 94305-2210, United States of America<sup>2</sup> College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter EX4 4QF, United Kingdom<sup>3</sup> Département de Géosciences, Laboratoire de Météorologie Dynamique, Institut Pierre-Simon Laplace, CNRS-ENS-UPMC-X, Ecole Normale Supérieure, 24 rue Lhomond, 75005 Paris, France<sup>4</sup> Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich Research Park, Norwich NR4 7TJ, United Kingdom<sup>5</sup> CICERO Center for International Climate Research, PO Box 1129 Blindern, 0318 Oslo, Norway<sup>6</sup> Global Carbon Project, CSIRO Oceans and Atmosphere, Canberra, ACT 2601, Australia<sup>7</sup> Laboratoire des Sciences du Climat et de l'Environnement, LSCE/IPSL, CEA-CNRS-UVSQ, Versailles, Versailles, France<sup>8</sup> Department of Earth System Science, University of California at Irvine, Irvine, CA 92697, United States of America<sup>9</sup> Department of Earth System Science, Tsinghua University, Beijing 100084, People's Republic of China

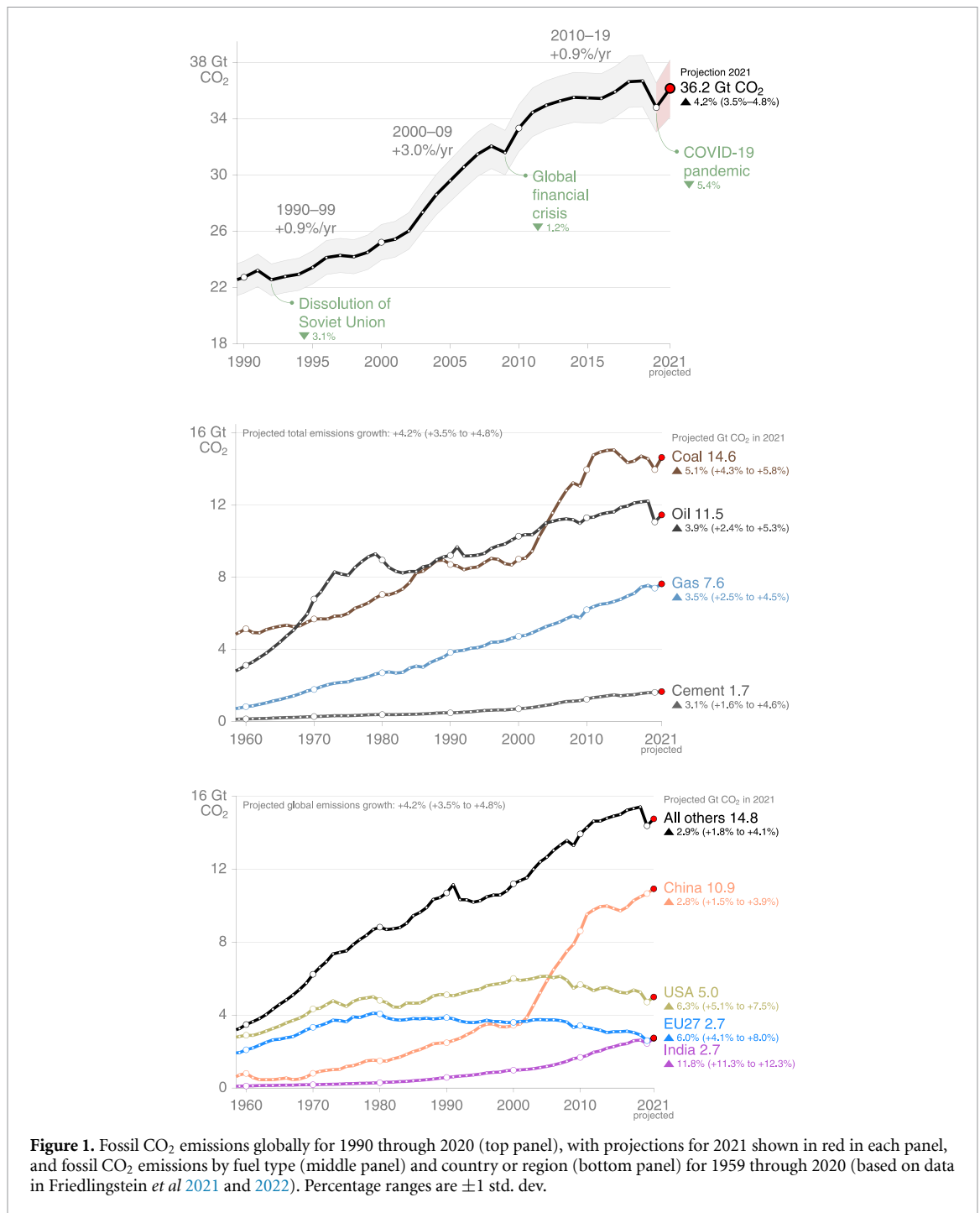
\* Author to whom any correspondence should be addressed.

E-mail: [rob.jackson@stanford.edu](mailto:rob.jackson@stanford.edu)**Keywords:** CO<sub>2</sub> emissions, coal, oil, and natural gas, climate change, COVID-19, fossil fuels, global carbon budget, energyRECEIVED  
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citation and DOI.**Abstract**Fossil CO<sub>2</sub> emissions in 2021 grew an estimated 4.2% (3.5%–4.8%) to 36.2 billion metric tons compared with 2020, pushing global emissions back close to 2019 levels (36.7 Gt CO<sub>2</sub>).**1. Introduction**

Prior to the emergence of COVID-19, average global growth in fossil CO<sub>2</sub> emissions had slowed to 0.9% annually during the 2010s (2010–2019), with global emissions in 2019 about the same as those in 2018 (~37.7 Gt CO<sub>2</sub> in both years; Jackson *et al* 2018, Friedlingstein *et al* 2020, 2022). Much of the decadal slowdown in emissions growth was attributable to the substitution of coal with gas and renewables in the electricity sector (Jackson *et al* 2016, 2019, Friedlingstein *et al* 2019, Peters *et al* 2020), and induced in part by the growing numbers of climate change laws worldwide (Eskander and Fankhauser 2020). Compared to the 2010s, average annual growth of global fossil CO<sub>2</sub> emissions was 3.0% in the 2000s, 0.9% in the 1990s, 1.6% in the 1980s, and 3.2% in the 1970s (Friedlingstein *et al* 2020, 2022).

The years 2020 and 2021 revealed unprecedented disruptions to global economic activity and fossil carbon dioxide (CO<sub>2</sub>) emissions attributable to the world's responses to the COVID-19 pandemic. Based on data and methods in Friedlingstein *et al* (2022), we estimate that global fossil CO<sub>2</sub> emissions in 2020 decreased 5.4%, from 36.7 Gt CO<sub>2</sub> in 2019 to 34.8 Gt CO<sub>2</sub> in 2020, an unprecedented decline of ~1.9 Gt CO<sub>2</sub>. Global fossil CO<sub>2</sub> emissions in 2021 rebounded

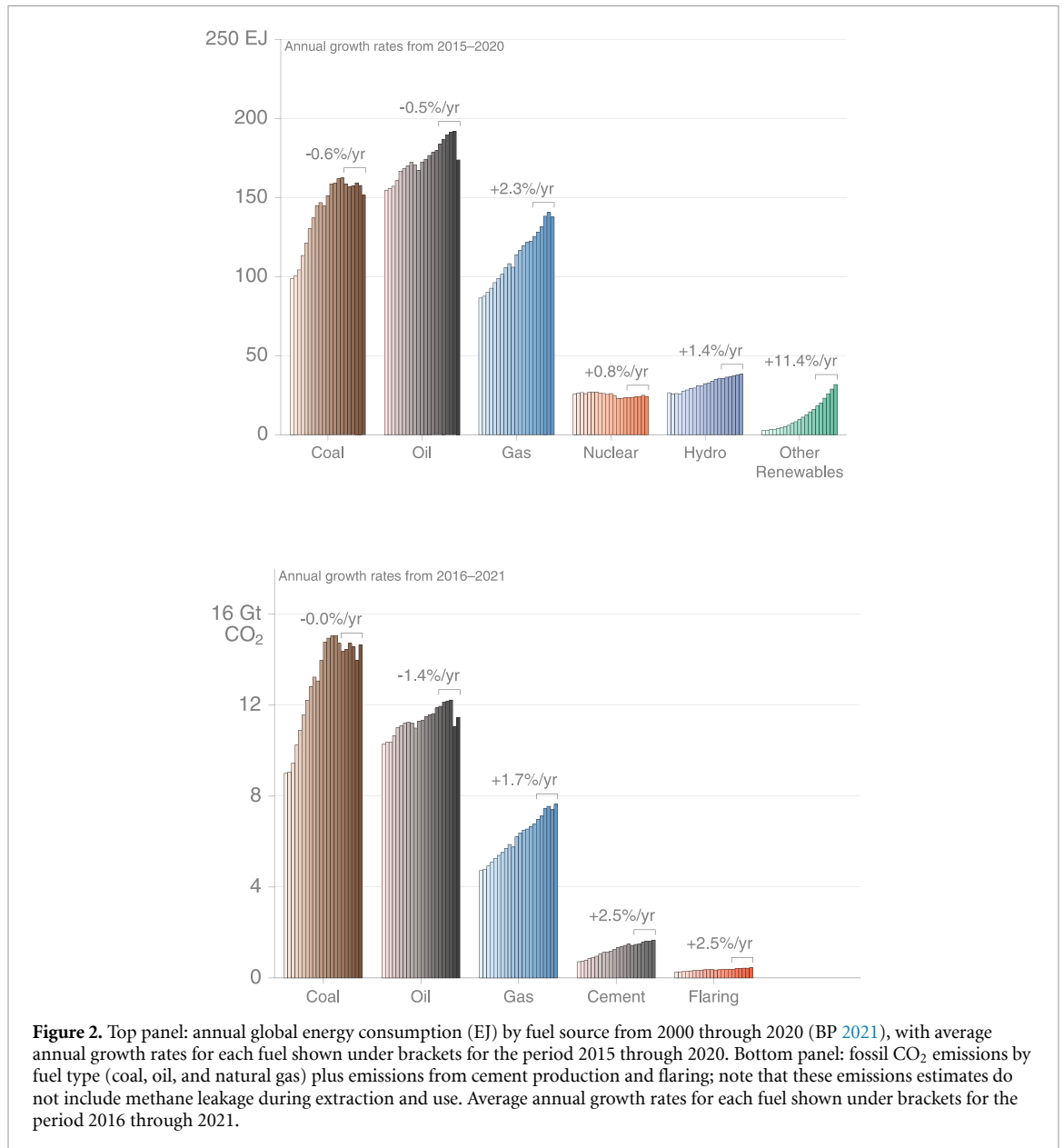
an estimated 4.2% (3.5%–4.8%, all ranges  $\pm 1$  std. dev.) compared to 2020 to 36.2 (35.9–36.4) Gt CO<sub>2</sub>, returning close to 2019 emission levels of 36.7 Gt CO<sub>2</sub>. Emissions in China were 4.2% higher in 2021 than in 2019 (reaching 10.9 Gt CO<sub>2</sub>) and similarly higher in India (a 3.8% increase in 2021 relative to 2019, reaching 2.7 Gt CO<sub>2</sub>). In contrast, projected 2021 emissions in the United States (5.0 Gt CO<sub>2</sub>), European Union (2.7 Gt CO<sub>2</sub>), and rest of the world (14.8 Gt CO<sub>2</sub>, in aggregate) remained below 2019 levels. For fossil fuels, we estimate CO<sub>2</sub> emissions from coal in 2021 rebounded above 2019 levels to 14.6 Gt CO<sub>2</sub>, primarily because of increased coal use in India and China, and will remain only slightly (2.8%) below their previous peak in 2014. Emissions from natural gas use also rose above 2019 levels in 2021 to 7.6 Gt CO<sub>2</sub>, continuing a steady trend of rising gas use that dates back at least 60 years. Only CO<sub>2</sub> emissions from oil remained well below 2019 levels in 2021 (11.5 Gt CO<sub>2</sub>). Emissions in the power and industry sectors increased global fossil CO<sub>2</sub> emissions the most in 2021, with emissions from surface transport and aviation still below 2019 levels. The rapid rebound in global fossil CO<sub>2</sub> emissions as economies recover from the COVID-19 pandemic reinforces the need for immediate and global coherence in the world's response to climate change.



## 2. Fossil carbon emissions in 2020

Confinement measures in response to the COVID-19 pandemic reduced social and global economic activity and CO<sub>2</sub> emissions substantially (Diffenbaugh *et al* 2020, Forster *et al* 2020, Friedlingstein *et al* 2020, Le Quéré *et al* 2020, Liu *et al* 2020, 2021, IEA 2021a). At the time of peak confinement in a given country, emissions decreased by one quarter (26%) on average (Le Quéré *et al* 2020). Daily global fossil CO<sub>2</sub> emissions decreased 17% at peak confinement in April of 2020 (compared to 2019), and

daily emissions decreased up to 75% in aviation, 50% in road transportation, and 35% in industry (Le Quéré *et al* 2020). Almost half of the decline in total annual fossil CO<sub>2</sub> emissions in 2020 was attributable to reductions in transport activity (Le Quéré *et al* 2020, Liu *et al* 2020). This large decrease in economic activity and global emissions also reduced aerosol amounts (particularly over southern and eastern Asia) and increased surface shortwave radiation levels but apparently did not affect near-surface temperatures or rainfall globally (Jones *et al* 2021).



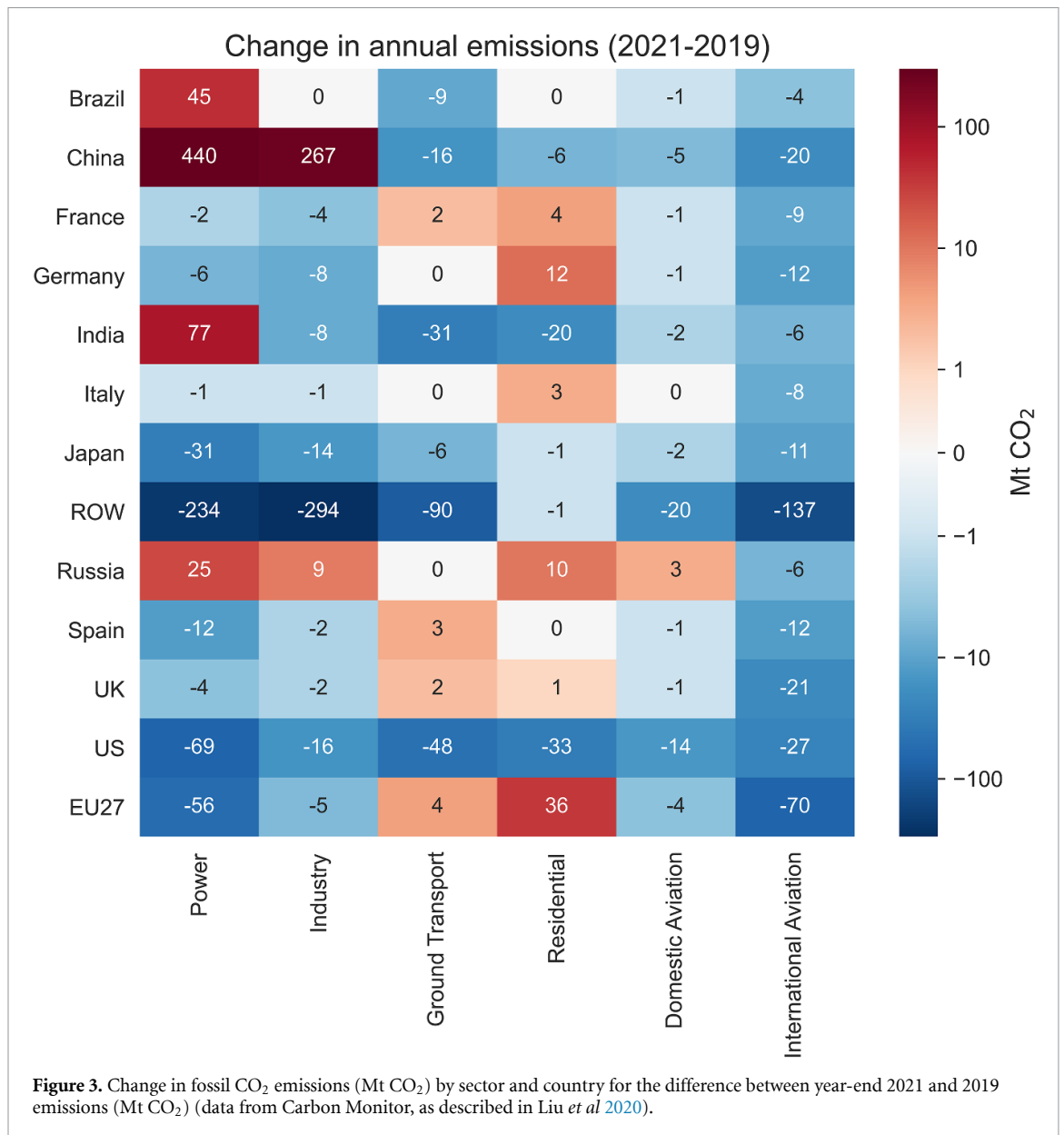
The economic disruption of COVID-19 in 2020 altered emissions in ways that varied by country, sector, and fuel type and that may have accelerated the transition to renewables. Global fossil CO<sub>2</sub> emissions in 2020 decreased from 36.7 Gt CO<sub>2</sub> in 2019 to 34.8 Gt CO<sub>2</sub> in 2020, a decline of 5.4% (and comparable to the International Energy Administration's estimate of a 5.8% decline in 2020; IEA 2021a). China was among the few large countries whose emissions increased in 2020 compared with 2019 (figure 1), despite a large but brief drop attributable to COVID-19. The increase in China's total emissions was attributable primarily to its power and industry sectors, where emissions increased by ~55 and 157 Mt CO<sub>2</sub>, respectively, in 2020 compared to 2019, according to preliminary estimates (Liu *et al* 2020). Most of this increase took place after April 2020 in the more industrialized coastal provinces of China (Zheng *et al* 2020), coinciding with the reopening of factories after the

initial COVID-19 lockdown. Most other sectors and large countries or regions (figure 1) showed substantial reductions in CO<sub>2</sub> emissions from 2019 to 2020 (Friedlingstein *et al* 2022).

For fuels globally in 2020, coal use fell 6.2 EJ to 151.4 EJ yr<sup>-1</sup>, a 4% decline compared to consumption in 2019 (figure 2). Petroleum consumption decreased even more (9.6%) in 2020—an 18.2 EJ drop to 173.7 EJ yr<sup>-1</sup>. Gas consumption fell a modest 2.1% to 137.6 EJ. In contrast, wind, solar, and other renewable sources jumped 10% in 2020 to 31.7 EJ, despite a substantial 25 EJ decline in global energy demand attributable to COVID-19 (figure 2).

### 3. Fossil carbon emissions in 2021

For 2021, our preliminary estimates are that global fossil CO<sub>2</sub> emissions compared with 2020 levels rebounded by 4.2% (3.5%–4.8%) to 36.2 Gt CO<sub>2</sub>,

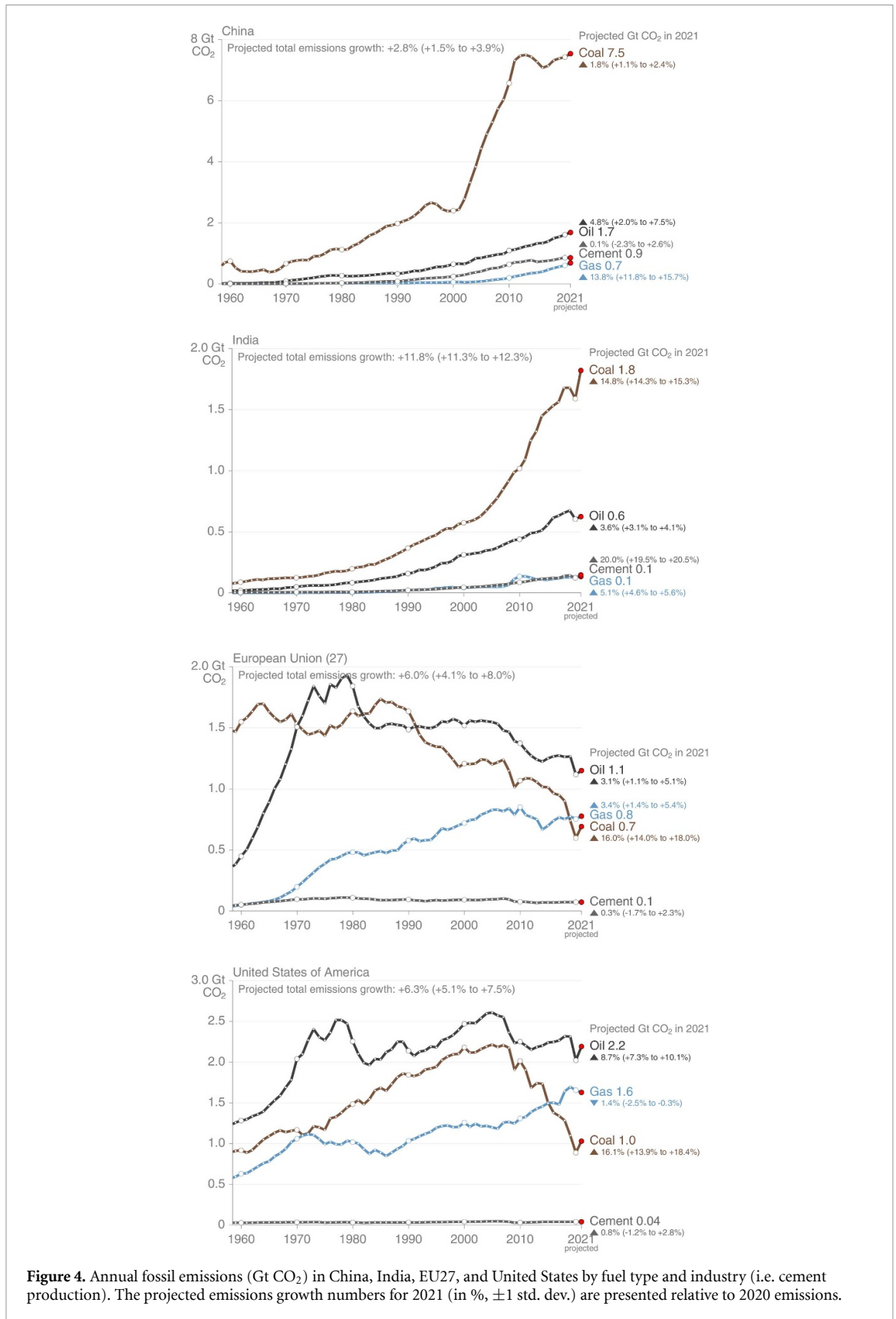


nearly reaching 2019 emission levels of 36.7 Gt CO<sub>2</sub> (figure 1) (Friedlingstein *et al* 2022). CO<sub>2</sub> emissions in 2021 are expected to have risen compared to 2020 in every country and region. Our 2021 fossil CO<sub>2</sub> emissions projections are based on energy data for coal, oil and gas for the first 9 to 12 months of the year for China, USA, EU27 + UK, and India, and a gross domestic product (GDP)-based projection for the Rest of the World. Full details are provided in Friedlingstein *et al* (2022).

Fossil emissions for China in 2021 are estimated to have been 10.9 Gt CO<sub>2</sub>, an increase of 2.8% (range 1.5%–3.9%) compared with 2020 emissions and 4% higher than in 2019 (figure 1). The largest increases across sectors and countries in 2021 compared with 2019 are found in China's power and industrial sectors (440 and 267 Mt CO<sub>2</sub>, respectively; figure 3). For India, estimated fossil CO<sub>2</sub> emissions in 2021 are 2.7 Gt CO<sub>2</sub>, a substantial rebound of 11.8%

(11.3%–12.3%) compared with 2020, and also ~4% above its 2019 emissions (figure 1). In contrast, fossil CO<sub>2</sub> emissions for the United States and European Union in 2021 remain below 2019 levels, despite substantial increases relative to 2020 of 6.3% (5.1%–7.5%) and 6.0% (4.1%–8.0%), respectively (figure 1). Our 2021 estimates reflect long-term background trends of increasing CO<sub>2</sub> emissions for India and decreasing CO<sub>2</sub> emissions for the United States and European Union. For China, in contrast, COVID-19 recovery may have sparked growth in CO<sub>2</sub> emissions, whereas for the Rest of the World (in aggregate), it may act to dampen the recent growth in emissions (figure 1).

For fuels in 2021, global CO<sub>2</sub> emissions from coal rebounded above 2019 levels to 14.6 Gt CO<sub>2</sub> (figure 1), primarily because of increased coal use in India and China (figure 4) and will remain only slightly (2.8%) below the global peak in 2014

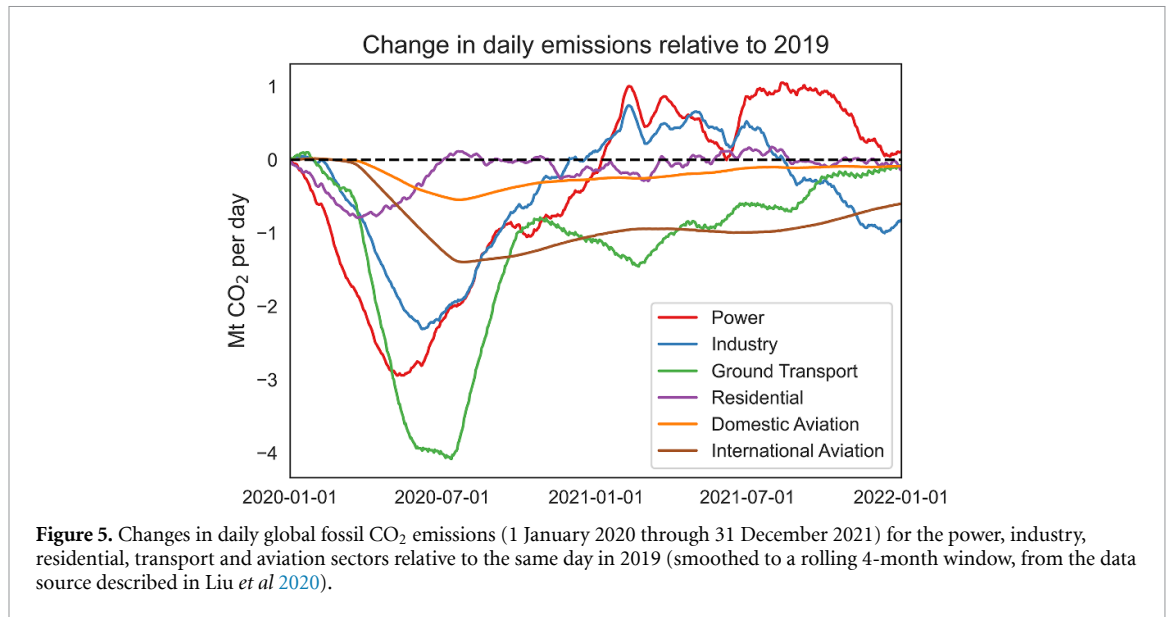


**Figure 4.** Annual fossil emissions (Gt CO<sub>2</sub>) in China, India, EU27, and United States by fuel type and industry (i.e. cement production). The projected emissions growth numbers for 2021 (in %, ±1 std. dev.) are presented relative to 2020 emissions.

(figure 1). Coal-based emissions in the EU and US rose about 1% in 2021 compared to 2020 but remained well below 2019 levels (figure 4). Global CO<sub>2</sub> emissions from natural gas use in 2021 (7.6 Gt CO<sub>2</sub>) rebounded above 2019 levels (figure 1). Only

CO<sub>2</sub> emissions from oil remained well below 2019 levels in 2021 at an estimated 11.5 Gt CO<sub>2</sub> (figures 1 and 2).

The distribution of the 2021 rebound in fossil CO<sub>2</sub> emissions was heterogenous across countries



and sectors (figures 3 and 4). Beyond the increases in China's power and industrial sectors in 2021 discussed above, other sectors that also surpassed 2019 levels included power in India and Brazil (77 and 45 Mt CO<sub>2</sub> higher, respectively), residential emissions in the European Union (36 Mt CO<sub>2</sub> higher), and all sectors in Russia other than ground transport and international aviation (41 Mt CO<sub>2</sub> higher in total) (figure 3). These increases are balanced by sustained reductions in many other sectors, primarily international aviation emissions, which are still well below 2019 levels in all major countries and regions (figure 3). The rebound was also heterogeneous across time, with a sharp reduction in growth in China during the second half of 2021.

#### 4. The clean energy transition

Rapidly increased market penetration of renewables that displace fossil fuels is critical for limiting climate change in the 1.5 °C–2 °C range (figure 2). Although most 1.5 °C mitigation scenarios (e.g. van Vuuren *et al* 2018) require the substitution to no- or low-carbon sources for almost all energy infrastructure by 2050, this transition is not currently occurring quickly enough to limit warming to 1.5 °C (IPCC 2018). Global gas use is rising particularly quickly. Despite the temporary effects of COVID-19 to suppress energy demand and supply, gas use and its associated CO<sub>2</sub> emissions rose almost 2% a year on average for the 5 years period of 2016–2021 (figures 1 and 2). If past trends continue, fossil CO<sub>2</sub> emissions associated with gas use over the next few years are likely to surpass 8 Gt CO<sub>2</sub> yr<sup>-1</sup>. The continuing rise in natural gas use is also problematic for climate because methane leakage associated with greater extraction and use rises, too (e.g. Hmiel *et al* 2020, IEA 2021b), emissions that are unaccounted for when examining only fossil

CO<sub>2</sub>. Just as for coal and oil (figures 1 and 2), carbon emissions from global gas use must drop quickly if global temperatures are to stabilize below increased thresholds of 1.5 °C or 2 °C (Davis *et al* 2019).

Climate change was revealed in many ways in 2021. The average global surface temperature in 2021 was about 1.11 (± 0.13) °C above average pre-industrial (1850–1900) levels (WMO 2022). Human-induced climate change is already increasing the frequency and intensity of weather and climate extremes in virtually every region of the globe (IPCC 2021); the United States, for instance, experienced 20 billion-dollar weather disasters in 2021, costing an estimated \$145 billion in damages and ~688 lives (NOAA 2022). Five years after the Paris Agreement, the emissions gap continues to grow: global emissions need to be 15 billion tons CO<sub>2</sub>e lower (for all greenhouse gases, not just CO<sub>2</sub>) than current nationally determined contributions for a 2 °C goal, and 32 billion tons CO<sub>2</sub>e lower for the 1.5 °C goal (WMO 2022). Progress in reducing emissions is occurring, albeit slowly (Le Quéré *et al* 2019, Eskander and Fankhauser 2020, 2021). Fossil CO<sub>2</sub> emissions significantly decreased in 23 countries during the decade 2010 through 2019; for the 5 years period of 2015 through 2019, fossil CO<sub>2</sub> emissions decreased in 64 countries globally (Friedlingstein *et al* 2022).

The rapid rebound in global fossil CO<sub>2</sub> emissions in 2021 (returning close to 2019 levels) we estimated to be 4.2% (similar to the 4.8% increase estimated by IEA (2021a)) was driven primarily by emissions in the power and industry sectors (figures 3 and 5). Fossil-based investments in economic stimulus packages in post-COVID recovery plans around the world appear to have overwhelmed substantial investments in green infrastructure (Hepburn *et al* 2020), resulting in a 'fossil-based recovery' that may cause the 'unaffordable delay to climate action' described by Rochedo



*et al* (2021). Indeed, the jump in fossil carbon emissions in 2021 and the data available on global stimulus packages suggest that the world is tracking the ‘fossil-fueled recovery’ scenario outlined in Forster *et al* (2020). The full effect of responses to the COVID-19 pandemic on CO<sub>2</sub> emissions remains uncertain, but a further rise in emissions in 2022 cannot be ruled out—given that surface transport and aviation sectors have yet to fully recover (figures 3 and 5). Green investments could still work to alter underlying emissions trends, as many will take years before showing their full effects (Andrijevic *et al* 2020, Kikstra *et al* 2021). These trends reinforce the need for strong and globally concerted actions to slow fossil-based investments (that continue to push CO<sub>2</sub> emissions up) and to set global emissions on a trajectory consistent with the temperature limits set in the Paris Agreement.

### Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: (<https://doi.org/10.18160/gcp-2021>).

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### ORCID iDs

R B Jackson  <https://orcid.org/0000-0001-8846-7147>  
 P Friedlingstein  <https://orcid.org/0000-0003-3309-4739>  
 C Le Quéré  <https://orcid.org/0000-0003-2319-0452>  
 S Abernethy  <https://orcid.org/0000-0002-3565-7243>  
 R M Andrew  <https://orcid.org/0000-0001-8590-6431>  
 J G Canadell  <https://orcid.org/0000-0002-8788-3218>

P Ciaia  <https://orcid.org/0000-0001-8560-4943>  
 S J Davis  <https://orcid.org/0000-0002-9338-0844>  
 Zhu Liu  <https://orcid.org/0000-0002-8968-7050>  
 J I Korsbakken  <https://orcid.org/0000-0002-2939-9778>  
 G P Peters  <https://orcid.org/0000-0001-7889-8568>

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