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# Supplementary information

# Global patterns of daily $CO_2$ emissions reductions in the first year of COVID-19

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**Supplementary Information**

# Global patterns of daily $CO_2$ emission reductions in the first year of COVID-19

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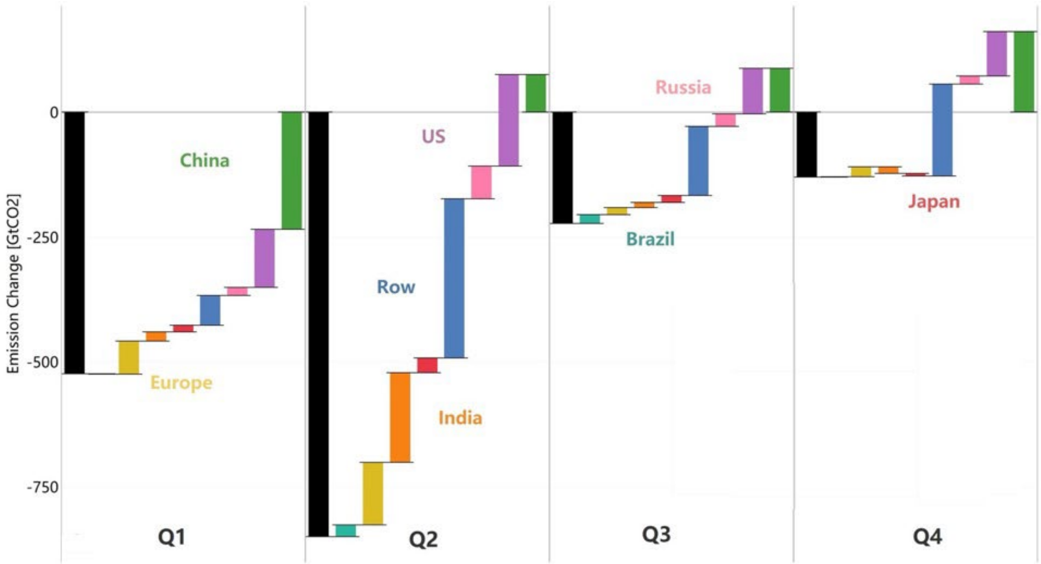
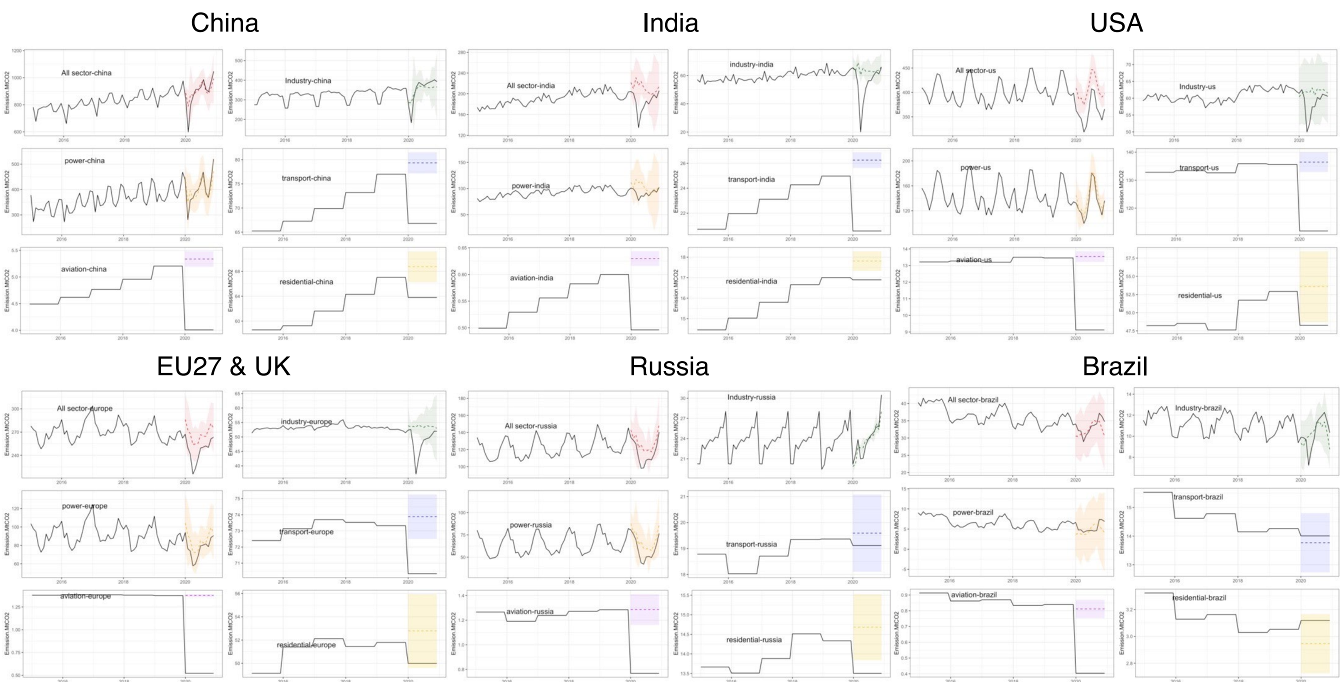
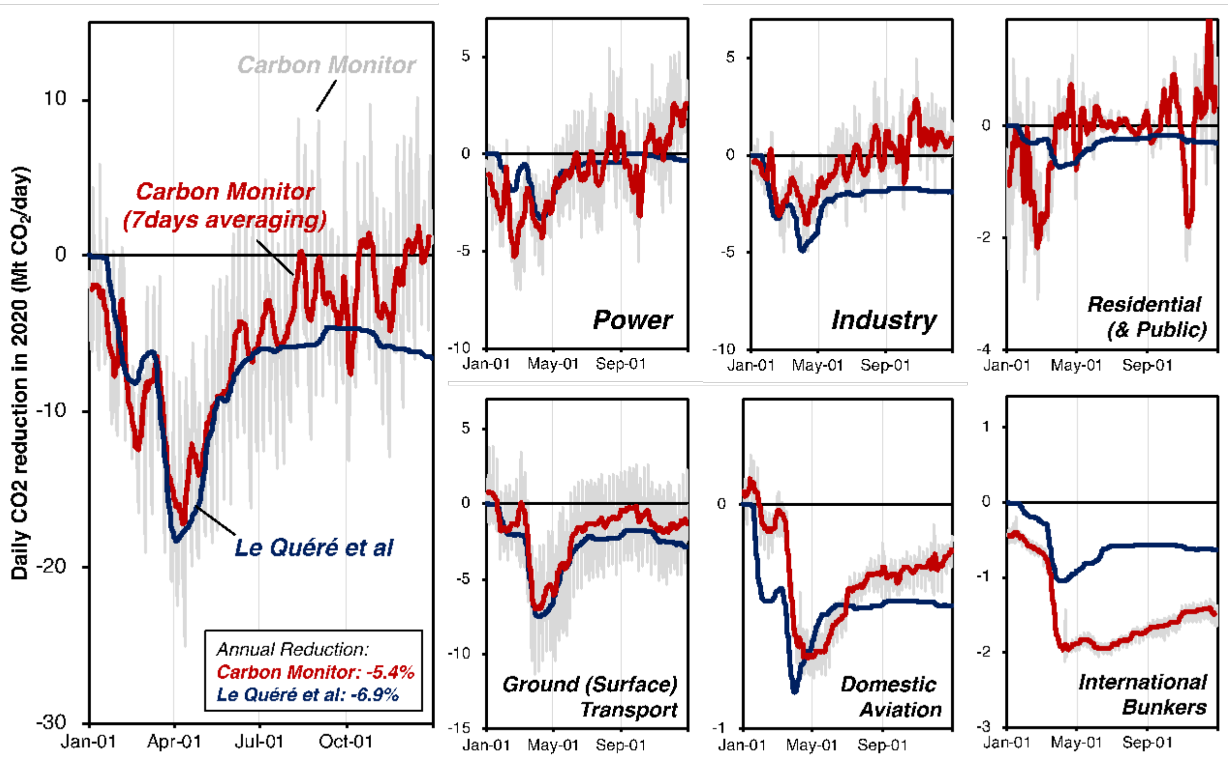



**SI Figure 1 | Contribution by major emitters in the four quarters in 2020**.




**SI Figure 2 | Historical trend per country/region.**




**SI Figure 3 | Comparison of estimates from this study (Carbon Monitor) and Le Quéré et al. (2020) study.** The grey lines denote the daily CO2 reduction in 2020 compared to the same day in 2019 from this study and the read lines denote the 7-day running mean values. The dark blue lines denote the estimation of daily CO2 reduction (7-day running mean) from Le Quéré et al. (2020).

**SI Table 1 | Sources of activity data from different sectors**

| Sector | Region | Data type | Source |
|---|---|---|---|
| Power Sector | China | thermal production / coal consumption | China National Power Grid (thermal production)<br>National Bureau of Statistics (thermal production)<br>WIND (coal consumption in Zhedian Company) |
| | India | thermal production | Power System Operation Corporation Limited (https://posoco.in/reports/daily-reports/) |
| | USA | thermal production | Energy Information Administration's (EIA) Hourly Electric Grid Monitor (https://www.eia.gov/beta/electricity/gridmonitor/) |
| | Europe | thermal production | ENTSO-E Transparent platform (https://transparency.entsoe.eu/dashboard/show) |
| | Russia | total Production | United Power System of Russia (http://www.so-ups.ru/index.php) |
| | Japan | thermal production / total demand | OCCTO (Organization for Cross-regional Coordination of Transmission Operators, https://www.occto.or.jp/)<br>Hokkaido Electric Power Network (http://www.rikuden.co.jp/nw/denki-yoho/index.html),<br>Tohoku Electric Power Network (https://setsuden.nw.tohoku-epco.co.jp/download.html), |

| | | | |
|---|---|---|---|
| | | | Tokyo Electric Power Company (https://www.tepco.co.jp/forecast/html/download-j.html), Chubu Electric Power Grid (https://powergrid.chuden.co.jp/denkiyoho/), Hokuriku Electric Power Company (http://denkiyoho.hepco.co.jp/area_forecast.html), Kansai Electric Power (https://www.kansai-td.co.jp/denkiyoho/download/index.html), Chugoku Electric Power Transmission & Distribution (https://www.energia.co.jp/nw/jukyuu/index.html), Shikoku Electric Power Company (https://www.yonden.co.jp/nw/denkiyoho/download.html), Kyushu Electric Power Transmission & Distribution (https://www.kyuden.co.jp/td_power_usages/history202010.html), and Okinawa Electric Power Company(http://www.okiden.co.jp/denki2/dl/) |
| | Brazil | Thermal production | Operator of the National Electricity System (http://www.ons.org.br/Paginas/) |
| Industry Sector | China | Industrial product outputs | National Bureau of Statistics (http://www.stats.gov.cn/english/) Trading Economics (https://tradingeconomics.com) |
| | India | Industrial Production Index | Ministry of Statistics and Programme Implementation (http://www.mospi.nic.in) Trading Economics (https://tradingeconomics.com) |
| | USA | Industrial Production Index | Federal Reserve Board (https://www.federalreserve.gov) Trading Economics (https://tradingeconomics.com) |
| | EU | Industrial Production Index | Eurostat (https://ec.europa.eu/eurostat/home) Trading Economics (https://tradingeconomics.com) |
| | Russia | Industrial Production Index | Federal State Statistics Service (https://eng.gks.ru) Trading Economics (https://tradingeconomics.com) |
| | Japan | Industrial Production Index | Ministry of Economy, Trade and Industry Trading Economics (https://tradingeconomics.com) |
| | Brazil | Industrial Production Index | Brazilian Institute of Geography and Statistics (https://www.ibge.gov.br/en/institutional/the-ibge.htm) Trading Economics (https://tradingeconomics.com) |
| Ground Transportation | 416 Cities | TomTom Congestion Level | TomTom Traffic Index (https://www.tomtom.com/en_gb/traffic-index/) |
| Aviation | World | Flight distance | FlightRadar24 (https://www.flightradar24.com/) |
| Residential | World | population-weighted heating degree days | ERA5 reanalysis of 2-meters air temperature (Copernicus Climate Change Service (C3S), 2019) |
| International Shipping | World | Baltic Dry Index | https://tradingeconomics.com/commodity/baltic |

**SI Table 2 | Data sources of the U.S. Carbon Monitor Project**

| Sector | Data type | Source |
|---|---|---|
| State-level monthly energy consumption data | | |
| Power sector | fuel-specific consumption data | EIA Electricity (https://www.eia.gov/electricity/data/state/) |
| Industry sector | natural gas consumption | EIA Natural Gas (https://www.eia.gov/naturalgas/data.php) |

| | | |
|---|---|---|
| Ground transportation | prime supplier sales volumes of motor gasoline and diesel | EIA Petroleum & Other Liquids (https://www.eia.gov/petroleum/data.php) |
| Aviation | prime supplier sales volumes of kerosene-type jet fuel | EIA Petroleum & Other Liquids (https://www.eia.gov/petroleum/data.php) |
| Residential and commercial | natural gas consumption | EIA Natural Gas (https://www.eia.gov/naturalgas/data.php) |
| State-level daily indicators | | |
| Power sector | thermal generation produced by coal, petroleum and gas | EIA Hourly Electric Grid Monitor (https://www.eia.gov/beta/electricity/gridmonitor/) |
| Industry sector | pipeline deliveries to industrial end users | Genscape Natural Gas (https://www.genscape.com) |
| Ground transportation | distance traveled | Trips by Distance data from Bureau of Transportation Statistics (https://data.bts.gov/Research-and-Statistics/Trips-by-Distance/w96p-f2qv) |
| Aviation | kilometers flown of flights | FlightRadar24 database (https://www.flightradar24.com) |
| Residential and commercial | population-weighted heating degree days | ERA5 reanalysis of 2-meters air temperature (https://cds.climate.copernicus.eu/) |

SI Table 3 | Daily $CO_2$ reduction in 2020 in ROW countries under 4 different levels of OxCGRT Workplace Closing Index.

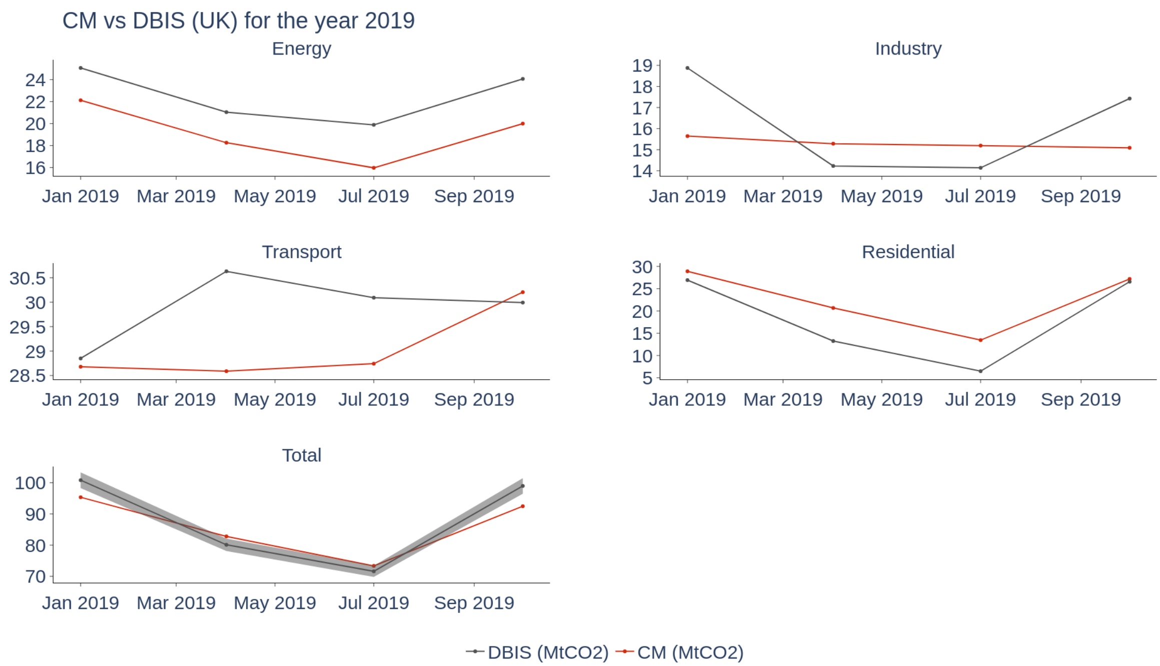
| Sector | Level 0 | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Power | 0% | -3% | -4% | -16% |
| Industry | 0% | -7% | -7% | -19% |

**SI Discussion | Comparison of Carbon Monitor emissions with other estimates based on energy data**

To date, not many emissions reports have been made public by the environmental / inventory agencies of the world. We collected available data to assess the performance of the baseline of the Carbon Monitor (year 2019) ex post.

**Department for Business, Energy & Industrial Strategy, UK Government**

The Department for Business, Energy & Industrial Strategy (DBIS) of the UK provides an emission report by quarter up to 2019[1]. Although the breakdown of emissions by sector is not the same as the Carbon Monitor, they are both based on UNFCCC standards and as such, the DBIS data is a good benchmark for the Carbon Monitor.



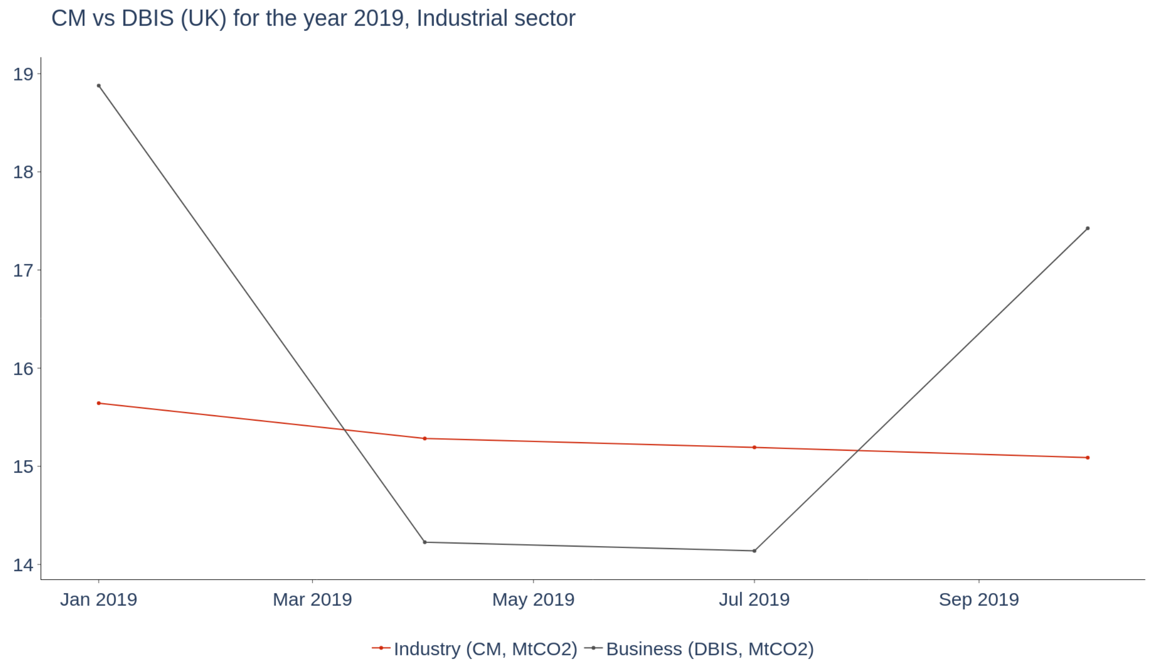

SI Figure 5 | Carbon Monitor sectoral emissions compared to DBIS data for 2019. Sectors have been summed when appropriate. Shadowed area corresponds to 95% confidence interval

The carbon dioxide emission total of the Carbon Monitor for each of the quarters of 2019 is in line with the DBIS total, with a maximum 7% deviation. In all sectors except the Transport and Industry sectors, seasonality is comparable. The discrepancy for the Industry sector (called "Business" in DBIS) with higher emissions in quarter 1 and quarter 4 in DBIS can be explained by the fact that DBIS takes heating of businesses and industry buildings into account in this category, while the Carbon Monitor does not (see 2). The data in SI Figure 6 show that the CM allocates 15% less emissions in the first and last quarter and 7% more to the second and third quarters compared to DBIS, although the annual DBIS and CM emissions for their respective definitions of the 'industrial' sector differ only by 5.4%.

The largest CM discrepancy to DBIS for the seasonality seems to be on the Transport side: DBIS takes domestic ship transport into account while CM does not. More importantly, CM is based on an emission spatial weighted average (from EDGARv4.3.1)

[1] https://www.gov.uk/government/collections/provisional-uk-greenhouse-gas-emissions-national-statistics

of temporal daily emissions from 25 cities with TomTom data, and thus ignores the contribution of other cities. This misfit of seasonality will be investigated in further work involving more precise geolocation data covering all urban areas and other roads transport.

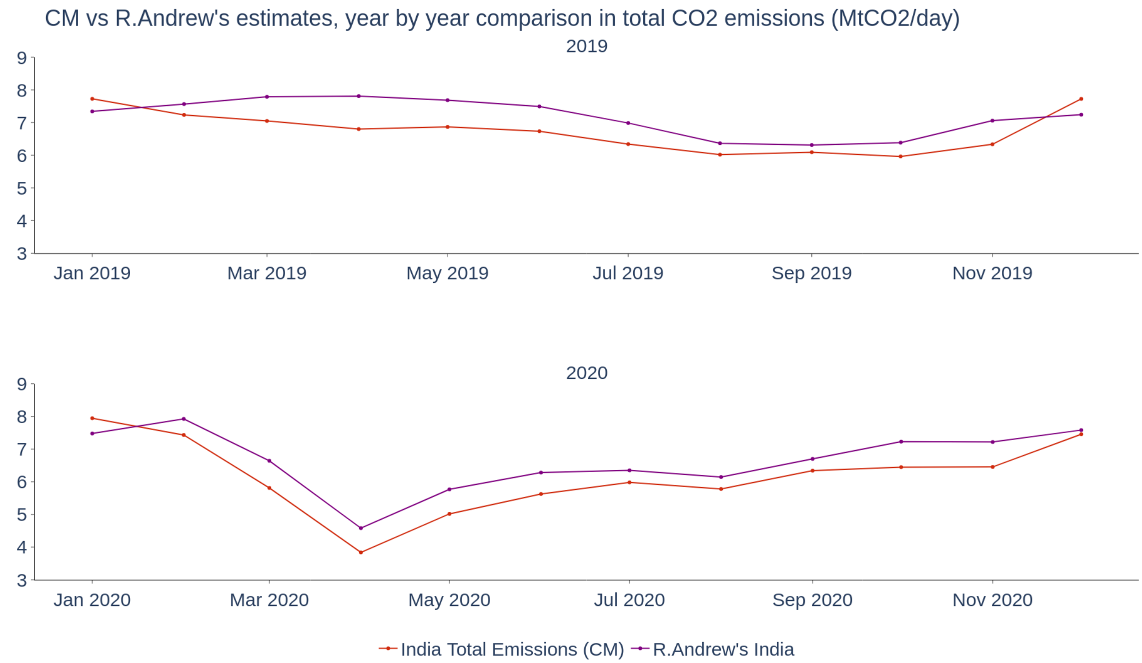



SI Figure 6 | Carbon Monitor "Industry" emissions compared to DBIS "Business" emission

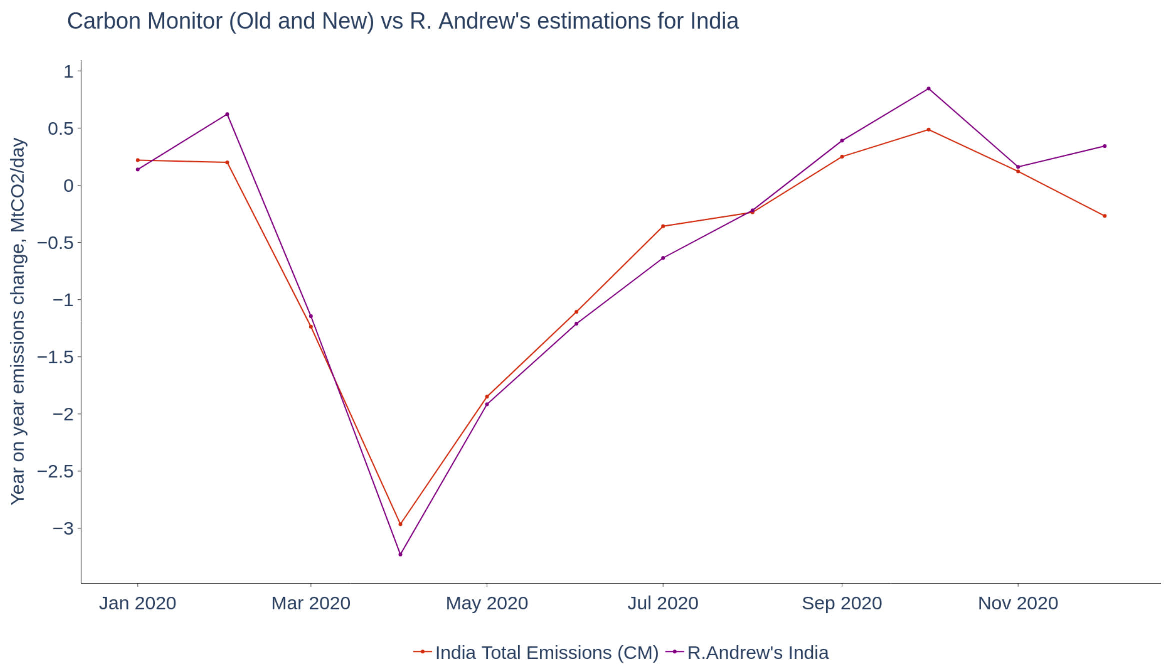
**India's monthly fossil CO2 emissions[2]**

Based on early data on fossil fuel use from the Indian government, R. Andrew [2] provided estimations of India's emissions in 2019 and 2020, available at [2]. The 2020 estimation of CM is very much in line with RA, given an annual mean relative difference of 8.7%. The 2019 estimation of CM is however systematically lower than RA from February to June (SI Figure 7). The annual mean relative difference in 2019 is 7.9%. This negative bias of CM in the first half of 2019 can be explained by the fact that this approach uses a constant emission factor for the power production, whereas, in reality, the fuel mix is evolving on the scale of days to months. The share of coal in the Indian electricity mix (SI Figure 9) indeed rose unusually from February to June 2019, hence a greater emission factor for electricity during that period. Because CM emissions have a small bias of the same sign during both years, the difference between the two years is more consistent between CM and RA (SI Figure 8).

[2] https://essd.copernicus.org/preprints/essd-2020-152/essd-2020-152.pdf

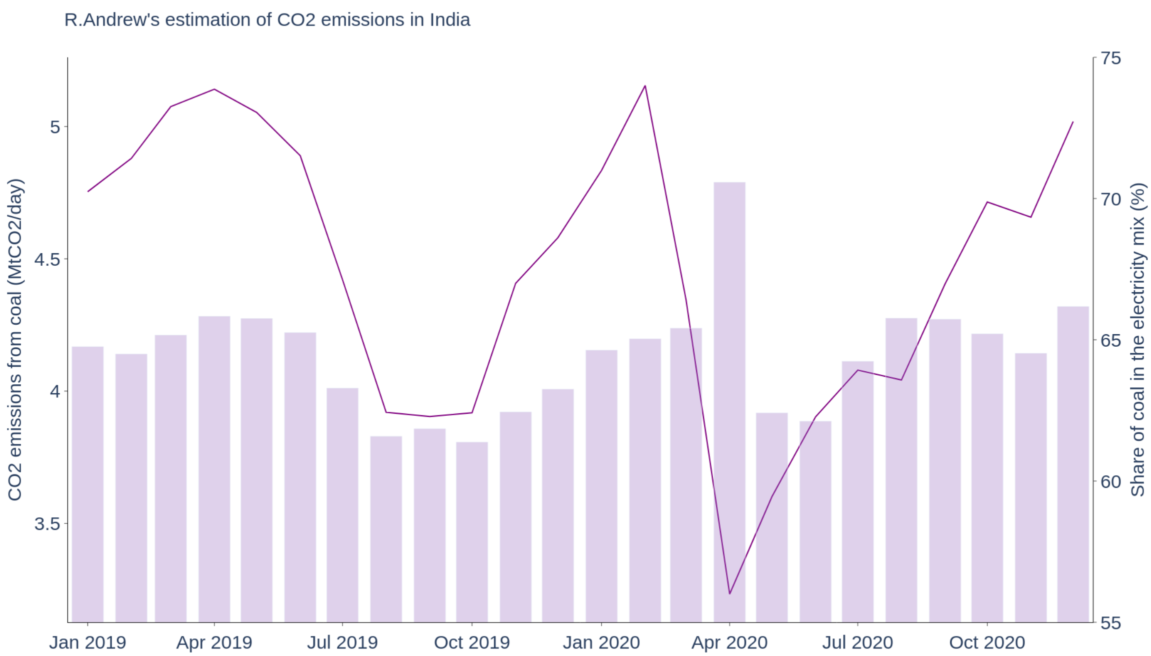



SI Figure 7 | Carbon Monitor compared to estimations provided by RA




SI Figure 8 | Carbon Monitor compared to estimations provided by RA, year-on-year changes 2020 minus 2019.

The estimation of CM is close to RA, given an annual mean relative difference of 8.7% in 2020 and 7.9% in 2019. The small systematic errors between the two estimations are likely due to differences in methodology. While RA accounts for varying fuel mix, CM uses a constant average emission factor. Indeed, India’s fuel mix is changing on the scale of months and the higher emissions in the first half of 2019 in Fig S3 can be explained by the higher share of coal in SI Figure 9.




SI Figure 9 | Share of coal in the electricity mix of India. The bars denote the CO2 emissions from coal and the line denotes the share of coal in the electricity mix.

**Energy Information Agency, USA**

The EIA regularly publishes CO2 emissions estimates for the US in its Monthly Energy Review[3] publication, and associated data. Recently the Carbon Monitor was enhanced[4] by using more of the EIA data as a baseline in 2017 and 2018, especially the sectoral breakdown of emissions (Peng et al. in preparation). As a result, the latest version of the Carbon Monitor matches EIA data for 2019 and 2020 used in this study much more closely than the older version of Liu et al., with a mean relative bias going from 34.8% MAE in 2019-2020 changes (older version) to 12.9% (latest version). Computations of absolute levels of emissions are also greatly improved as well. The table below presents these improvements.

| Year | MAE (%) | RMSE (%) |
|---|---|---|
| 2019, older method | 5.1 | 6.1 |

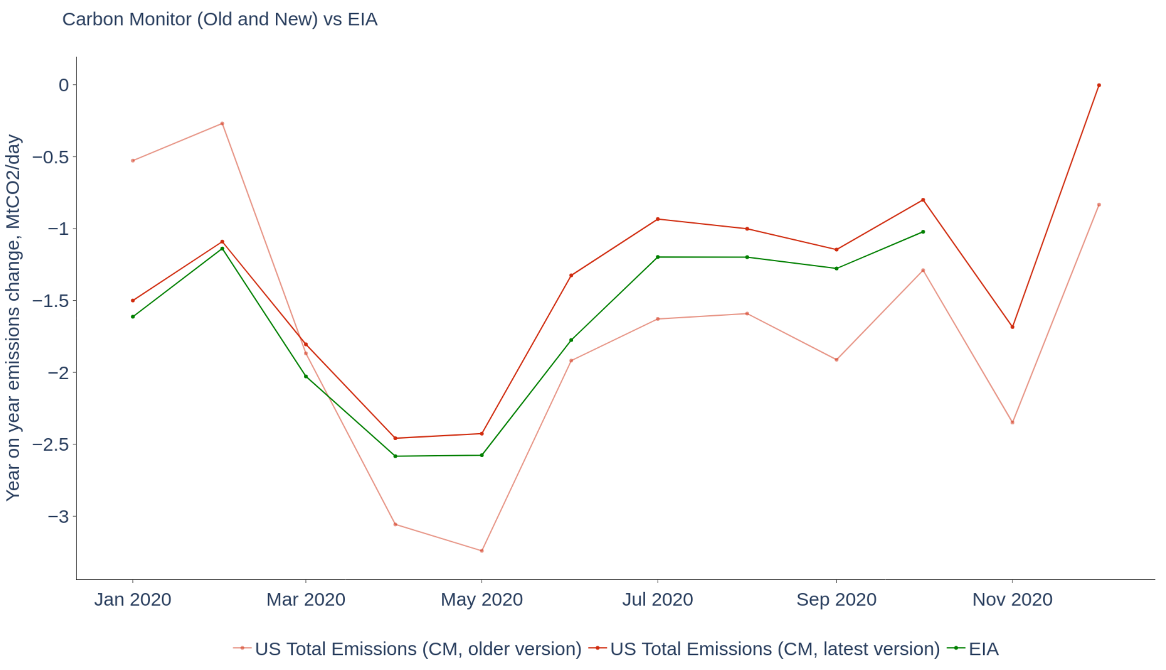
[3] https://www.eia.gov/totalenergy/data/monthly/#environment

[4] “Carbon Monitor, a near-real time daily dataset of global CO2 emissions from fossil fuel and cement production”, revised 20-02-2020

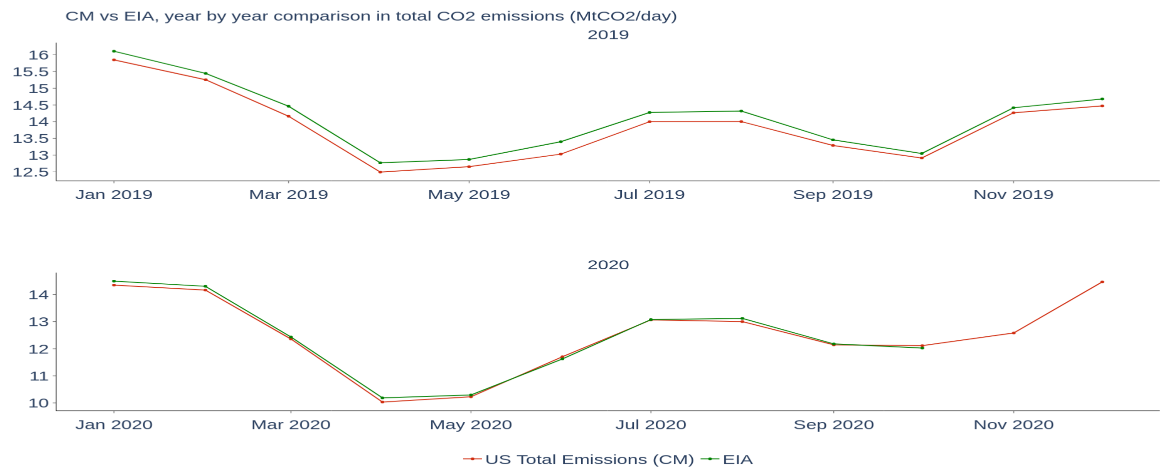
| | | |
|---|---|---|
| 2019, latest method | 1.7 | 0.74 |
| 2020, older method | 6.7 | 7.1 |
| 2020, latest method | 1.78 | 0.83 |

SI Table 6 | Mean absolute error (MAE) and Root Mean Square Error (RMSE) between EIA emissions and CM older (Liu et al. 2020) and latest versions (this study)

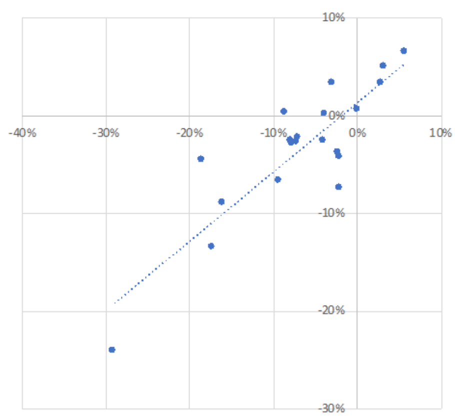
SI Figure 10 | Latest vs older method estimates for Carbon Monitor US



SI Figure 11 | $CO_2$ emissions levels in 2019 and 2020




**SI Section 2 | Comparing CO2 decreases and the GDP changes.**




SI Figure 12 | The relationship between quarterly CO2 emission reductions (x-axis) in China, USA, India, EU27 and Russia and their quarterly GDP growth (y-axis) in 2020 compared to the same period of previous year. Detailed data are shown in SI Table 7.

SI Table 7 | Quarterly CO2 emission reductions in China, USA, India, EU27 and Russia and their quarterly GDP growth in 2020 compared to the same period of previous year. GDP data are collected from OECD Data (https://data.oecd.org/gdp/quarterly-gdp.htm)

| Country | Category | Q1 | Q2 | Q3 | Q4 |
|---|---|---|---|---|---|
| China | CO2 | -9.3% | +3.0% | +3.3% | +5.8% |
| | GDP | -6.8% | +3.2% | +4.9% | +6.5% |
| USA | CO2 | -8.6% | -16.0% | -7.2% | -7% |
| | GDP | +0.3% | -9.0% | -2.8% | -2.4% |
| India | CO2 | -2.8% | -29.0% | -1.9% | +0.2% |
| | GDP | +3.2% | -24.2% | -7.5% | +0.5% |

| | | | | | |
|---|---|---|---|---|---|
| EU27 | CO2 | -7.9% | -17.2% | -2.2% | -1.9% |
| | GDP | -2.6% | -13.6% | -3.9% | -4.3% |
| Russia | CO2 | -3.7% | -18.5% | -7.6% | -3.9% |
| | GDP | +0.1% | -4.6% | -3.0% | -2.7% |