Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement

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Abstract

Government policies during the COVID-19 pandemic have drastically altered patterns of energy demand around the world. Many international borders were closed and populations were confined to their homes, reducing transport and consumption patterns. Here we compile government policies and activity data to estimate the decrease in CO_2 emissions during forced confinement. Daily global CO_2 emissions decreased by –17% (–11% to –25%) by early April 2020 compared to mean 2019 levels, primarily from changes in surface transport. At their peak, emissions in individual countries decreased by –27% on average. The impact on 2020 annual emissions depends on the duration of the confinement, with a low estimate of –4% (–2% to –7%) if pre-pandemic conditions return by mid-June, and a high estimate of –8% (–3% to –14%) if some restrictions remain worldwide until end of 2020. Government actions and economic incentives post-crisis will likely influence the global CO_2 emissions path for decades.

Introduction

Before the COVID-19 pandemic of 2020, emissions of carbon dioxide had been rising by about one percent per year over the previous decade[1-3], with no growth in 2019[4] (also updated from Peters et al. 2020[3]; see Methods). Renewable energy production was expanding rapidly amid plummeting prices[5], but much of the renewable energy was being deployed alongside fossil energy and did not replace it[6], while emissions from surface transport continued to rise[3,7].

The emergence of COVID-19 was first identified on 30 December 2019[8] and declared a global pandemic by the World Health Organization on 11 March 2020. Cases rapidly spread initially mainly in China during January, but quickly expanding to South Korea, Japan, Europe (mainly Italy, France and Spain) and the US between late January and mid-February, before reaching global proportions by the time the pandemic was declared[9]. Increasingly stringent measures were put in place by world governments in an effort, initially, to isolate cases and stop the transmission of the virus, and later to slow down its rate of spread. Measures imposed ramped up from the isolation of symptomatic individuals, to the ban of mass gatherings, mandatory closure of schools, and even mandatory home confinement (Table 1). Population confinement is leading to drastic changes in energy use, with expected impacts on CO_2 emissions.

Despite the critical importance of CO_2 emissions for understanding global climate change, systems are not in place to monitor global emissions in real time. CO_2 emissions are reported as annual values[1], often released months or even years after the end of the calendar year. Despite this, some proxy data is available in near real time or at monthly intervals. High-frequency electricity data is available for some regions (e.g., Europe[10] and US[11]), but rarely the associated CO_2 emissions data. Fossil fuel use is estimated for some countries at the monthly level, with data usually released a few months later[1,12]. Observations of CO_2 concentration in the atmosphere are available near-real time[13,14], but the influence of the natural variability of the carbon cycle and meteorology is large and masks the variability in anthropogenic signal over short period[15,16]. Satellite measurements of column CO_2 inventory[17] have large uncertainties and also reflect the variability of the natural CO_2 fluxes[18], and thus cannot yet be used in near-real time to determine anthropogenic emissions.

Given the lack of real time CO_2 emissions data, we take an alternative approach to estimate country level emissions based on a confinement index representing the effect of different policies. The change in CO_2 emissions associated with the confinement is informative in multiple ways. First, the changes in emissions are entirely due to a forced reduction in energy demand. Although in this case the demand disruption was neither intentional nor welcome, the effect provides a quantitative indication of the potential and limits that extreme measures could deliver with the current energy mix (for example, a higher rate of home working or reducing consumption). Second, during previous economic crises, the decrease in emissions was short-lived with a post-crisis rebound that restored emissions to their original trajectory, except when these crises were driven by energy factors such as the oil crises of the 1970s and 1980s, which led to significant shifts in energy efficiency and development of alternative energy sources[19] (Fig. 1). For example, the 2008-2009 Global Financial Crisis saw global CO_2 emissions decline –1.4% in 2009, immediately followed by a growth in emissions of +5.1% in 2010[20], well above the long-term average. Emissions soon returned to their previous path almost as if the crisis had not occurred.

The economic crisis associated with COVID-19 is markedly different from previous economic crises in that it is more deeply anchored in constrained individual behaviour. At present it is unclear how long and deep the crisis will be, and how the recovery path will look, and therefore, how CO_2 emissions will be affected. Keeping track of evolving CO_2 emissions can help inform government responses to the COVID-19 pandemic to avoid locking future emissions trajectories in carbon-intensive pathways.

Method and results

In this analysis, we use a combination of energy, activity, and policy data available up to the end of April 2020 to estimate the changes in daily emissions during the confinement from the COVID-19 pandemic, and its implications for the growth in CO_2 emissions in 2020. We compare this change in emissions to mean daily emissions for the latest available year (2019 for the globe) to provide a quantitative measure of relative change compared to pre-COVID conditions.

Changes in CO_2 emissions are estimated for three levels confinement and for six sectors of the economy, as the product of the CO_2 emissions by sector before confinement and the fractional decrease in those emissions due to the severity of the confinement and its impact on each sector (Eq.1, see Method). The analysis is done over 69 countries, 50 US states and 30 Chinese provinces representing 85% of the world population and 97% of global CO_2 emissions.

The confinement index is defined on a scale of 0 to 3 that allocates the degree to which normal daily activities were constrained for part or all of the population (Table 1). A scale of 0 indicates no measures are in place, 1: policies are targeted at small groups of individuals suspected of carrying infection, 2: policies are targeted at entire cities or regions or that affect about 50% of society, and 3: national policies significantly restrict the daily routine of all but key workers, affecting approximately 80% of society (see Extended Methods in Supplementary Information). During the early confinement phase around Chinese New Year in China (starting January 25), around 30% of global emissions were in areas under some confinement (Fig. 1). This increased to 70% by the end of February, and over 85% by mid-March when confinement in Europe, India and the US started, while China later relaxed confinement (Fig. 1). At its peak in early April, 89% of global emissions were in areas under some confinement.

The six economic sectors covered in this analysis are: (1) power (44.3% of global fossil CO_2 emissions), (2) surface transport (20.6%), (3) industry (22.4%), (4) public buildings and commerce (here shortened to “public”; 4.2%), (5) residential (5.6%), and (6) aviation (2.8%; see Methods). We collected time-series data (mainly daily) representative of activities emitting CO_2 in each sector, to inform the changes in each sector as a function of the confinement level (Fig. 2). The data represents changes in activity, such as electricity demand or road and air traffic, rather than direct changes in CO_2 emissions. We make a number of assumptions to cover the six sectors based on the available data and the nature of the confinement (Table 2; see Methods; Supplementary Tables S1-S10). Changes in the surface transport and aviation sectors were best constrained by indicators of traffic from a range of countries, including both urban and nation-wide data. Changes in power-sector emissions were inferred from electricity data from Europe, US, and India. Changes in industry were inferred mainly from industrial activity in China and steel production in the US. Changes in the residential sector were inferred from UK smart meter data, while changes in the public sector was based on assumptions about the nature of the confinement. All activity changes are relative to typical activity level prior to the COVID-19 pandemic (see Extended Methods in the Supplementary Information).

Activity data shows the changes in daily activities were largest in the aviation sector, with a decrease in daily activity of –75% (–60% to –90%) during confinement level 3 (Table 2). Surface transport saw its activity reduce by –50% (–40% to –65%), while industry and public sectors saw their activity reduce by –35% (–25% to –45%) and –33% (–15% to –50%), respectively. Still during confinement level 3, power saw its activity decrease by a modest –15% (–5% to –25%), while the residential sector saw its activity increase by +5% (0% to +10%). Activity data also shows substantial decreases in activity during confinement levels 2, and only small decreases during confinement level 1 (Table 2).

Daily changes in CO_2 emissions

The effect of the confinement was to decrease daily global CO_2 emissions by –17 (–11 to –25) $MtCO_2\ d^{-1}$, or –17% (–11% to –25%) by 7 April 2020 (Table 2), relative to the mean level of emissions in 2019. The change in emissions on 7 April was the largest estimated daily change during 1 January to 30 April 2020. Daily emissions in early April are comparable to their levels of 2006 (Fig. 3). The values in $MtCO_2$ d^{-1} are close to the value in percent coincidentally, because we currently emit about 100 $MtCO_2$ d^{-1}. For individual countries, the maximum daily decrease averaged to –27% (±9% for ±1σ), although the maximum daily decrease did not occur during the same day across countries, hence the decrease is more pronounced than the global maximum daily decrease. Estimated changes quantify the effect of confinement only, and is relative to underlying trends prior to the COVID-19 pandemic. The daily decrease in CO_2 emissions during the pandemic is as large as the seasonal amplitude in emissions estimated from data published elsewhere[21,22] (–17 $MtCO_2$ d^{-1}), which results primarily from the higher energy use in winter than summer in the Northern Hemisphere. The range in estimate reflects the range of parameter values (Table 2) based on the spread in underlying data (Fig. 2).

Global emissions from surface transport fell by –36% or –7.5 (–5.9 to –9.6) $MtCO_2$ d^{-1} by 7 April 2020 and made the largest contribution to the total emissions change (–43%; Fig. 4; Table 2). Emissions fell by –7.4% or –3.3 (–1.0 to –6.8) $MtCO_2$ d^{-1} in the power sector, and by –19% or –4.3 (–2.3 to –6.5) in the industry sector. Emissions from surface transport, power and industry were the most affected sectors in absolute values, accounting for 86% of the total reduction in global emissions. CO_2 emissions declined by –60% or –1.7 (–1.3 to –2.2) $MtCO_2$ d^{-1} in the aviation sector, yielding the largest relative anomaly of any sector, and by –21% or –0.9 (–0.3 to –1.4) $MtCO_2$ d^{-1} in the public sector. The large relative anomalies in the aviation sector correspond with the disproportionate effect of confinement on air travel (Table 2). A small growth in global emissions occurred in the residential sector, with +2.8% or +0.2 (–0.1 to +0.4) $MtCO_2$ d^{-1} and only marginally offsets the decrease in emissions in other sectors.

The total change in emissions until the end of April is estimated to amount to –1048 (–543 to –1638) $MtCO_2$ (Table S13). Of this, the changes are largest in China where the confinement started, with a decrease of –242 (–108 to –394) $MtCO_2$, then in the US, with –207 (–112 to –314) $MtCO_2$, then Europe, with –123 (–78 to –177) $MtCO_2$, and India, with –98 (–47 to –154) $MtCO_2$. These changes reflect both the fact that these are regions that emit high levels of CO_2 on average, and their severe confinement in the period through end of April. The integrated changes in emissions over China $MtCO_2$ are comparable in magnitude with the estimate –250 $MtCO_2$ of Myllyvirta (2020)[23] up to the end of March. The global changes in emissions is also consistent with global changes in NO_2 inventory from satellite data, although the concentration data is complex to interpret (see Supplementary Figures S1-S2).

Implications for global fossil CO_2 emissions in 2020

The change for the rest of the year will depend on the duration and extent of the confinement, the time it will take to resume normal activities, and the degree to which life will resume its pre-confinement course. At the time of press, most countries that were under confinement level 3 had announced dates when they anticipated some confinement would be lifted. Dates ranged between mid-April and mid-May. We use those dates where available, and for other countries we assume end of confinement corresponding to neighbouring regions or States (see Supplementary Tables S15-S16). It is possible that end of confinement is delayed in some countries and therefore these dates are likely the earliest possible dates. Nevertheless, the mounting social[24,25] and economic pressure[26], along with improving management of healthcare means systematic postponement is unlikely.

We assessed the effect of the recovery time by conducting three sensitivity tests. Our sensitivity tests are not intended to provide a full range of possibilities, but rather to indicate the approximate effect of the extent of the confinement on CO_2 emissions. Before COVID-19 we expected global emissions to be similar to those in 2019[2], so the effect of confinement on CO_2 emissions provided above might be approximately equivalent to the actual change from 2019 emissions. Our sensitivity tests do not attempt to quantify the effects of multiple confinement waves, or of deeper and sustained changes in the economy that could result from either the collapse of tens of thousands of small and medium businesses or government economic stimulus packages.

In the first sensitivity test, we assume that after the announced dates for initial deconfinement, activities will return to pre-crisis level within 6 weeks (around mid-June), as observed for coal use in industry in China[23]. In this case, the decrease in emissions from the COVID-19 crisis would be –1524 (–795 to –2403) $MtCO_2$, or –4.4% (–2.3% to –7.0%). In the second sensitivity test, we assume it takes 12 weeks to reach pre-confinement levels (around the second half of July), because of low productivity resulting from social trauma, and low confidence. This longer period is more aligned with announcements of gradual deconfinements, for example in France, UK and Norway, where a gradual deconfinement is planned over the coming months, and with time-scales for expected progression of the illness[27]. In this case, the decrease in emissions from the COVID-19 crisis would be –1923 (–965 to –3083) $MtCO_2$, or –5.6% (–2.8% to –9.0%).

In the third sensitivity test, we make the same assumption as the second test, but further assume that confinement level 1 remains in place in all countries examined until the end of the year. This is consistent with the situation in China in general, where although measures were lifted at the end of February in most provinces, there are still some restrictions on specific activities such as restricted international travel. It is also more aligned with latest understanding of the dynamics of transmission of the disease, suggesting prolonged or intermittend social distancing may be necessary into 2022[28]. In this case, the decrease in emissions from the COVID-19 crisis would be –2729 (–986 to –4717) $MtCO_2$, or –8.0% (–2.9% to –14%).

At the regional levels, the low sensitivity test led to mid-point decreases in emissions for year 2020 of –2.3%, –6.7%, –5.6% and –5.3% respectively for China, the US, Europe (EU27+UK) and India, while the high sensitivity test led to mid-point decreases of –5.1%, –11.3%, –9.3%, and –8.8% for those same countries (Table S14). For comparison for the US alone, the EIA (2020) provides a forecast of a decrease in emissions of –7.5% in 2020 [29], taking into account all projected economic factors, which is between our scenario tests 1 & 2.

In spite of the broader effects on the economy that are not included in our analysis, our 2020 estimates are similar to what can be inferred based on the projections of the International Monetary Fund (IMF) for 2020 of –3% reduction in global Gross Domestic Product[30] combined with an average CO_2/GDP improvement of –2.7% over the past decade[31], which gives a –5.7% reduction in CO_2 emissions in 2020. These independent global and US projections are similar to the middle sensitivity test 2 of confinement that we present in this publication (see Table S14), while the projection of the International Energy Agency of –8% decrease in CO_2 emissions in 2020 aligns with our high-end test 3[32]. The IMF and EIA further forecast that emissions will rebound +5.8% and +3.5% in 2021, respectively for the world and US economies.

Discussion

The estimated decrease in daily CO_2 emissions from the severe and forced confinement of world populations of –17% (–11% to –25%) at its peak are extreme and probably unseen before. Still, these correspond to the level of emissions in 2006 only. The associated annual decrease will be much lower (–4.4% to –8.0% according to our sensitivity tests), which is comparable to the rates of decrease needed year-on-year over the next decades to limit climate change to 1.5°C warming[33,34]. These numbers put in perspective both the large growth in global emissions observed over the past 14 years, and the size of the challenge we have to limit climate change in line with the Paris climate Agreement.

Furthermore, most changes observed in 2020 are likely to be temporary as they do not reflect structural changes in the economic, transport, or energy systems. The social trauma of confinement and associated changes could alter the future trajectory in unpredictable ways[35], but social responses alone, as shown here, would not drive the deep and sustained reductions needed to reach net zero emissions. Scenarios of low-energy/material demand explored for climate stabilisation explicitly aim to match reduced demand with higher wellbeing[35,36], an objective that is not met by mandatory confinements. Still opportunities exist to set structural changes in motion by implementing economic stimuli aligned with low carbon pathways.

Our study reveals how responsive the surface transportation sector's emissions can be to policy changes and economic shifts. Surface transport accounts for nearly half the decrease in emissions during confinement, while active travel (walking and cycling, including ebikes) has attributes of social distancing that are likely to be desirable for some time[28] and could help to cut back CO_2 emissions and air pollution as confinement is eased. For example, cities like Bogota, New York, and Berlin are rededicating street space for pedestrians and cyclists to enable safe individual mobility, with some changes likely to become permanent. Follow-up research could explore further the potential of near-term emissions reductions in the transport sector without impacting societal well-being.

Several drivers push towards a rebound with an even higher emission trajectory compared to policy-induced trajectories before the COVID-19 pandemic, including calls by some governments[37] and industry to delay Green New Deal programs and to weaken vehicle emission standards[38], and the disruption to clean energy deployment and research from supply issues. The extent to which world leaders consider the net zero emissions targets and the imperatives of climate change when planning their economic responses to COVID-19 is likely to influence the pathway of CO_2 emissions for decades to come.

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Methods.

Changes in emissions

Changes in emissions $\Delta CO_2^{c,s,d}$ in $MtCO_2$ d^{-1} for each country/state/province (*c*), sector (*s*), and day (*d*) are estimated using the following Equation:

$$\Delta CO_2^{c,s,d} = CO_2^c \times \delta S^c \times \Delta A^{s,d(CI,c)} \qquad (1)$$

Where CO_2^c in $MtCO_2$ d^{-1} is the mean daily emissions for the latest available year (2017 to 2019) updated from the Global Carbon Project for world countries (GCP; 2019)[1] (see Extended Methods in the Supplementary Information), EIA[39] for the US, and national statistics[40] for Chinese provinces. δS^c is the fraction of emissions in each sector using data from the IEA[41] for world countries, EIA[39] for the US, and national statistics[40] for Chinese provinces. $\Delta A^{s,d(CI)}$ is the fractional change in activity level for each sector compared with pre-COVID levels (Table 2), as a function of the confinement index *CI* for each day of the year and each country (see Supplementary Tables S15-S16). The combination of CO_2 emissions data from GCP and sector distribution from IEA enabled the use of country's own reported emissions to the UNFCCC, building on our previous work[42], and means more recent emissions could be used. Our analysis is done for 69 countries accounting for 97% of global emissions. We do not estimate changes in other countries.

Parameter choices

The choices of parameters by sector is based on data that represent changes in activity rather than directly changes in CO_2 emissions, and assumptions about the nature of the confinement. Most data are available daily up to 15 April 2020. All data (Fig. 2) are representative of changes compared to a typical day prior to confinement, taking into account seasonality and day of the week. The changes were calculated differently depending on the data availability and the causes of the seasonality and weekly variability. Sectors and parameter choices are described in detail in the Extended Methods section of the Supplementary Information with the key elements summarised here.

The power sector (44.3% of global CO_2 emissions) includes energy conversion for electricity and heat generation. The change in electricity and heat assumes this sector follows the change observed in electricity demand data for the US[43], selected European countries[10], and India[44].

The industry sector (22.4%) includes production of materials (e.g. steel), manufacturing, and cement. The change in industry is based on China coal consumption for six coal producers[23] and on steel production in the US[45].

The surface transport sector (20.6%) includes cars, light vehicles, buses and trucks, as well as national and international shipping. The change in transport is based on the Apple mobility data[46] for world countries, US [47] and UK [48] traffic data and urban congestion data from TOMTOM [49]. The changes in shipping are based on forecast by the World Trade Organization.

The public sector (4.2%) includes public buildings and commerce. The change in the public sector is based on surface transport for the upper limit, assuming it is proportional to the change in the workforce. It is based on electricity changes for the lower limit, with the central value interpolated between the two.

The residential sector (5.6%) represents mostly residential buildings. The changes in residential sector is based on reports of residential use monitored with UK smart meters[50].

The aviation sector (2.8%) includes both domestic and international aviation. It is based on the total number of departing flights by Aircrafts on Ground (OAG [51]).

Data availability

Global Carbon Project CO_2 emissions data are available at: https://www.icos-cp.eu/global-carbon-budget-2019
International Energy Agency IEA World Energy Balances 2019 @IEA are available at www.iea.org/statistics/
European Network of Transmission System Operators Electricity Transparency Platform (ENTSOE) are available at https://transparency.entsoe.eu/
Power System Operation Corporation Limited (POSOCO) data are available at https://posoco.in/reports/daily-reports/
Energy Information Administration (IEA) data are available at https://www.eia.gov/realtime_grid/
CO_2 emissions data for China are available at http://dx.doi.org/10.1038/s41597-020-0393-y/
Coal changes from China industry are available at https://www.carbonbrief.org/analysis-coronavirus-has-temporarily-reduced-chinas-co2-emissions-by-a-quarter/
American Iron and Steel Institute data are available at https://www.steel.org/industry-data/
TOMTOM Traffic Index are available at https://www.tomtom.com/en_gb/traffic-index/
MS2 Corporation traffic data are available at https://www.ms2soft.com/traffic-dashboard/
Apple Mobility Trends data are available at https://www.apple.com/covid19/mobility/,
UK traffic data from the Cabinet Office Briefing are available at https://www.gov.uk/government/collections/slides-and-datasets-to-accompany-coronavirus-press-conferences
Octopus Energy Tech smartmeter data are available at https://tech.octopus.energy/data-discourse/2020-social-distancing/index.html

Aircraft on Ground OAG data are available at https://www.oag.com/coronavirus-airline-schedules-data/

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Author contributions

C.L.Q., R.B.J., J.G.C., P.F., and G.P.P. conceived and designed the project. C.L.Q. and A.J.P.S. conceived the Confinement index and together with Y.S. they produced it. C.L.Q., R.B.J., M.W.J., S.A., R.M.A., A.J.D.-G., D.R.W., F.C. provided and analysed data. C.L.Q. produced the analysis. All authors contributed to the interpretation of the results and wrote the paper.

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Table 1. Definition of the Confinement Index (CI). The Confinement Index categorises the level of restrictions to normal activities that have the potential to influence CO_2 emissions. It is based on the policies adopted by national and sub-national governments.

Level	Description	Policy examples
0	No restrictions	
1	Policies targeted at long distance travel or groups of individuals where outbreak first nucleates	- Isolation of sick or symptomatic individuals - Self-quarantine of travellers arriving from affected countries - Screening passengers at transport hubs - Ban of mass gatherings >5000 - Closure of selected national borders & restricted international travel - Citizen repatriation
2	Regional policies that restrict entire city/region or ~50% of society from normal daily routines	- Closure of all national borders - Mandatory closure of schools, universities, public buildings, religious/cultural buildings, restaurants, bars, and other non-essential businesses, within a city or region - Ban public gathering >100 and social distancing >2m - Perhaps also accompanied by recommended closures at a broader or national level - Mandatory night curfew
3	National policies that significantly restrict the daily routine of all but key workers, ~80% of workforce.	- Mandatory national ‘lockdown’ requiring household confinement of all but key-workers - Ban public gathering >2 and social distancing >2m

Table 2. Change in activity as a function of the confinement level (percent). (Left) Parameters used in Eq. 1 for each sector (ΔA^s). (Right) Results for the globe, on the day with the maximum change (4th April 2020). The change is estimated relative to the mean level of emissions in 2019 (see Methods).

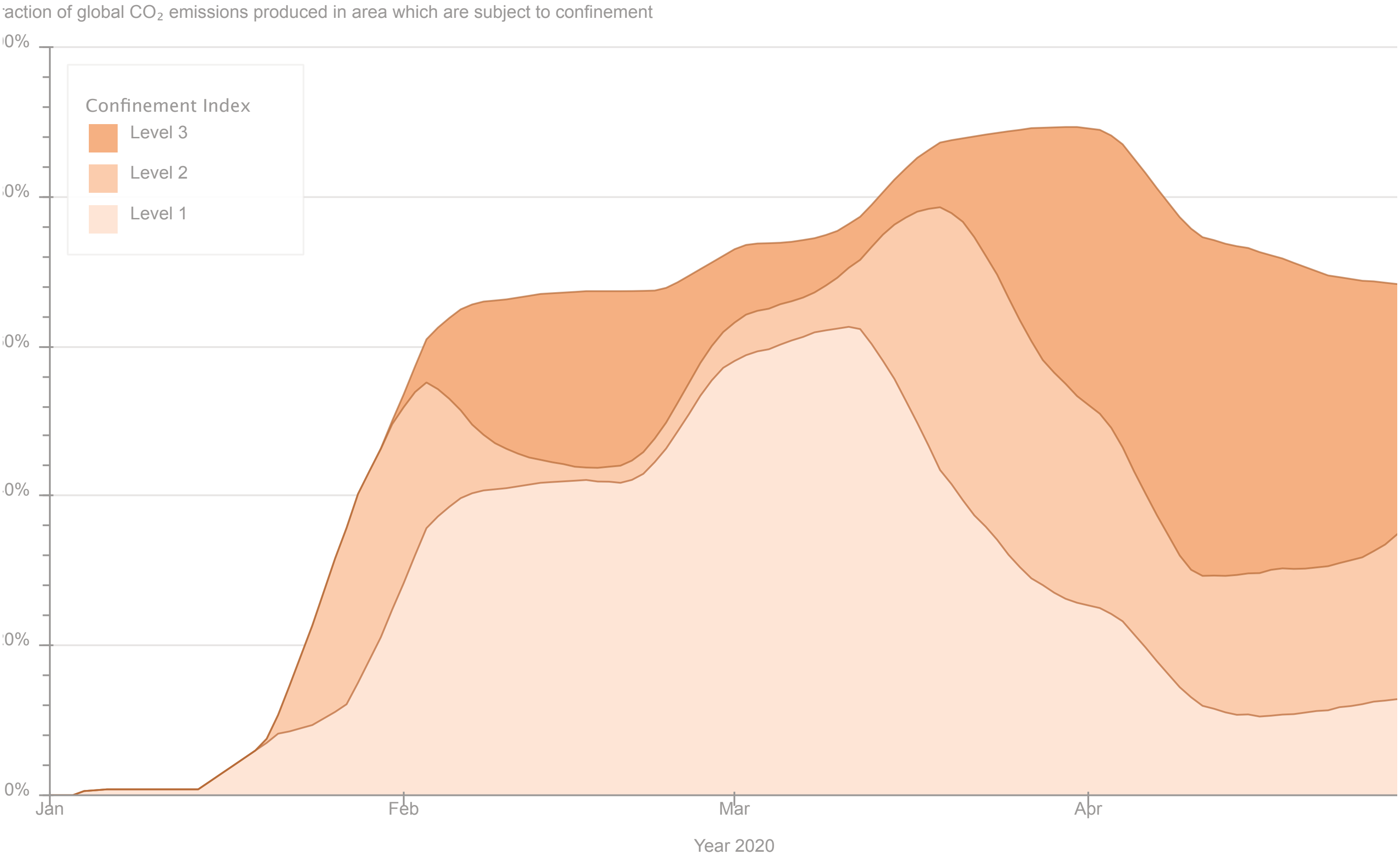
	Change in activity as a function of confinement level (Eq. 1)			Results
	Level 1	**Level 2**	**Level 3**	**daily change 7 April 2020**
Power	0% (0% to 0%)	–5% (0% to –15%)	–15% (–5% to –25%)	–7.4% (–2.2% to –14%)
Industry	–10% (0% to –20%)	–15% (0% to –35%)	–35% (–25% to –45%)	–19% (–10% to –29%)
Surface Transport	–10% (0% to –20%)	–40% (–35% to –45%)	–50% (–40% to –65%)	–36% (–28% to –46%)
Public	–5% (0% to –10%)	–22.5% (–5% to –40%)	–32.5% (–15% to –50%)	–21% (–8.1% to –33%)
Residential	0% (0% to 0%)	0% (–5% to +5%)	+5% (0% to +10%)	+2.8% (–1.0% to +6.7%)
Aviation	–20% (0% to –50%)	–75% (–55% to –95%)	–75% (–60% to –90%)	–60% (–44% to –76%)
Total				–17% (–11% to –25%)

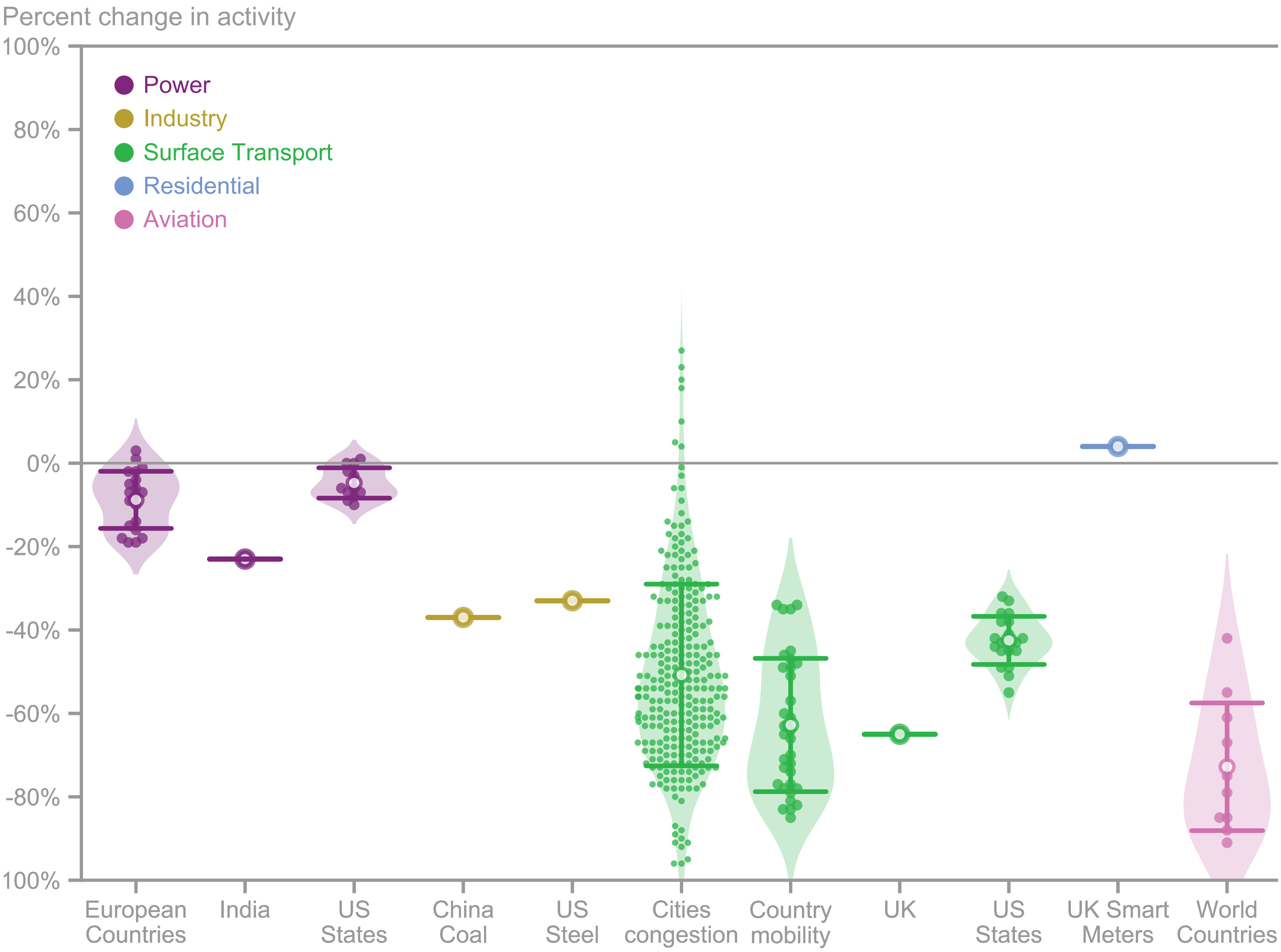
Figure 1. Fraction of global CO_2 emissions produced in areas which are subject to confinement (percent). CO_2 emissions from nations and states in each confinement level (see Table 1) are aggregated as a fraction of global CO_2 emissions. CO_2 emissions are from the Global Carbon Project[1] (see Methods).

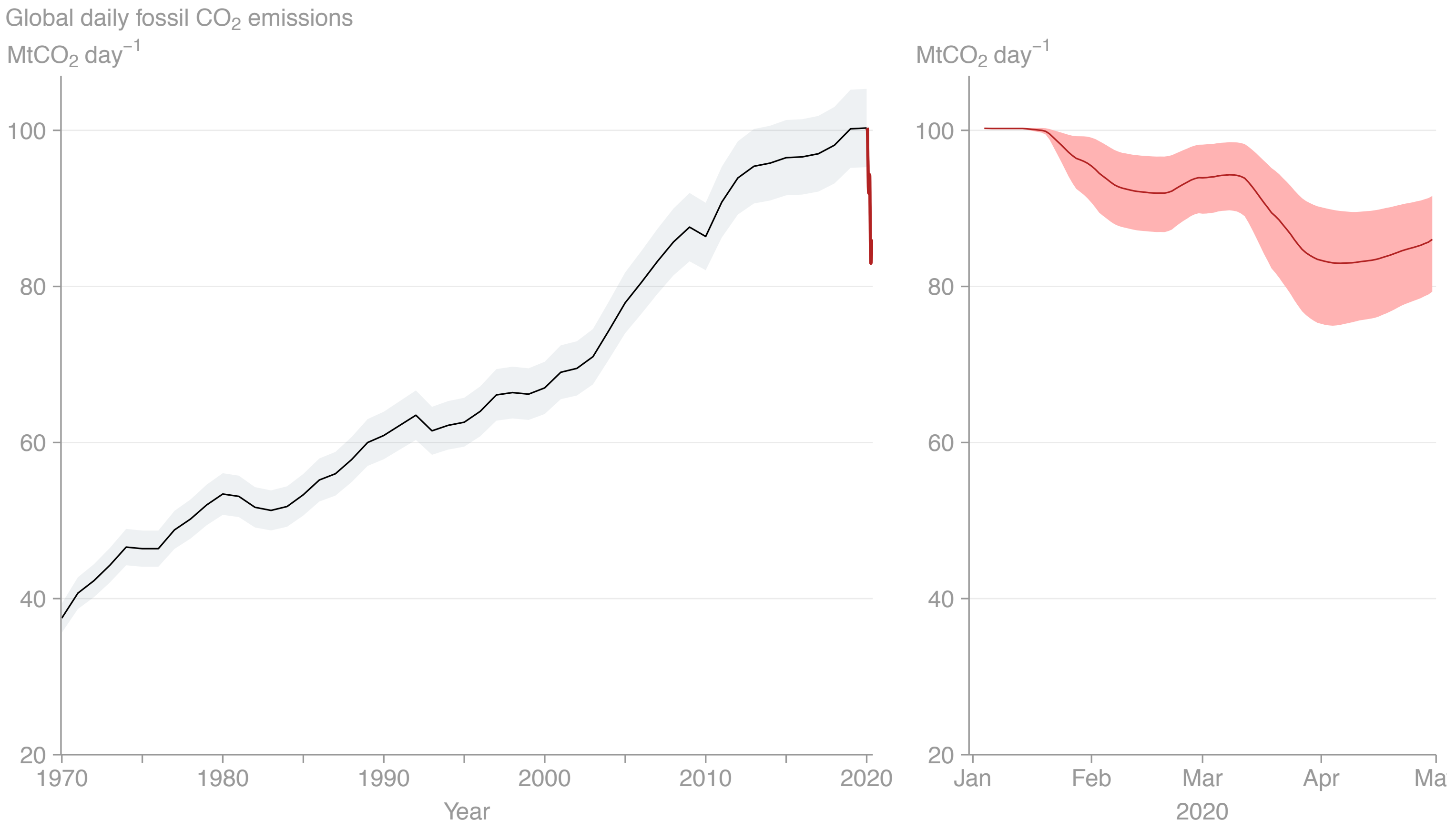
Figure 2. Change in activity by sector during Confinement level 3 (percent). The data includes: for the power sector, temperature-adjusted electricity trends in Europe[10], India[44], and the US[43]; for the industry sector, coal use in industry in China[23] and US steel production[45]; for the surface transport sector, cities congestion[49], country mobility[46], UK[48] and US state[47] traffic data; for the residential sector, UK smart meter data[50]; and for aviation, aircraft departures[51]. Each data point (filled circles) represents the analysis of a full time series, and shows the changes in activity compared to typical activity levels prior to COVID-19, correcting for seasonal and weekly biases. These changes along with the nature of the confinement are used to set the parameters in Eq. 1. (See Methods). The data is randomly spaced to highlight the volume of some data streams. Empty points represent mean value amongst the sample of data points, while the whiskers mark the standard deviation from the mean. The plotted violins represent the kernel density estimate of the probability density function for each sample of data points.

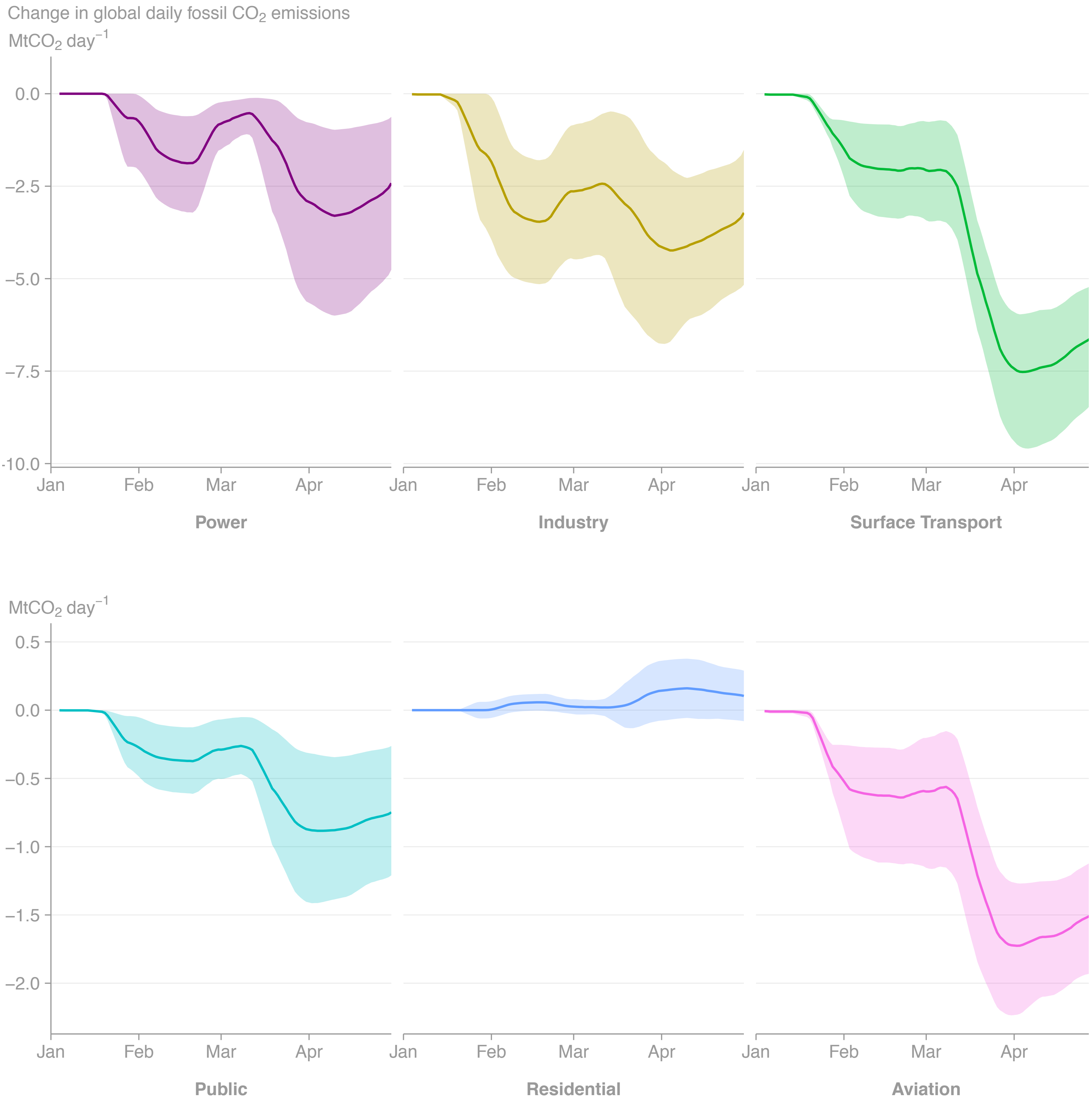
Figure 3. Global daily CO_2 emissions ($MtCO_2\ d^{-1}$). **(Left panel)** Annual mean daily emissions in the period 2000-2019 (black line), updated from the Global Carbon Project[1,3] (See Methods), with uncertainty of ±5% (±1σ; grey shading). Also on this panel are the daily emissions in 2020 estimated here (red line). **(Right panel)** Daily CO_2 emissions in 2020 (red line, same as left panel) based on the confinement index (CI) and corresponding change in activity for each CI level (Figure 2), and its uncertainty (red shading; Table 2). Daily emissions in 2020 are smoothed with a 7-day box filter to account for the transition between confinement levels.

Figure 4. Change in global daily fossil CO_2 emissions by sector ($MtCO_2\ d^{-1}$). The uncertainty ranges represent the full range of our estimates. Changes are relative to annual mean daily emissions from those sectors in 2019 (see Methods). Daily emissions are smoothed with a 7-day box filter to account for the transition between confinement levels. Note that the y-axes range differs for the upper and lower panels.


raction of global CO_2 emissions produced in area which are subject to confinement
0%
0%
0%
0%
0%
0%
Confinement Index
Level 3
Level 2
Level 1
Jan
Feb
Mar
Apr
Year 2020


Percent change in activity
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
100%
● Power
● Industry
● Surface Transport
● Residential
● Aviation
European Countries
India
US States
China Coal
US Steel
Cities congestion
Country mobility
UK
US States
UK Smart Meters
World Countries


Global daily fossil CO$_2$ emissions
MtCO$_2$ day^{-1}
100
80
60
40
20
1970
1980
1990
2000
2010
2020
Year
MtCO$_2$ day^{-1}
100
80
60
40
20
Jan
Feb
Mar
Apr
Ma
2020


Change in global daily fossil CO2 emissions
MtCO2 day−1
0.0
−2.5
−5.0
−7.5
-10.0
Jan
Feb
Mar
Apr
Power
Industry
Surface Transport
MtCO2 day−1
0.5
0.0
−0.5
−1.0
−1.5
−2.0
Public
Residential
Aviation

Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement

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Supplementary Information

Table of Contents

1. Extended methods

1.1. Updated 2019 global fossil CO_2 emissions

Extending the approach used by Friedlingstein et al 2019[1], we update estimates of global fossil CO_2 emissions growth in 2019 based on revised and newer data from China, US, EU, India, and updated estimates of economic growth from IMF[2]. This update produces an estimated growth rate of global CO_2 emissions in 2019 of +0.1% (–0.5% to +0.6%), compared to +0.6% (–0.2% to +1.5%) projected in November 2019[1,3]. Likewise the updated growth in 2019 emissions is: +2.0% for China, compared to +2.6% (+0.7% to +4.4%); –2.6% for the US, compared to – 1.7% (–3.7% to +0.3%); –3.9% (–5.4% to –2.4%) for EU28, compared to –1.7% (–3.4% to +0.1%); +1.0% (+0.7% to +1.3%) for India, compared to +1.8% (+0.7% to +3.7%); and +0.5 (–0.8% to +1.9%) for the rest of the world, compared to +0.5% (–0.8% to +1.8%). Revised estimates are for a decrease in coal in 2019 by –2.0%, and increases in oil and natural gas of 0.6% and 2.6%, respectively.

1.2. Confinement Index

To define the confinement index (CI) a detailed online search of government websites, news articles and Wikipedia was undertaken to identify the full range of policies that have been applied to tackle the COVID-19 outbreak. These policies were ordered by the timing in which they were typically applied to strengthen a nation's response, while policies with the potential to impact CO_2 emissions were highlighted. Three groups of policies were formed, based on the range of people impacted and the perceived restriction of daily activities, corresponding to a progressive reduction of CO_2 emissions.

A subsequent online search was undertaken for each country, in order of COVID-19 outbreak severity and CO_2 emissions, to identify dates that confinement policies were introduced. Up to 19th April, the date each country transitioned between CI levels was recorded, including as countries descend levels when policies are relaxed. Information from government websites was prioritised, while information from news articles and Wikipedia that was more readily accessible, was fact-checked wherever possible. Despite efforts to maintain a consistent approach, there remains some uncertainty where countries introduce multiple policies from one CI level over multiple days. In these situations, the date of the policy with the greatest impact on CO_2 emissions was selected or, if information was lacking, a median date was selected. The analysis was undertaken by one researcher to consistently allocate dates that countries move between CI levels.

For China and the USA analysis was conducted at State or Province level while other countries were analysed at national level. To further improve the quality of the analysis, the most populous cities in each country were analysed individually to capture local variation in the date policies were introduced. Analysis over China provinces were crossed-checked by two people. When the CI was needed over aggregated region (e.g. for the whole of China or USA), the index was weighted with the emissions of the regions, and the closest CI was used.

We have cross-checked our confinement index with that produced in parallel by Oxford University, called OxCGRT[4], which looks at 13 indicators of government response and is broader in its intended use (while we focus on those measures that have an impact on CO_2 emissions only). To compare our database to the Oxford study we applied a logic that matched policy interventions as closely as possible and cross-plotted those dates in order to detect bias in the data. For the four policies that are most similar to both studies, there is no bias and the mean difference between the studies is -0.65 ±5.36 days for CI3 and -0.17 ±5.47 days for CI2. Given the difficulty grouping policies into three confinement levels, some differences were expected. The outliers were therefore investigated manually, and our CI was updated when appropriate. Following these changes, comparing the remaining differences between the two datasets, the mean difference for CI3 reduced to 0.09 ±0.87 days, while for CI2 the difference reduced to 0.02 ±1.66 days.

1.3. Seasonal and weekly adjustment

All input data are representative of changes compared to a typical day prior to confinement, taking into account seasonality and day of the week. The changes were calculated differently depending on the data available and the causes of the seasonality and weekly variability. The choices of method are detailed for each data stream, and was primarily dictated by the availability of the data. Some data sources are provided in each section below, with details of the additional processing provided in this section.

The treatment for the data for European countries electricity demand (load) is as follows. The data was obtained from the European Network of Transmission System Operators for Electricity[5] (ENTSOE). Aggregate daily loads were calculated by taking daily mean power demands and outputs and multiplying by 24 hours to obtain MWhrs. In order to obtain an anomaly measure that removes a signal for the weekly cycle, the difference between the daily load is compared to the average of the previous 5-years for the closest day-of-the week to the date in question. ENTSOE electricity data was temperature adjusted to take into account variability caused by heating. We use Heating Degree Days (HDD) defined as the outside temperature below a threshold of 15.5°C multiplied by the time outside of the respective threshold [6] [7]. To obtain the most recent temperature measures, ERA5 [8] reanalysis data for air temperature at 2m was taken (0.25°x0.25°, hourly) up to 17 April 2020, and bias corrected with the measured Climatic Research Unit time-series version 4.03 (CRU-TSv4.03) [9] (0.5°x0.5°, hourly) for the period 2001-2018. A population-weighted HDD was calculated hourly at a 0.5° spatial resolution, and combined for a timezone-corrected daily average for each country.

The electricity data for India from POSOCO[10] was also compared to the previous 5-years for the closest day-of-the week to the date in question. The average was normalised to January values for year 2020 to remove the bias from growth in electricity use in recent years.

The U.S. daily electricity demand data were sourced from the Energy Information Administration[11] (EIA) and downloaded for 13 regions, covering the 48 contiguous states (i.e. excluding Alaska & Hawaii). The following states were used for each regions, organized by Independent System Operator (ISO) or other relevant body: Electric Reliability Council of Texas (ERCoT): *Texas Region*: Texas; Florida Reliability Coordinating Council: *Florida region*: Florida ; Midcontinent ISO: *Midwest region*: North Dakota, Minnesota, Wisconsin, Michigan, Iowa, Missouri, Illinois, Arkansas, Louisiana ; New England ISO: *New England region*: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island; New York ISO: *New York Region*: New York; PJM: *Mid Atlantic region*: Pennsylvania, New Jersey, Delaware, Maryland, Ohio, Kentucky, West Virginia, Virginia; SERC Reliability Corporation: *Carolinas region*: North Carolina, South Carolina; *Southeast region*: Georgia, Alabama; *Tennessee region*: Tennessee; Southwest Power Pool (SPP): *Central region*: North Dakota, South Dakota, Nebraska, Kansas, Oklahoma; Western Electricity Coordinating Council (WECC), including California ISO: *California region*: California: *Northwest Region*: Washington, Idaho, Montana, Oregon, Wyoming, Nevada, Utah, Colorado; *Southwest Region*: Arizona, New Mexico.

The data on coal consumption in China was taken from Myllyvirta (2020[12]). It averages coal consumption for the 6 main providers of electricity from the WIND platform (https://www.wind.com.cn/en/). Daily averages were obtained from 2014-2020 with anomaly data taken as the difference between the 5-year average for the day of the year relative to the Chinese New Year and the day in question, to minimise the effect of the event on the anomaly signal. The average was normalised to January values for year 2020 to remove the bias from growth in coal consumption in recent years.

1.4. Parameters values

The parameters for the change in activity level (ΔA^s in Eq. 1) were estimated based on a range of data for energy or activity use. Details of the calculations are given below for each sector, but the general approach is to compare 2020 data to a reference level prior to the COVID-19 pandemic. The reference level is either levels for 2019 or the average of 2015-2019 to obtain a percent change, or sometimes pre-pandemic days (e.g. January 2020) depending on the nature and availability of the data. Individual time series (for countries, state, province, region, or cities as described below) where then mapped to their corresponding confinement level for each day when available, or week. The percentage changes for each time-series analysed is then averaged, and that information along with the standard deviation across data was then used to estimate the parameter values for each level of confinement, where possible. These are the changes that are summarised in Figure 2 and Table 2 of the main manuscript. Where no data is available, information about the nature of the confinement was used.

The uncertainty is intended to represent approximately ±1σ around the most representative mean value for the sector. This range was estimated by combining multiple streams of data, examining the spread of the data within and among data streams, and assessing the representation of each activity data for worldwide sectoral activity. This assessment is detailed below for each sector.

1.4.1. Power sector

Power includes electricity, both residential and public/commercial, and heat production (44.3% of global CO_2 emissions). The change in power is based on three primary sources (Table S1).

Table S1. Data used to inform the parameters in the power sector. Each data point is the result of the analysis of a time series. See the text in this supplementary material for details.

Power

European electricity data from ENTSOE

country	Level 1	Level 2	Level 3
Austria		-9%	-9%
Belgium		-10%	-18%
Bulgaria	-1%	3%	
Cyprus			-18%
Czecia	4%	1%	-5%
Germany		-2%	-6%
Denmark		1%	1%
Estonia		-4%	-4%
Finland		-2%	
France	1%	-7%	-15%
Greece	-2%	-6%	-2%
Hungary		3%	-7%
Ireland	8%	6%	-1%
Italy	-3%	-5%	-19%
Latvia		-3%	
Lithuania		7%	-2%
Luxembourg		-1%	-19%
Netherlands		-25%	
Norway			3%
Poland	0%	-3%	-8%
Portugal		-1%	-10%
Roumania	-1%	-4%	-7%
Slovakia		-8%	
Slovania	1%	-7%	
Spain		-10%	-14%
Sweden	4%	-4%	
Ukraine		-11%	
United Kingdom	-6%	-7%	-16%
average	0%	-4%	-9%
standard deviation	4%	6%	7%
number of countries	11	26	20

USA regional electricity data from EIA

region	Level 1	Level 2	Level 3
California	10%		-2%
Carolinas	0%		-8%
Central	-5%	-3%	
Florida	2%	17%	1%
Mid-Atlantic	-5%	-7%	-7%
Midwest	-5%	2%	-7%
New England	-7%	-3%	-6%
Northwest	-2%	3%	0%
New York	-6%		-9%
Southeast	3%	0%	-10%
Southwest	0%	-1%	-3%
Tennessee	0%	-5%	-6%
Texas	3%	5%	0%
United States Lower 48	-2%	0%	-5%
average	-1%	1%	-5%
standard deviation	4%	6%	4%
number of regions	13	10	12

India electricity demand from POSOCO

	Level 1	Level 2	Level 3
average	3%	-16%	-23%
standard deviation	4%	2%	3%

Electricity data for European countries from ENTSO up to 17 April 2020 (see above): We used the daily electricity load. The electricity data was adjusted for the anomaly in cooling degree days (HDD), by fitting for each country the mean load versus the mean HDD for daily winter months (October to March) during 2015-2019. The HDD adjustment led to a steeper reduction in electricity of around 2% during confinement level 3. Data for 28 European countries were analysed. These data suggest a reduction in electricity use of -9% during confinement level 3, with a non-significant reduction of -4% during confinement level 2 and no reduction during confinement level 1.

Electricity data for US from the EIA[11] up to 15 April 2020. We analysed daily electricity demand data and calculated the anomaly for 2020 based on the difference from the same week in 2019. The electricity data were also adjusted for HDD[13]. Data for 13 regions were analysed as well as aggregated data at a national level (the contiguous 48 states). The data suggest a small decrease in electricity use of -5% for confinement level 3, consistently when computed from data for individual regions and for the US as a whole.

Electricity data for India from POSOCO[10] up to 19 April 2020. We use data on daily energy use. The electricity data in India was not adjusted for HDD because electricity and HDD anomalies did not show a significant relationship, possibly due to the relatively low use of active heating or cooling in the country. The data was reported nationally for India and suggests a decrease in electricity use of -16% and -23% for confinement levels 2 and 3.

The three data sources are approximate indicators of changes in power, which includes heat as well as electricity generation. The differences between the European countries and US data could be accounted for by the fact that the European countries have been in confinement level 3 for longer, and there is some inertia in the changes as activities wind down and countries adjust to the new confinement. The large changes in electricity in India could reflect the larger portion of electricity use in public and commercial sectors compared to the residential sectors. The difference in electricity generation also responds to user demand, with expected increased demand in the residential sector, and decreased demand in industry and commerce.

To reflect these complexities, we adopt parameter values that average the changes in these three regions, rounded off to the nearest 5 to reflect uncertainty in the data. Likewise, the minimum and maximum values are the minimum and maximum of these three regions, rounded off to the nearest 5. The parameters used are summarised in Table S2.

Table S2. Parameters for the power sector.

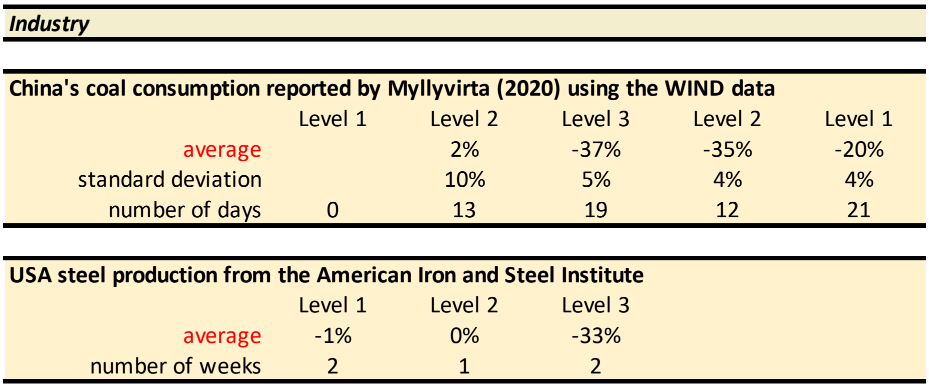
Power	Level 1	Level 2	Level 3
	0 (0 to 0)	-5 (0 to -15)	-15 (-5 to -25)

1.4.2. Industry sector

Industry (22.4% of global CO_2 emissions) includes production of materials (e.g. steel), manufacturing, and cement. The change in industry is based primarily on changes in China's coal consumption as reported by Myllyvirta (2020)[12] for six coal producers, based on commercial data from WIND (Table S3), using data up to 4 April 2020. Because China has been in and out of confinement, we were able to analyse the data for confinement level 2 before and after the confinement level 3. For the early phase of confinement level 2, there was no decrease in industry observed compared to previous years. However, the inference from the data is made more difficult from the fact that China was also celebrating New Years at that time, and industrial production is relatively low and the data across years is highly variable. Decreases in coal consumption was -37% in level 3, and -35% and -20% when confinement decreased to levels 2 and 1, respectively.

This data is consistent with weekly report from USA steel production of the American Iron and Steel Institute [14]. Although only five weeks of data are available, they also show no change in production at confinement levels 1 and 2, and a change of -33% when confinement level 3 was established the two weeks ending on 11 and 19 April. Note that the decrease in steel production was smaller the first April week (-19%), probably due to the fact that the response of steel production is more related to the time lag in demand rather than to employee availability. These industrial data are also consistent with reports by the French electricity provider of -27% decrease in electricity use by the manufacturing sector[15].

Table S3. Data used to inform the parameters in the industry sector. See the text in this supplementary material for details.



Industry

China's coal consumption reported by Myllyvirta (2020) using the WIND data					
	Level 1	Level 2	Level 3	Level 2	Level 1
average		2%	-37%	-35%	-20%
standard deviation		10%	5%	4%	4%
number of days	0	13	19	12	21

USA steel production from the American Iron and Steel Institute			
	Level 1	Level 2	Level 3
average	-1%	0%	-33%
number of weeks	2	1	2

We adopt parameter values that average from the China and US data sets for the confinement level 3, and use 2 standard deviation for the uncertainty, as limited data was available. For confinement level 1 and 2, we use the average of changes in China's coal consumption before and after the confinement level 3, with the high and low ranges also from the values before and after confinement level 3. The parameters are rounded off to the nearest 5 to reflect uncertainty in the data. The parameters used are as follows:

Table S4. Parameters for the industry sector.

Industry	Level 1	Level 2	Level 3
	-10 (0 to -20)	-15 (0 to -35)	-35 (-25 to -45)

1.4.3. Surface transport sector

Surface transport (20.6% of global emissions) includes cars, light vehicles, buses and trucks, as well as shipping. The change in surface transport is based on four primary sources (Table S5).

Table S5. Data used to inform the parameters in the surface transport sector. See the text in this supplementary material for details.

Surface transport

Mobility trends report from Apple

	Level 1	Level 2	Level 3	
Africa	10%	-42%	-77%	n=5
Europe	1%	-41%	-61%	n=30
Middle East and Asia	-2%	-39%	-61%	n=11
North America	-16%	-52%	-46%	n=3
Oceania	4%	-35%	-67%	n=2
South America	-20%	-67%	-72%	n=3
average	-2%	-43%	-63%	
standard deviation	18%	20%	16%	
number of countries	32	51	33	

Urban congestion index from TOMTOM

	Level 1	Level 2	Level 3	number of cities
Africa			-34%	n=6
China	-21%			n=21
Europe		-34%	-46%	n=132
Middle East and Asia	-9%	-43%	-94%	n=25
North America		-58%	-62%	n=91
Oceania			-27%	n=22
South America		-49%	-40%	n=18
average (all cities)	-18%	-46%	-50%	
standard deviation	23%	25%	23%	
number of data	26	113	272	

State traffic data for the USA from MS2

	State traffic		
state	Level 1	Level 2	Level 3
Washington	1%	-16%	-41%
Montana	-8%		-36%
Colorado	-17%		-45%
Arizona	-2%	-26%	-38%
New Mexico	-8%		-38%
Texas	-12%	-37%	-36%
Missouri	-20%	-42%	-45%
Louisiana	3%		-32%
Illinois	-9%		-42%
Indiana	-12%		-42%
Michigan	-13%		-55%
Ohio	-14%		-45%
Tennessee	-6%	-25%	-33%
Virginia	-26%		-44%
North Carolina	-18%		-43%
Florida	-10%	-33%	-43%
Vermont	-15%		-51%
Massachusetts	-15%	-49%	-49%
Connecticut	-14%		-49%
Rhode Island	-2%	-31%	-43%
average	-11%	-33%	-42%
standard deviation	7%	10%	6%
number of data	20	8	15

Total traffic data from the UK Cabinet office

	Traffic from all motor vehicles		
	Level 1	Level 2	Level 3
average	1%	-20%	-65%
standard deviation	3%	9%	6%
number of days	18	8	28

Mobility trends reported by Apple. This dataset shows a relative volume of requests for directions compared to a baseline volume on January 13 2020. We use daily data up to 17 April data for 58 countries. The mobility trends include all transports, including pedestrians and cycles. These data suggest a change in mobility of -63% during confinement level 3, -43% during confinement level 2, and no change during confinement level 1 (see Table S5).

Congestion index reported by TOMTOM[16]. The congestion index indicates the additional time needed to go from a to b, compared to uncongested conditions. The metrics reported by TOMTOM give the changes in congestion index for 7 days compared to the average congestion in 2019. Data for 413 cities were available, and were analysed for the week ending 4 April 2020. We excluded data from the city of Pamplona which was a clear outlier showing an increase in congestion of +80% for CI=3. These data suggest decreases in congestion by -50%, -46%, and -18% for confinement levels 3, 2, and 1, respectively (see Table S5).

Traffic data for US states from MS2 corporation[17]. The metrics reported by MS2 give the change in daily traffic volume compared to the same day of week in 2019. It is based on traffic sensors and smart traffic signals. Data for 20 states were available, and were analysed daily up to 15 April 2020. These data suggest decreases in traffic by -42, -33%, and -11% for for confinement levels 3, 2, and 1, respectively (see Table S5).

Total traffic from the UK Cabinet Office. This dataset includes the percentage change in the total volume of traffic from all motor vehicles on UK roads, daily for 27 February to 20 April. No seasonal adjustment is mentioned in the data source. The data suggests a decrease in traffic of -65%, -28% and -10% during confinement levels 3, 2, and 1, respectively (see Table S5).

All four metrics are indicators of CO_2 emissions, but they may be biased in different ways due to the nature of the metric, the regional differences, and the urban/rural differences. In the UK where we have three datasets, they are very close with the TOMTOM urban data, the Apple mobility trends, and the UK Cabinet office showing decreases in road transport of -60%, -66% and -65%, respectively. For the US where we also have three datasets, the differences are much larger. The MS2 state data has the smallest change of -42% for confinement level 3, with the TOMTOM urban congestion index for US city at -62%, and the Apple mobility data in between at 54%. Given the differences in the nature of the data, it is not possible to decide if there is one or more that are most representative of CO_2 emissions. We adopt parameter values for surface transport which average the findings based on the Apple mobility trends, the TOMTOM urban congestion, and the US MS2 state traffic data, and use the low and high database to set the low and high ends of the parameter uncertainty. The values are rounded off to the nearest 5 to reflect the uncertainty in the data. The parameters used are as follows:

Table S6. Parameters for the surface transport sector.

Surface transport	Level 1	Level 2	Level 3
	-10 (0 to -20)	-40 (-35 to -45)	-50 (-40 to -65)

International container shipping is dominated by China, featuring 7 of the 10 largest cargo ports worldwide. International shipping was held up in February with the China confinement, measured as delay, but not as reduced capacity, as ships were either mostly idling in quarantine/waiting for load (17% reduced vessel calls in week 7 2020 compared to week 7 2019). Hence, 15-20% present the immediate supply-driven effects Level 2 and 3 confinement on maritime transport. Demand-driven effects are likely to dominate the longer time scales. Lines are cutting down capacity to adjust for reduced demand and disrupted supply chains. Sea shipping is slow and many orders from a few months ago are now shipped, whereas the full impact of COVID-19 on shipping will be only visible by end of the year, also reflecting potentially reduced demand for products. Sea Intelligence estimates 10-38% reduction in volume traded in 2020. Here we adopt the projections of the World Trade Organization, at similar magnitude, of an expected fall of between 13% and 32% in 2020, and adopt a decrease of -20% (-10 to -30%) in shipping, regardless of the confinement level. The results for shipping are reported in the surface transport, although they are calculated separately.

1.4.4. Public sector

The public sector (4.2% of global CO_2 emissions) includes commercial and public buildings, including offices, schools, hospitals and government buildings. Aggregated data were not available that could represent this sector specifically. We therefore adopt parameter values based on the changes observed in other sectors, with our own assessment of the nature of the confinement. For the upper limit, we base the change in the public sector on changes in surface transport, assuming it is proportional to the change in the workforce. For the lower limit, we base the changes in the public sector on changes in electricity, assuming a range of buildings remain open and operational (e.g. hospitals, government buildings) in spite of the confinement. The central value is interpolated between the two.

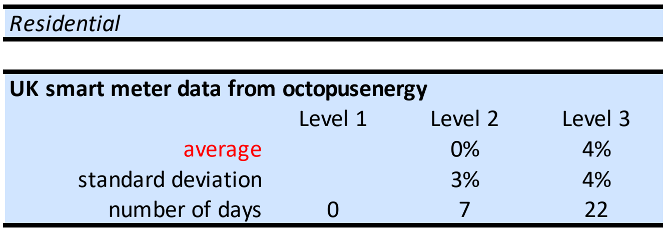
Table S7. Parameters for the public sector.

Public sector	Level 1	Level 2	Level 3
	-5 (0 to -10)	-23 (-5 to -40)	-33 (-15 to -50)

1.4.5. Residential sector

The residential sector (5.6% of global CO_2 emissions) represents mostly residential buildings.

Table S8. Data used to inform the parameters in the residential sector. See the text in this supplementary material for details.



Residential

UK smart meter data from octopusenergy

	Level 1	Level 2	Level 3
average		0%	4%
standard deviation		3%	4%
number of days	0	7	22

Here we use reports of residential electricity use monitored with UK smart meters from octopusenergy[18], representing 120,000 users across the UK. Data are available daily from 9 March to 13 April, and are provided already adjusted for temperature variations[18]. The data shows no significant changes in electricity use during confinement levels 1 and 2, and a small increase of 4% during confinement level 3. Although users who do not normally stay home have tended to use substantially more electricity than they would otherwise (around 20% according to OCTOPUS who provided the data), only a fraction of the users were in that position. Taken as a whole, the increase is much smaller. This is consistent with report of the French electricity provider of a small 'overconsumption'[15]. We therefore use the UK smart meter data to allocate the parameters for changes in the residential sector at confinement level 3. We assume zero changes at confinement level 1 and average between the two for confinement level 2.

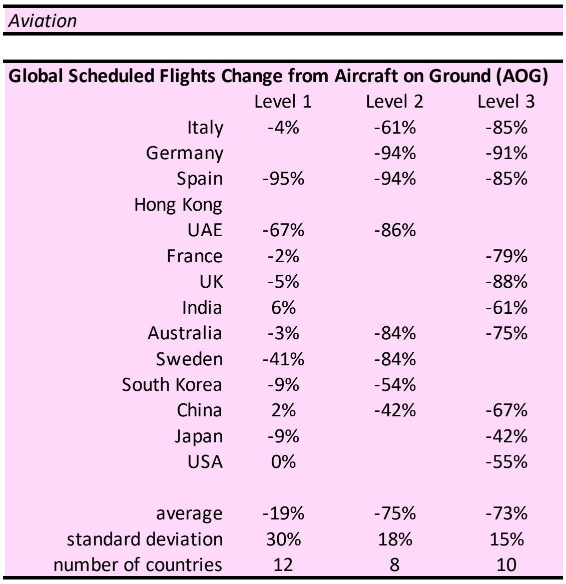
Table S9. Parameters for the residential sector.

Residential	Level 1	Level 2	Level 3
	0 (0 to 0)	0 (-5 to 5)	5 (0 to 10)

1.4.6. Aviation sector

Aviation (2.8% of global CO_2 emissions, with radiative forcing index of 2[19]) consists of both domestic and international flights. The change in aircraft emissions is estimated from weekly comparisons of the number of aircrafts departing from each country compared to the corresponding week in 2019, as reported by the OAG corporation[20]. We use data up to the week ending on 20 April 2020. For confinement levels 2 & 3, there was a big difference between the first week of confinement, where the changes were relatively small, and subsequent weeks. This was likely caused by inertia in the sector, and the repatriation of citizens as confinement started which kept airlines open. We therefore removed the first week of data during confinement levels 2 & 3 for each country to get a better representation of the changes in aviation. We also set the lower end of level 1 to zero because the variability of the data did not suggest systematic increase in aviation at that level that could be inferred from the standard deviation alone. The parameter values are taken to be the average across countries with ± one standard deviation as the range, again rounded to the nearest 5.

Table S10. Data used to inform the parameters in the aviation sector. See the text in this supplementary material for details.



Aviation

Global Scheduled Flights Change from Aircraft on Ground (AOG)

	Level 1	Level 2	Level 3
Italy	-4%	-61%	-85%
Germany		-94%	-91%
Spain	-95%	-94%	-85%
Hong Kong			
UAE	-67%	-86%	
France	-2%		-79%
UK	-5%		-88%
India	6%		-61%
Australia	-3%	-84%	-75%
Sweden	-41%	-84%	
South Korea	-9%	-54%	
China	2%	-42%	-67%
Japan	-9%		-42%
USA	0%		-55%
average	-19%	-75%	-73%
standard deviation	30%	18%	15%
number of countries	12	8	10

Table S11. Parameters for the aviation sector.

Aviation	Level 1	Level 2	Level 3
	-20 (0 to -50)	-75 (-55 to -95)	-75 (-60 to -90)

2. Additional tables of results

Table S12. Change in daily fossil CO_2 emission on 7 April 2020 compared to mean daily 2019 levels. The change in emissions on 7 April was the largest estimated daily change during 1 January to 30 April 2020. The right-hand column shows the contribution of each sector to the total absolute change in CO_2 emissions.

	Absolute change	**Change relative to mean 2019 sector level**	**Contribution to global CO_2 decrease**
	$MtCO_2$ per day	**percent**	**percent**
Total	-17 (-11 to -25)	-17% (-11% to -25%)	
Power	-3.3 (-1.0 to -6.0)	-7.4% (-2.2% to -14%)	19%
Industry	-4.3 (-2.3 to -6.5)	-19% (-10.1% to -29%)	25%
Surface Transport	-7.5 (-5.9 to -9.6)	-36% (-28% to -46%)	43%
Public	-0.9 (-0.3 to -1.4)	-21% (-8.1% to -33%)	5.1%
Residential	0.2 (-0.1 to 0.4)	2.8% (-1.0% to 6.7%)	-0.9%
Aviation	-1.7 (-1.3 to -2.2)	-60% (-44% to -76%)	9.7%

Table S13. Change in fossil CO_2 emission during 1 January to 30 April 2020 (4 months), with the percent change relative to annual 2019 emissions (12 months), for the Globe, US, China, India, EU27+UK.

	$MtCO_2$	**percent from 2019 level**
Global	-1048 (-543 to -1638)	-2.9% (-1.5% to -4.5%)
China	-242 (-108 to -394)	-2.6% (-1.2% to -4.3%)
US	-207 (-112 to -314)	-3.9% (-2.1% to -6.0%)
EU27+UK	-123 (-78 to -177)	-3.3% (-2.1% to -4.7%)
India	-98 (-47 to -154)	-3.6% (-1.7% to -5.6%)

Table S14. Change in fossil CO_2 emission during 1 January to 31 December 2020 compared to 2019 levels, for the Globe, US, China, India, EU27+UK. Changes are for the three sensitivity tests described in the text.

	$MtCO_2$	percent from 2019 level
Scenario 1		
Global	-1524 (-795 to -2403)	-4.2% (-2.2% to -6.6%)
China	-243 (-108 to -396)	-2.6% (-1.2% to -4.3%)
US	-355 (-209 to -529)	-6.7% (-4.0% to -10.0%)
EU27+UK	-189 (-114 to -280)	-5.1% (-3.0% to -7.5%)
India	-143 (-65 to -238)	-5.2% (-2.4% to -8.7%)
Scenario 2		
Global	-1923 (-965 to -3083)	-5.3% (-2.6% to -8.4%)
China	-288 (-108 to -488)	-3.1% (-1.2% to -5.3%)
US	-471 (-283 to -700)	-8.9% (-5.4% to -13.3%)
EU27+UK	-234 (-135 to -350)	-6.2% (-3.6% to -9.4%)
India	-185 (-81 to -317)	-6.8% (-3.0% to -11.6%)
Scenario 3		
Global	-2729 (-986 to -4717)	-7.5% (-2.7% to -12.9%)
China	-522 (-108 to -965)	-5.6% (-1.2% to -10.4%)
US	-604 (-283 to -973)	-11.5% (-5.4% to -18.5%)
EU27+UK	-316 (-140 to -517)	-8.5% (-3.8% to -13.8%)
India	-238 (-81 to -425)	-8.7% (-3.0% to -15.6%)

3. Comparison to Earth Observations

Insights from Earth observations of co-emitted species offer insights into the feasibility of the calculated changes to CO_2 emission. NO_2 is a useful indicator of rapid changes in fossil fuel combustion at regional and local scales[21-23] because around two-thirds of global surface NO_2 emissions derive from fossil fuel combustion [21] and its residence time is less than one day. We assessed changes in the NO_2 atmospheric column density using data from the NASA OMI/Aura NO2 Cloud-Screened Total and Tropospheric Column L3 Global Gridded 0.25 degree x 0.25 degree V3 (OMNO2d 003) [24]. We used NO_2 total column density from pixel level data passing a good quality filter and with cloud cover <30% (product variable name: ColumnAmountNO2CloudScreened). We averaged the daily total column NO_2 from OMNO2d 003 at the global scale and within large regions for the period 1st January 2005-2nd April 2020. Daily anomalies were calculated for 2020 relative to the 2015-2019 mean. The Aura satellite, on which the OMI sensor is deployed, has a sun-synchronous orbit and thus processes through one complete revolution each year. This enables daily retrievals of vertical atmospheric column NO_2 to be compared across years.

Daily anomalies in the global mean NO_2 atmospheric column density averaged –5% relative to the 2015-2019 mean since the first Chinese provinces implemented CI2 restrictions on 22nd January 2020, –6% since Italy implemented CI2 restrictions one month later, and –7% in the final week of March 2020 (Fig. 4). In the month prior to the first implementation of CI2 in China, daily anomalies in global mean NO_2 atmospheric column density were typical for the time of year, averaging –2.5%. Although these observations do not provide direct quantification of reductions in global or regional NO_2 emissions fluxes, they do nonetheless indicate a substantial deficit in NO_2 emission relative to NO_2 removal in the period of the COVID-19 outbreak versus previous years.

There was strong congruence between the observed anomalies in atmospheric column NO_2 and the estimated anomalies in CO_2 emission in the period January-March 2020, according to a significant zero-intercept (CO_2 anomaly = 0.989 × NO_2 anomaly; Adjusted $R^2 = 0.81$, $p < 1 \times 10^{-15}$; zero-intercept model fitted after verifying that the intercept was non-significant).

Figure S1: (Left panel) Global mean vertical column density of NO_2 (molecules cm^{-2}) for all years 2005-2019 (light blue lines) and for the period 1st January-15th April 2020 (red line), based on the NASA OMI/Aura NO2 Cloud-Screened Total and Tropospheric Column L3 Global Gridded 0.25 degree x 0.25 degree V3 (OMNO2d 003) [24]. The dark blue line marks the inter-annual average daily value for 2005-2019. **(Right panel)** Equivalent daily anomalies relative to the 2015-2019 mean.

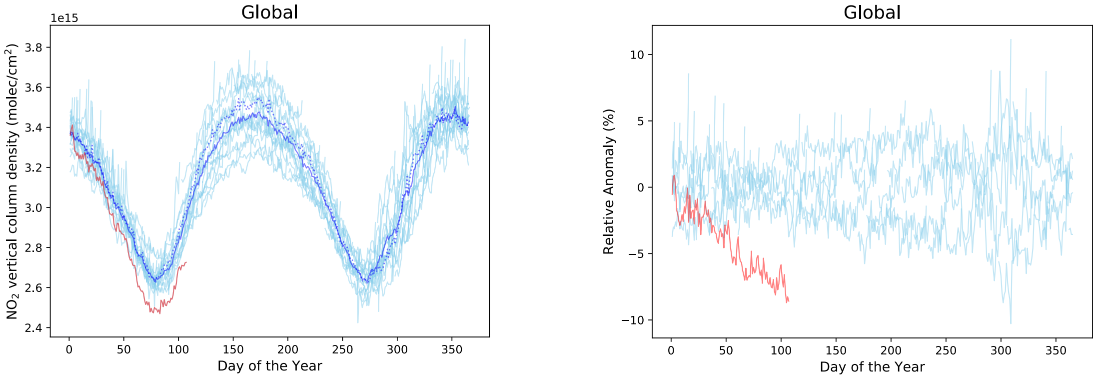
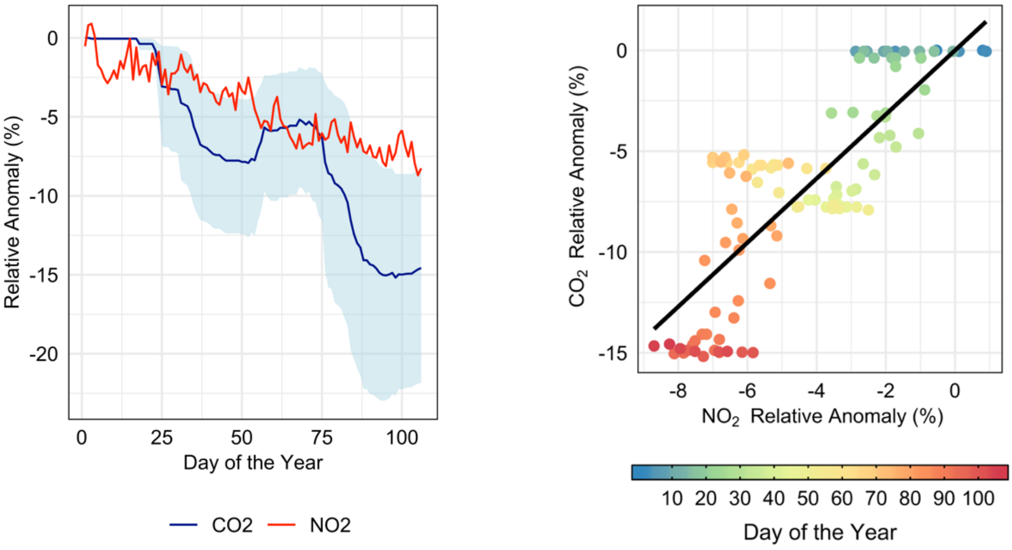
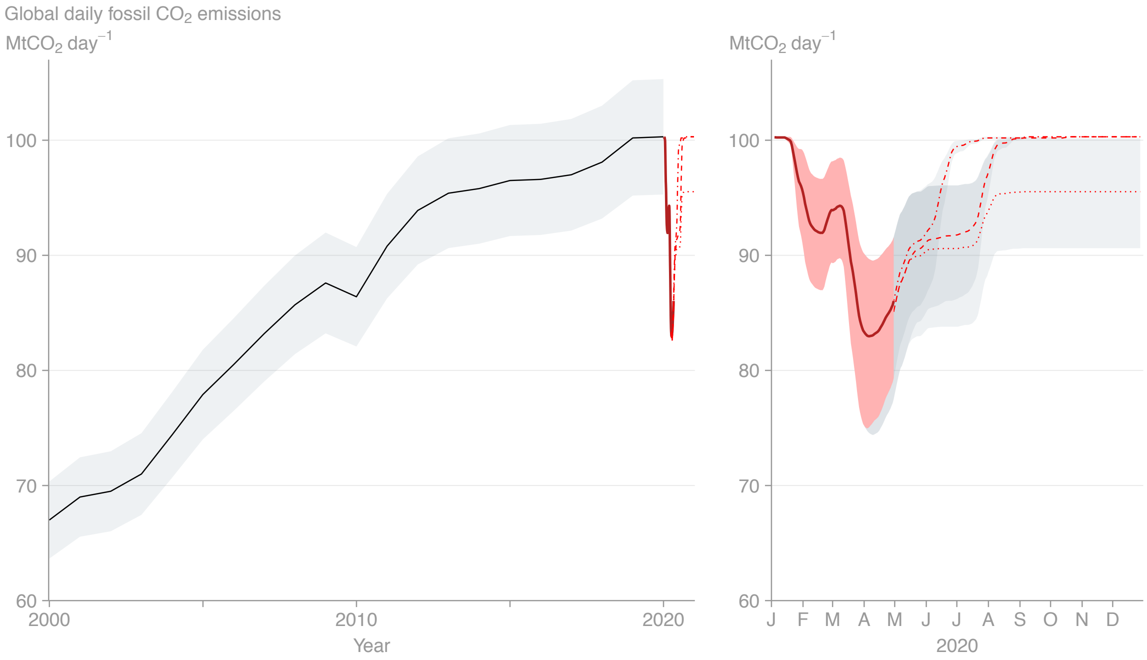


Figure S2: Comparison of the relative anomalies in regional mean vertical column density of NO_2 anomalies (see figure S1) and estimated anomalies in total CO_2 emission in the period 1st January-15th April 2020. The panels show (left panel) a times series of the anomalies to April 2nd 2020 and (right panel) a scatter plot of the daily anomalies for each variable. The black line in the right panel shows the simple linear regression equation fitted to the variables (CO_2 anomaly = 1.59 NO_2; Adjusted $R^2 = 0.88$, $p < 1 \times 10^{-15}$; zero-intercept model fitted after verifying that the intercept was non-significant).



4. Scenario Figures

Figure S3: Global daily fossil CO_2 emissions in $MtCO_2\ d^{-1}$. **(Left panel)** Annual mean daily emissions in the period 2000-2019 updated from the Global Carbon Project[1,3]. The grey uncertainty range represents ±5% (±1σ) uncertainty in global fossil CO_2 emissions. **(Right panel)** Change in daily CO_2 emissions in the year 2020 relative to annual mean daily emissions in the year 2019. The solid red line represents our estimates based on the confinement index (CI) and corresponding change in activity for each CI level (Figure 2). The red uncertainty range accounts for uncertainty in the changes in activity data (Table 2). The broken red lines represent projected changes in emissions in the three future scenarios described in the text: sensitivity test 3 (high end) (dotted); sensitivity test 2 (middle) (dashed line); sensitivity test 1 (low end) (dot-dashed line). Daily emissions in 2020 are smoothed with a 7-day box filter to account for the transition between confinement levels.



5. Country, provinces and state details

Table S15. Date when confinement index levels 1-3 were reached and relaxed by country, China provinces and US states (as of 19th April 2020). Future dates for policy relaxation are as announced as of 30th April 2020, sometimes informally and conditional to the evolving situation, while § symbol represents an assumed date for relaxation of policy as actual date not yet announced. Blank cells represent CI level skipped or policy end date not yet announced.

		Confinement Index Level						
	Country name	0	1	2	3	2	1	0
GLOBAL	Algeria	01-Jan		17-Mar	04-Apr	24-Apr		31-Dec
	Argentina	01-Jan		16-Mar	20-Mar	26-Apr	10-May	31-Dec
	Australia	01-Jan	01-Feb	22-Mar	26-Mar	27-Apr		31-Dec
	Austria	01-Jan		15-Mar	16-Mar	14-Apr	15-May	31-Dec
	Bangladesh	01-Jan	01-Feb	17-Mar	26-Mar	27-Apr		31-Dec
	Belgium	01-Jan		12-Mar	18-Mar	04-May	18-May	31-Dec
	Brazil	01-Jan	14-Mar	17-Mar			07-Apr	31-Dec
	Bulgaria	01-Jan	08-Mar	13-Mar			07-Apr	31-Dec
	Canada	01-Jan	16-Mar	24-Mar			04-May §	31-Dec
	Chile	01-Jan		22-Mar			23-Apr	31-Dec
	China	Analysed separately						
	Colombia	01-Jan	12-Mar	16-Mar	25-Mar	27-Apr	11-May	31-Dec
	Croatia	01-Jan	24-Feb	16-Mar	21-Mar	27-Apr	11-May	31-Dec
	Cyprus	01-Jan		13-Mar	24-Mar	30-Apr		31-Dec
	Czech Republic	01-Jan	03-Mar	10-Mar	16-Mar	20-Apr	08-Jun	31-Dec
	Denmark	01-Jan		11-Mar	16-Mar	15-Apr	10-May	31-Dec
	Egypt	01-Jan	14-Feb	19-Mar			23-Apr	31-Dec
	Estonia	01-Jan		16-Mar			15-May	31-Dec
	Finland	01-Jan		16-Mar		19-Apr	31-May	31-Dec
	France	01-Jan	29-Feb	12-Mar	17-Mar	11-May		31-Dec
	Germany	01-Jan		16-Mar	23-Mar	20-Apr	04-May	31-Dec
	Greece	01-Jan	09-Mar	13-Mar	23-Mar	10-May		31-Dec
	Hungary	01-Jan		11-Mar	28-Mar	03-May §		31-Dec
	India	01-Jan	18-Jan	16-Mar	25-Mar	25-Apr	03-May	31-Dec
	Indonesia	01-Jan	05-Feb	16-Mar		22-May	25-Jul	31-Dec
	Iran	01-Jan		28-Feb			18-Apr	31-Dec
	Iraq	01-Jan		27-Feb	22-Mar	23-Apr		31-Dec
	Ireland	01-Jan	29-Feb	12-Mar	28-Mar	05-May		31-Dec
	Israel	01-Jan		10-Mar	19-Mar	19-Apr §	03-May §	31-Dec
	Italy	01-Jan	30-Jan	23-Feb	09-Mar	14-Apr	01-Jun	31-Dec
	Japan	01-Jan	28-Jan	28-Mar	07-Apr	06-May		31-Dec
	Kazakhstan	01-Jan	26-Jan	16-Mar			28-Apr	31-Dec
	South Korea	01-Jan	04-Feb	21-Feb			20-Apr §	31-Dec
	Kuwait	01-Jan		12-Mar			25-Apr	31-Dec
	Latvia	01-Jan		13-Mar			12-May	31-Dec
	Lithuania	01-Jan		12-Mar	16-Mar	27-Apr	11-May	31-Dec
	Luxembourg	01-Jan		13-Mar	15-Mar	20-Apr §	04-May	31-Dec
	Malaysia	01-Jan	28-Feb	14-Mar	18-Mar	12-May		31-Dec
	Malta	01-Jan	24-Feb	12-Mar	22-Mar	11-May §		31-Dec
	Mexico	01-Jan		24-Mar			30-May	31-Dec
	Morocco	01-Jan		14-Mar	19-Mar	20-May		31-Dec
	Netherlands	01-Jan		16-Mar			20-May	31-Dec
	New Zealand	01-Jan	02-Feb	20-Mar	26-Mar	27-Apr		31-Dec
	Nigeria	01-Jan		30-Mar			04-May	31-Dec
	Norway	01-Jan			12-Mar	20-Apr	15-Jun	31-Dec
	Oman	01-Jan		17-Mar			08-May §	31-Dec
	Pakistan	01-Jan		13-Mar	24-Mar	14-Apr	09-May	31-Dec
	Philippines	01-Jan	02-Feb	15-Mar			15-May	31-Dec
	Poland	01-Jan	25-Jan	12-Mar	25-Mar	19-Apr	03-May	31-Dec
	Portugal	01-Jan		12-Mar	19-Mar	03-May		31-Dec
	Qatar	01-Jan	09-Mar	17-Mar			25-Apr §	31-Dec
	Romania	01-Jan	25-Feb	11-Mar	24-Mar	15-May		31-Dec
	Russian Federation	01-Jan	03-Feb	19-Mar	28-Mar	12-May		31-Dec
	Saudi Arabia	01-Jan	27-Feb	14-Mar	06-Apr	29-Apr	13-May §	31-Dec
	Slovakia	01-Jan		13-Mar		22-Apr		31-Dec
	Slovenia	01-Jan	09-Mar	16-Mar		20-Apr	04-May	31-Dec
	South Africa	01-Jan	14-Mar	15-Mar	26-Mar	01-May §		31-Dec
	Spain	01-Jan		10-Mar	14-Mar	13-Apr		31-Dec
	Sweden	01-Jan	12-Mar	04-Apr			11-May §	31-Dec
	Thailand	01-Jan	03-Jan	17-Mar			31-May	31-Dec
	Turkey	01-Jan	24-Jan	16-Mar			20-May	31-Dec
	Turkmenistan	01-Jan	20-Mar				30-Apr §	31-Dec
	Ukraine	01-Jan		17-Mar			12-May	31-Dec
	United Arab Emirates	01-Jan	17-Mar	26-Mar			25-Apr	31-Dec
	United Kingdom	01-Jan	10-Feb	16-Mar	24-Mar	08-May		31-Dec
	USA	Analysed separately						
	Uzbekistan	01-Jan	15-Mar	20-Mar	27-Mar	12-May §		31-Dec
	Venezuela	01-Jan	02-Feb	12-Mar	17-Mar	12-May		31-Dec
	Vietnam	01-Jan	01-Feb	22-Mar	01-Apr	15-Apr	22-Apr	31-Dec

Table S15 (continued).

		Confinement Index Level						
	Country name	0	1	2	3	2	1	0
CHINA	Beijing	01-Jan		24-Jan	09-Feb		29-Feb	31-Dec
	Tianjin	01-Jan		24-Jan	06-Feb		29-Feb	31-Dec
	Hebei	01-Jan		24-Jan	06-Feb		25-Mar	31-Dec
	Shanxi	01-Jan		25-Jan	09-Feb		24-Feb	31-Dec
	Inner Mongolia	01-Jan		25-Jan	13-Feb		26-Feb	31-Dec
	Liaoning	01-Jan		25-Jan	06-Feb		22-Feb	31-Dec
	Jilin	01-Jan		25-Jan	06-Feb		26-Feb	31-Dec
	Heilongjiang	01-Jan		25-Jan	04-Feb		05-Mar	31-Dec
	Shanghai	01-Jan		24-Jan	10-Feb		23-Mar	31-Dec
	Jiangsu	01-Jan		25-Jan	04-Feb		25-Feb	31-Dec
	Zhejiang	01-Jan		23-Jan	04-Feb		02-Mar	31-Dec
	Anhui	01-Jan		24-Jan	07-Feb		25-Feb	31-Dec
	Fujian	01-Jan		24-Jan	04-Feb		26-Feb	31-Dec
	Jiangxi	01-Jan		24-Jan	04-Feb		12-Mar	31-Dec
	Shandong	01-Jan		24-Jan	05-Feb		08-Mar	31-Dec
	Henan	01-Jan		25-Jan	03-Feb		19-Mar	31-Dec
	Hubei	01-Jan		23-Jan	03-Feb	12-Mar	28-Mar	31-Dec
	Hunan	01-Jan		23-Jan	14-Feb		11-Mar	31-Dec
	Guangdong	01-Jan		23-Jan	04-Feb		24-Feb	31-Dec
	Guangxi	01-Jan		24-Jan	05-Feb		26-Feb	31-Dec
	Hainan	01-Jan		25-Jan	04-Feb		26-Feb	31-Dec
	Chongqing	01-Jan		24-Jan	08-Feb		11-Mar	31-Dec
	Sichuan	01-Jan		24-Jan	05-Feb		26-Feb	31-Dec
	Guizhou	01-Jan		24-Jan	02-Feb		24-Feb	31-Dec
	Yunnan	01-Jan		24-Jan	11-Feb		24-Feb	31-Dec
	Shaanxi	01-Jan		25-Jan	19-Feb		28-Feb	31-Dec
	Gansu	01-Jan		25-Jan	08-Feb		21-Feb	31-Dec
	Qinghai	01-Jan		25-Jan			26-Feb	31-Dec
	Ningxia	01-Jan		25-Jan	10-Feb		28-Feb	31-Dec
	Xinjiang	01-Jan		25-Jan			26-Feb	31-Dec
USA	Alabama	01-Jan	31-Jan	16-Mar	04-Apr	30-Apr	15-May	31-Dec
	Alaska	01-Jan	31-Jan	22-Mar	28-Mar	24-Apr		31-Dec
	Arizona	01-Jan	31-Jan	16-Mar	31-Mar	30-Apr		31-Dec
	Arkansas	01-Jan	31-Jan	19-Mar			04-May	31-Dec
	California	01-Jan	31-Jan		19-Mar	14-May		31-Dec
	Colorado	01-Jan	31-Jan		26-Mar	27-Apr		31-Dec
	Connecticut	01-Jan	31-Jan		23-Mar	20-May		31-Dec
	Delaware	01-Jan	31-Jan		24-Mar	15-May		31-Dec
	District of Columbia	01-Jan	31-Jan		01-Apr	15-May		31-Dec
	Florida	01-Jan	31-Jan	24-Mar	03-Apr	30-Apr		31-Dec
	Georgia	01-Jan	31-Jan	25-Mar	03-Apr	24-Apr	13-May	31-Dec
	Hawaii	01-Jan	31-Jan		25-Mar	31-May		31-Dec
	Idaho	01-Jan	31-Jan		25-Mar	30-Apr		31-Dec
	Illinois	01-Jan	31-Jan		21-Mar	30-May		31-Dec
	Indiana	01-Jan	31-Jan		25-Mar	02-May		31-Dec
	Iowa	01-Jan	31-Jan	17-Mar			30-Apr	31-Dec
	Kansas	01-Jan	31-Jan	24-Mar	30-Mar	03-May		31-Dec
	Kentucky	01-Jan	31-Jan		26-Mar	11-May		31-Dec
	Louisiana	01-Jan	31-Jan		23-Mar	15-May		31-Dec
	Maine	01-Jan	31-Jan	25-Mar	02-Apr	15-May		31-Dec
	Maryland	01-Jan	31-Jan		30-Mar	15-May §		31-Dec
	Massachusetts	01-Jan	31-Jan	24-Mar	31-Mar	04-May		31-Dec
	Michigan	01-Jan	31-Jan		24-Mar	15-May		31-Dec
	Minnesota	01-Jan	31-Jan		27-Mar	27-Apr		31-Dec
	Mississippi	01-Jan	31-Jan	22-Mar	03-Apr	11-May		31-Dec
	Missouri	01-Jan	31-Jan	23-Mar	06-Apr	03-May		31-Dec
	Montana	01-Jan	31-Jan		28-Mar	26-Apr	07-May	31-Dec
	Nebraska	01-Jan	31-Jan	20-Mar	09-Apr	04-May	31-May	31-Dec
	Nevada	01-Jan	31-Jan	20-Mar	01-Apr	15-May		31-Dec
	New Hampshire	01-Jan	31-Jan		27-Mar	15-May		31-Dec
	New Jersey	01-Jan	31-Jan		21-Mar	15-May §		31-Dec
	New Mexico	01-Jan	31-Jan		24-Mar	15-May		31-Dec
	New York	01-Jan	31-Jan		22-Mar	15-May		31-Dec
	North Carolina	01-Jan	31-Jan		30-Mar	08-May		31-Dec
	North Dakota	01-Jan	31-Jan	20-Mar			01-May	31-Dec
	Ohio	01-Jan	31-Jan		24-Mar	04-May		31-Dec
	Oklahoma	01-Jan	31-Jan	26-Mar		24-Apr		31-Dec
	Oregon	01-Jan	31-Jan		23-Mar	01-May		31-Dec
	Pennsylvania	01-Jan	31-Jan	23-Mar	01-Apr	01-May		31-Dec
	Rhode Island	01-Jan	31-Jan	16-Mar	28-Mar	08-May		31-Dec
	South Carolina	01-Jan	31-Jan	26-Mar			21-Apr	31-Dec
	South Dakota	01-Jan	31-Jan	23-Mar			02-May	31-Dec
	Tennessee	01-Jan	31-Jan	23-Mar	31-Mar	29-Apr		31-Dec
	Texas	01-Jan	31-Jan	27-Mar	02-Apr	01-May		31-Dec
	Utah	01-Jan	31-Jan	27-Mar			01-May	31-Dec
	Vermont	01-Jan	31-Jan		25-Mar	15-May		31-Dec
	Virginia	01-Jan	31-Jan		30-Mar	10-Jun		31-Dec
	Washington	01-Jan	31-Jan	12-Mar	23-Mar	05-May		31-Dec
	West Virginia	01-Jan	31-Jan		24-Mar	04-May		31-Dec
	Wisconsin	01-Jan	31-Jan		24-Mar	26-May		31-Dec
	Wyoming	01-Jan	31-Jan	28-Mar			15-May	31-Dec

Table S16. Sector allocation by country, US states and China provinces, total CO_2 emissions for the last year available, and population. Sector allocations are from the IEA[25] for world countries, EIA[13] for the US, and national statistics[26] for Chinese provinces. CO_2 emissions are the mean daily emissions for the latest available year (2017 to 2019) updated from the Global Carbon Project for world countries (GCP; 2019) [1], EIA[13] for the US, and national statistics[26] for Chinese provinces.

		Power	Industry	Transport	Public	Residential	Aviation	Population	CO_2 emissions	**Reduced CO_2 emissions**
	Country name	percent	percent	percent	percent	percent	percent	(000s; 2018)	(MtCO2/d; 2018)	**percent**
GLOBAL	Algeria	33.9%	14.9%	31.9%	2.8%	15.4%	1.1%	42228	0.43	**-27.1%**
	Argentina	36.1%	17.4%	24.5%	7.9%	11.5%	2.5%	44495	0.55	**-27.3%**
	Australia	56.2%	10.2%	22.4%	3.2%	2.3%	5.6%	24992	1.20	**-28.3%**
	Austria	29.8%	18.9%	35.4%	2.9%	9.8%	3.3%	8847	0.20	**-31.7%**
	Bangladesh	45.9%	22.4%	14.0%	4.8%	11.3%	1.5%	161356	0.24	**-23.7%**
	Belgium	18.2%	17.1%	40.6%	7.1%	13.0%	3.9%	11422	0.36	**-27.7%**
	Brazil	21.3%	23.6%	43.9%	3.7%	3.9%	3.6%	209469	1.30	**-25.2%**
	Bulgaria	61.3%	12.4%	20.9%	1.7%	1.9%	1.7%	7024	0.12	**-14.8%**
	Canada	38.5%	13.2%	28.1%	10.1%	6.9%	3.3%	37059	1.57	**-19.8%**
	Chile	40.8%	17.1%	29.5%	4.4%	4.5%	3.8%	18729	0.24	**-20.1%**
	China	48.6%	34.8%	8.4%	3.4%	3.8%	1.0%	1392730	27.74	**-23.9%**
	Colombia	19.8%	25.4%	37.6%	8.2%	4.3%	4.8%	49649	0.28	**-36.5%**
	Croatia	25.0%	20.3%	36.4%	7.1%	8.6%	2.6%	4089	0.05	**-32.9%**
	Cyprus	35.8%	16.9%	30.9%	2.2%	3.9%	10.2%	1189	0.03	**-32.3%**
	Czech Republic	55.6%	13.3%	17.6%	4.3%	8.0%	1.2%	10626	0.29	**-23.7%**
	Denmark	30.9%	13.2%	36.8%	5.6%	5.5%	8.1%	5797	0.11	**-33.9%**
	Egypt	42.2%	23.1%	24.6%	1.4%	7.3%	1.4%	98424	0.66	**-16.7%**
	Estonia	69.7%	5.3%	19.6%	3.4%	0.9%	1.0%	1321	0.06	**-12.5%**
	Finland	42.9%	17.3%	26.4%	6.1%	2.5%	4.8%	5518	0.14	**-19.8%**
	France	17.6%	14.1%	38.2%	11.0%	12.7%	6.4%	66987	1.00	**-34%**
	Germany	42.7%	14.0%	22.0%	6.0%	11.4%	4.0%	82928	2.18	**-26.4%**
	Greece	44.4%	12.7%	30.2%	2.0%	6.1%	4.6%	10728	0.23	**-27.3%**
	Hungary	28.9%	16.9%	27.2%	9.1%	16.5%	1.4%	9769	0.14	**-27.1%**
	India	49.5%	29.4%	12.4%	3.9%	3.7%	1.1%	1352617	7.32	**-25.7%**
	Indonesia	41.2%	25.0%	25.1%	2.0%	4.1%	2.6%	267663	1.70	**-18.2%**
	Iran	33.9%	19.4%	22.9%	4.9%	18.1%	0.8%	81800	2.01	**-15.3%**
	Iraq	63.1%	8.8%	20.3%	0.0%	6.4%	1.4%	38434	0.57	**-23.2%**
	Ireland	29.3%	14.4%	29.4%	6.1%	13.6%	7.3%	4854	0.12	**-30.6%**
	Israel	56.1%	9.1%	26.5%	3.1%	0.5%	4.8%	8884	0.19	**-29.1%**
	Italy	34.9%	11.4%	29.6%	7.0%	13.4%	3.6%	60431	0.98	**-27.7%**
	Japan	49.4%	19.4%	17.5%	6.2%	4.9%	2.6%	126529	3.28	**-26.3%**
	Kazakhstan	58.5%	25.5%	5.6%	3.6%	6.1%	0.7%	18276	0.89	**-10.3%**
	South Korea	54.2%	14.4%	19.7%	3.6%	5.2%	2.8%	51635	1.94	**-14.7%**
	Kuwait	58.9%	20.5%	16.7%	0.0%	0.9%	3.0%	4137	0.29	**-14.3%**
	Latvia	18.8%	12.7%	48.5%	9.4%	5.5%	5.0%	1927	0.02	**-26.3%**
	Lithuania	21.5%	13.2%	51.8%	4.7%	6.2%	2.6%	2790	0.04	**-35.6%**
	Luxembourg	2.5%	12.3%	53.1%	5.9%	10.2%	16.0%	608	0.03	**-44.6%**
	Malaysia	47.6%	18.3%	26.2%	2.4%	1.3%	4.2%	31529	0.73	**-30.3%**
	Malta	8.2%	0.6%	84.7%	1.2%	0.5%	4.8%	484	0.02	**-24.5%**
	Mexico	40.6%	18.3%	32.1%	3.1%	3.5%	2.5%	126191	1.35	**-20.1%**
	Morocco	32.9%	23.2%	26.3%	4.6%	9.7%	3.3%	36029	0.19	**-29.5%**
	Netherlands	33.2%	12.8%	32.9%	7.3%	8.0%	5.8%	17231	0.58	**-19.2%**
	New Zealand	18.7%	18.6%	41.8%	6.8%	1.6%	12.6%	4886	0.11	**-41.1%**
	Nigeria	26.1%	15.8%	53.5%	0.9%	1.9%	1.9%	195875	0.36	**-26.5%**
	Norway	37.4%	18.8%	30.9%	5.2%	0.6%	7.1%	5314	0.13	**-34.2%**
	Oman	35.0%	25.6%	21.6%	15.8%	0.8%	1.3%	4829	0.20	**-17.9%**
	Pakistan	27.9%	33.3%	26.8%	2.3%	8.2%	1.4%	212215	0.62	**-30.6%**
	Philippines	45.4%	19.4%	23.5%	5.0%	2.2%	4.4%	106652	0.38	**-19%**
	Poland	50.4%	11.9%	19.7%	5.7%	11.4%	0.8%	37979	0.95	**-23.4%**
	Portugal	41.1%	13.8%	31.3%	3.7%	2.9%	7.3%	10282	0.16	**-31.9%**
	Qatar	58.2%	17.0%	14.8%	0.0%	0.4%	9.6%	2782	0.32	**-18.6%**
	Romania	41.0%	20.1%	23.4%	5.4%	8.7%	1.4%	19474	0.21	**-27.3%**
	Russian Federation	51.9%	17.5%	16.6%	2.0%	10.0%	2.0%	144478	4.85	**-23.2%**
	Saudi Arabia	47.8%	26.2%	22.8%	0.0%	0.9%	2.2%	33700	1.77	**-28.9%**
	Slovakia	35.2%	27.1%	23.1%	5.7%	8.5%	0.4%	5447	0.10	**-16.7%**
	Slovenia	34.3%	15.0%	41.3%	4.1%	4.7%	0.5%	2067	0.04	**-21.2%**
	South Africa	63.6%	11.6%	13.2%	4.5%	5.2%	1.9%	57780	1.32	**-22.4%**
	Spain	33.2%	13.3%	35.8%	5.4%	5.7%	6.6%	46724	0.83	**-31.9%**
	Sweden	19.9%	16.2%	54.1%	2.9%	0.3%	6.5%	10183	0.14	**-27.6%**
	Thailand	37.4%	24.0%	27.4%	3.7%	1.6%	5.8%	69429	0.84	**-21.4%**
	Turkey	36.9%	24.7%	19.1%	7.9%	8.1%	3.3%	82320	1.21	**-17.4%**
	Turkmenistan	36.1%	5.1%	16.4%	39.7%	0.6%	2.0%	5851	0.22	**-4.5%**
	Ukraine	49.1%	19.9%	14.5%	3.5%	12.5%	0.4%	44623	0.62	**-12.4%**
	United Arab Emirates	33.2%	25.7%	31.8%	0.0%	0.4%	9.0%	9631	0.76	**-21.5%**
	United Kingdom	28.2%	10.2%	31.4%	5.6%	15.6%	8.9%	66489	1.16	**-30.7%**
	USA	41.7%	9.5%	32.8%	5.2%	5.8%	5.0%	327167	15.28	**-31.6%**
	Uzbekistan	50.9%	14.8%	5.7%	7.3%	21.0%	0.4%	32955	0.25	**-17.3%**
	Venezuela	43.1%	22.1%	29.7%	1.0%	3.1%	0.9%	28870	0.39	**-29.5%**
	Vietnam	31.9%	42.0%	16.3%	3.1%	4.5%	2.2%	95540	0.6	**-30%**

Table S16 (continued).

		Power	Industry	Transport	Commerce	Residential	Aviation	Population	CO_2 emissions	**Reduced CO_2 emissions**
	Country name	percent	percent	percent	percent	percent	percent	(000s; 2018)	($MtCO_2$/d; 2017)	**percent**
CHINA	Beijing	34%	5%	29%	12%	20%	0.4%	2154	0.2	**-24.6%**
	Tianjin	45%	37%	6%	5%	6%	1%	1560	0.4	**-24.7%**
	Hebei	32%	57%	3%	2%	6%	1%	7556	1.9	**-27%**
	Shanxi	57%	32%	4%	2%	4%	1%	3718	1.3	**-23.1%**
	Inner Mongolia	77%	15%	3%	2%	2%	2%	2534	1.7	**-20.1%**
	Liaoning	45%	39%	8%	3%	4%	1%	4359	1.3	**-26%**
	Jilin	55%	28%	7%	5%	3%	2%	2704	0.5	**-24.5%**
	Heilongjiang	54%	19%	8%	11%	4%	5%	3773	0.7	**-25.7%**
	Shanghai	33%	25%	27%	8%	7%	1%	2424	0.5	**-29.7%**
	Jiangsu	60%	30%	6%	0%	3%	1%	8051	1.9	**-23.2%**
	Zhejiang	70%	12%	9%	3%	5%	2%	5737	1.0	**-21.1%**
	Anhui	61%	25%	7%	2%	5%	1%	6324	0.9	**-22.4%**
	Fujian	57%	27%	11%	1%	3%	1%	3941	0.6	**-24.7%**
	Jiangxi	47%	38%	7%	2%	4%	1%	4648	0.5	**-25.3%**
	Shandong	60%	27%	6%	2%	4%	1%	10047	2.1	**-22.6%**
	Henan	56%	30%	6%	2%	5%	1%	9605	1.2	**-23.3%**
	Hubei	42%	31%	12%	6%	7%	2%	5917	0.8	**-26.6%**
	Hunan	26%	46%	11%	8%	7%	4%	6899	0.8	**-30%**
	Guangdong	58%	16%	14%	3%	8%	1%	11346	1.4	**-22.6%**
	Guangxi	37%	46%	11%	1%	3%	2%	4926	0.5	**-28.6%**
	Hainan	60%	10%	17%	5%	4%	5%	934	0.1	**-25.7%**
	Chongqing	40%	35%	14%	3%	7%	1%	3102	0.4	**-27.1%**
	Sichuan	17%	56%	11%	6%	9%	2%	8341	0.7	**-30.4%**
	Guizhou	55%	11%	6%	18%	8%	2%	3600	0.6	**-22.4%**
	Yunnan	20%	54%	14%	4%	7%	3%	4830	0.4	**-31.6%**
	Shaanxi	57%	29%	5%	3%	5%	1%	3864	0.7	**-22.7%**
	Gansu	56%	25%	7%	4%	7%	2%	2637	0.4	**-22.8%**
	Qinghai	36%	42%	8%	6%	7%	1%	603	0.1	**-13.2%**
	Ningxia	76%	20%	2%	1%	1%	0.2%	688	0.5	**-19.8%**
	Xinjiang	66%	22%	5%	2%	4%	2%	2487	1.1	**-10.4%**
	international aviation	0%	0%	0%	0%	0%	100%	-	0.1	**-75%**
	international shipping	0%	0%	100%	0%	0%	0%	-	0.1	**-20%**
USA	Alabama	47%	19%	30%	2%	2%	1%	4888	0.3	**-29.8%**
	Alaska	7%	48%	19%	6%	5%	15%	737	0.1	**-40.4%**
	Arizona	51%	5%	37%	3%	2%	2%	7172	0.2	**-29.9%**
	Arkansas	50%	13%	30%	5%	2%	1%	3014	0.2	**-17.9%**
	California	9%	19%	50%	5%	7%	10%	39557	1.0	**-41.8%**
	Colorado	40%	14%	29%	5%	8%	4%	5696	0.2	**-29.3%**
	Connecticut	19%	5%	44%	12%	19%	1%	3573	0.1	**-30.4%**
	Delaware	24%	24%	38%	8%	7%	0%	967	0.0	**-33.1%**
	District of Columbia	0%	1%	38%	36%	25%	0%	702	0.0	**-30%**
	Florida	45%	5%	43%	3%	1%	4%	21299	0.6	**-33.6%**
	Georgia	39%	9%	42%	3%	5%	1%	10519	0.4	**-31.9%**
	Hawaii	32%	8%	58%	3%	0%	0%	1420	0.0	**-37.1%**
	Idaho	6%	18%	57%	8%	10%	2%	1754	0.1	**-38.6%**
	Illinois	32%	17%	30%	7%	11%	4%	12741	0.6	**-30.2%**
	Indiana	46%	23%	22%	3%	4%	2%	6692	0.5	**-28.1%**
	Iowa	34%	29%	26%	5%	6%	0.4%	3156	0.2	**-17.9%**
	Kansas	37%	22%	30%	4%	6%	1%	2912	0.2	**-30%**
	Kentucky	56%	11%	25%	2%	2%	3%	4468	0.3	**-27.8%**
	Louisiana	15%	60%	19%	1%	1%	4%	4660	0.6	**-36.3%**
	Maine	7%	9%	53%	11%	19%	2%	1338	0.0	**-34.5%**
	Maryland	23%	4%	52%	10%	10%	1%	6043	0.1	**-34.2%**
	Massachusetts	16%	5%	43%	12%	19%	5%	6902	0.2	**-32.2%**
	Michigan	37%	12%	32%	7%	12%	1%	9996	0.4	**-27.7%**
	Minnesota	29%	19%	34%	8%	10%	1%	5611	0.2	**-30.8%**
	Mississippi	35%	16%	36%	2%	2%	9%	2987	0.2	**-36%**
	Missouri	56%	6%	30%	3%	4%	1%	6126	0.3	**-26.8%**
	Montana	51%	13%	25%	5%	6%	1%	1062	0.1	**-26.7%**
	Nebraska	43%	19%	28%	4%	5%	1%	1929	0.1	**-29%**
	Nevada	35%	9%	38%	7%	7%	5%	3034	0.1	**-32.7%**
	New Hampshire	13%	6%	49%	10%	21%	1%	1356	0.0	**-31.9%**
	New Jersey	16%	8%	44%	10%	14%	8%	8909	0.3	**-36%**
	New Mexico	47%	15%	30%	3%	4%	1%	2095	0.1	**-28.8%**
	New York	14%	5%	41%	14%	20%	6%	19542	0.4	**-32.7%**
	North Carolina	41%	8%	42%	4%	4%	1%	10384	0.3	**-31.7%**
	North Dakota	52%	29%	15%	2%	2%	0.4%	760	0.2	**-13.7%**
	Ohio	39%	17%	29%	5%	8%	2%	11689	0.6	**-28.9%**
	Oklahoma	33%	26%	32%	3%	4%	3%	3943	0.3	**-21.1%**
	Oregon	20%	12%	50%	7%	8%	4%	4191	0.1	**-36.8%**
	Pennsylvania	36%	22%	27%	5%	9%	3%	12807	0.6	**-29.5%**
	Rhode Island	28%	6%	40%	9%	18%	0%	1057	0.0	**-27.9%**
	South Carolina	36%	11%	47%	3%	2%	1%	5084	0.2	**-23.5%**
	South Dakota	17%	26%	44%	5%	7%	1%	882	0.0	**-24.4%**
	Tennessee	33%	16%	40%	4%	4%	4%	6770	0.3	**-34.5%**
	Texas	30%	34%	29%	2%	1%	4%	28702	1.8	**-34.3%**
	Utah	47%	12%	27%	5%	7%	3%	3161	0.2	**-18.4%**
	Vermont	0%	7%	56%	13%	23%	0%	626	0.0	**-33.8%**
	Virginia	29%	11%	45%	6%	6%	3%	8518	0.3	**-34.8%**
	Washington	13%	13%	52%	6%	8%	8%	7536	0.2	**-40.2%**
	West Virginia	72%	12%	13%	2%	2%	0%	1806	0.2	**-21.8%**
	Wisconsin	42%	14%	29%	6%	9%	1%	5814	0.3	**-27.4%**
	Wyoming	67%	17%	12%	2%	2%	0.4%	578	0.2	**-11.6%**
	international aviation	0%	0%	0%	0%	0%	100%	-	0.2	**-75%**
	international shipping	0%	0%	100%	0%	0%	0%	-	0.2	**-20%**

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