Near-real-time and state-level monitoring of U.S. CO_2 emissions

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As the ambition and urgency of climate mitigation efforts across the U.S. increase, annual estimates of national CO_2 emissions provide only vague and outdated information about changes and progress. Using near-real-time activity data compiled from numerous sources, here we present and analyze daily, state-level estimates of fossil fuel CO_2 emissions from January 2019 through December 2020. Our results quantify the abrupt but temporary decreases in emissions due to the COVID-19 pandemic (particularly related to transportation in April and May of 2020), but also reveal substantial variations across states according to the stringency of their public health responses. We also find that decreases in commercial demand for natural gas and electricity were partially but not fully offset by increases in residential demands in most places. Further, the carbon intensity of electricity and the share of electricity from coal decreased in many states in the first half of 2020 as compared to 2019, but then rebounded in the second half of 2020 when natural gas prices increased. In the future, as COVID-related restrictions dissipate and energy infrastructure evolves, our data and methods will allow state policymakers and energy analysts to closely monitor emissions trends, decarbonization progress and more quickly adjust policies and programs. [*201 words*]

Inventories of fossil fuel CO_2 emissions have historically been updated annually, but often lagging current state by a year or more[1]. For example, since the 1990s, the U.S. Environmental Protection Agency publishes a draft document each February reporting annual emissions from the U.S. during the year that ended 13 months prior[2]. In comparison, the U.S. Energy Information Administration publishes annual emissions estimates at the state-level, but the March 2021 release included estimates only through the end of 2018[3]. In the context of state-level targets that increasingly entail rapid decreases in emissions, such as reaching net-zero emissions[1] by 2045 (California, Virginia) or 2050 (Hawaii, Louisiana, Massachusetts, Maine, Montana, Washington)[4], available emissions inventories may not be specific enough or timely enough to be helpful. These shortcomings of existing inventories were brought to the fore in 2020, as the COVID-19 pandemic profoundly disrupted human activities, and analysts scrambled to assess the effects on energy and emissions[5-8]. Although a few studies were able to quickly estimate COVID-related changes in countries' CO_2 emissions using confinement indices[6,9], country-level estimates based on energy statistics[10] and near-real-time activity data[5,11] were somewhat slower. And even still, the changes in total U.S. emissions reported by these studies inevitably masked considerable subnational variation related to states' substantially different economies, energy systems, and populations, as well as COVID-19 incidence rates and public health responses[12]. Thus, as states reopen and recover from the pandemic and policymakers pursue rapid changes in energy infrastructure and reductions in emissions, there remains an urgent need for more timely, detailed, and accurate estimates of U.S. emissions.

[1] In some cases, these net-zero targets are CO_2-only, and in others encompass all greenhouse gases.

Here, we present a database of near-real-time, sector-specific, state-level estimates of daily fossil fuel CO_2 emissions (which we name the U.S. Carbon Monitor, us.carbonmonitor.org) and use it to analyze changes and variability in emissions between January 1, 2019 and December 31, 2020. Details of our data sources and approach are found in the *Methods* section. In summary, we calculate daily, state-level CO_2 emissions using datasets of hourly electricity power production by energy sources[13], daily natural gas consumption[14], daily distance traveled[15], daily aircraft flights and distance flown[16], and monthly consumption/sales of motor gasoline, diesel, jet fuel and natural gas[17,18]. We then compare differences in states' emissions and evaluate key drivers of such differences using additional datasets of daily temperature[19], gross domestic product (GDP)[20], COVID-19 incidence rates[21], and stringency of public health responses[12].

Near-real-time daily emissions

Figure 1 and Supplementary Figure 1 compare daily fossil CO_2 emissions in 2020 and 2019 for the U.S. as a whole (Fig. 1A) and the U.S. states (Figs. 1B-1R and S1). As a whole, U.S. emissions decreased by 10.1% (517 Mt CO_2) in 2020 as compared to 2019 (Fig. 1A). This emission decline began before the COVID-19 pandemic was contributed by the power, residential and commercial sectors (Fig. 2A). The sudden and sharp drop of emissions in mid-March corresponds to the start of strict COVID-19 lockdowns, with daily emissions reaching ~10 Mt CO_2 per day in April of 2020—probably the lowest level in decades (monthly emissions during 1973-2018 were greater than 332 Mt[22]—roughly 11 Mt per day). The COVID-related decrease in 2020 emissions was most pronounced in April and May (−20% in those months compared with 2019), and emissions began to recover in late May and June, as lockdown restrictions in many states eased. During the months of June through November, national emissions remained 7-13% lower in 2020 than 2019, but higher emissions from the power and residential sectors partially offset decreases in transportation emissions during December 2020 so that total emissions were similar to December 2019 (Figs. 2 and S2).

Among states, percent changes in 2020 emissions varied considerably, from large decreases in Hawaii and Montana (-22.7% and -20.8%, respectively; Figs. 1B-1J and 2C) to more modest decreases and even increases in other states (Figs. 1K-1R and 2C). The states with larger relative decreases include both large emitters such as California (−14.0%), Illinois (−17.3%), Indiana (−14.6%) and Georgia (−15.6%), as well as smaller emitters such as New Jersey (−17.3%), Washington (−14.7%), Arkansas (−15.0%), Massachusetts (−16.8%), Montana (−20.8%), and Hawaii (−22.7%) (Figs. 1, 2C and S1). In nearly two-thirds of U.S. states, December emissions were still lower in 2020 than 2019, including California, New Jersey, Washington, Massachusetts and Hawaii (where emissions were 11-18% lower in 2020 than 2019; Figs. 1 and S1).

Sectoral patterns

The bar charts in Figure 1 show the sectoral breakdown of each states' 2019 emissions for reference, and Figure 2 highlights sector-specific changes in emissions 2019-2020 both for the U.S.

overall (Figs. 2A) and each state (Figs. 2B and 2D). States with the largest decreases in emissions include some in which most of the reductions were related to road transportation and aviation, such as California, New Jersey, Washington, Massachusetts and Hawaii (green and blue in Figs. 2B, 2D, and S3), and others in which more than half of the decreases were from the power sector, such as Illinois, Indiana, Georgia, Washington, Arkansas and Montana (red in Figs. 2B and 2D).

States with smaller relative decreases in 2020 emissions were also often states with lower overall emissions, such as Alaska, Mississippi, Delaware, North Dakota, Idaho, Louisiana, Connecticut and Kansas, where statewide lockdowns were also brief or absent. However, relative decreases in emissions 2020-2019 were also modest among some higher emitting states where lockdowns were not very strict, such as Texas, Florida, Louisiana and Ohio (where emissions in each case only fell by 4%-7%). Indeed, in Louisiana and Ohio, December emissions were 7% and 3% higher in 2020 than 2019, respectively.

Nationwide, roughly half of the decrease in 2020 emissions occurred in the road transport and aviation sectors, which dropped by 159 and 90 Mt CO_2 respectively, compared to 2019 (31% and 17% of the total drop, respectively; Figs. 2A and S2). The sudden onset of these emissions decreases was coincident with the beginning of lockdowns in mid-March as all states responded to the pandemic (Figs. S2 and S3). In the month of April, emissions from road transportation and aviation were 30% and 65% lower in 2020 than 2019 (Fig. S2). As lockdowns eased in May and June, emissions from road transportation and aviation in many states began to recover, and in the month of December 2020 road emissions were approaching 2019 levels in Mississippi, Delaware, Idaho, Louisiana, Connecticut, Kansas, Florida, Arkansas, Georgia, Montana and Hawaii (Figs. 2, S2 and S3). However, this was not the case everywhere in the U.S. For example, in California, New Jersey and Washington, road transportation emissions were still 11%-21% lower in December of 2020 than in 2019. In total, December 2020 road transportation and aviation emissions in the U.S. remained 8% and 33% lower respectively than in December of 2019.

Emissions from the U.S. power sector also decreased substantially in 2020, down 10.6% from 2019 levels (-171 Mt CO_2, accounting for a third of the total decrease in 2020), but unlike transportation emissions, this decline began before the COVID-19 pandemic in many states (red in Figs. 2A and S4). This is because the decrease in power sector emissions reflects a combination of weather (a warmer winter in 2020[23]), longer-term decreases in the carbon intensity of electricity generation (e.g., due to transition from coal to natural gas and renewables), as well as changes in electricity demand due to the pandemic. Decreases in power sector emissions were concentrated in the first half of 2020; from January through May of 2020, power emissions were 18.5% lower in 2020 than in 2019, but were only 2.4% lower in the months of July and August, and December emissions (and fossil fuel power generation) were greater in 2020 than 2019 (Fig. S2). Among the different states, 2020 decreases in power sector emissions were largest in Montana, New Jersey, Illinois, Georgia, Arkansas, Washington and Indiana where in each case electricity generation from fossil fuels also dropped markedly (Figs. 2B and S4).

U.S. residential and commercial emissions decreased by 8.0% (-28 Mt CO_2) and 10.9% (also -28 Mt), respectively (each accounting for ~5% of the total 2020 decrease; tan and gold in Fig. 2A). As with electricity-related emissions, the 2020 decrease in residential and commercial emissions began before COVID as a result of the warmer winter[23] (Fig. 3D). Between April and June, residential emissions were 6%-15% greater than in 2019 but commercial emissions were 6%-8% less, reflecting the combined effects of differences in weather and COVID lockdowns (Fig. S2). After correcting for differences in temperature in the two years, we find a 6% drop in natural gas consumed by the commercial sector (which may be attributed to lockdowns), but only a very small decrease in residential gas consumption (-0.4%; Fig. 3D).

Lastly, emissions from U.S. industry were 4.2% lower in 2020 than 2019 (−42 Mt CO_2, or ~8% of the total U.S. decrease; orange in Fig. 2A). Prior to March 2020, industry emissions fluctuated around the same level as in 2019, down 3.1% in January and up 4.1% in February. But emissions dropped sharply during the initial lockdowns, declining by 10.3% and 11.2% in April and May, respectively. However, as with electricity, industry emissions recovered beginning in June and in December 2020 had approached the level of 2019 (Fig. S2).

Decarbonization

Figure 3A decomposes U.S. fossil CO_2 emissions 2016-2020 (black curve) into quarterly changes in Gross Domestic Product (GDP; red), energy use per unit GDP (energy intensity of the economy; orange), and CO_2 emissions per unit energy (carbon intensity of energy; blue) as per the Kaya identity[24]. Doing so reveals that the 10.1% decrease in U.S annual emissions from 2019 to 2020 was caused by a 3.5% decrease in GDP, a 4.0% in energy intensity of the economy, and a 3.0% decrease in carbon intensity of energy (Fig. 3A). Although the declines in these factors were particularly sharp in the second quarter of 2020, we also see that emissions are typically at their lowest in Q2 (Fig. 1A) when demands for heating/cooling and transportation are low (i.e. not a major holiday or vacation season and milder climate with decreased heating and low cooling demand). Yet the 2020 decreases in energy and carbon intensities build on longer-term trends: the U.S. economy has been decarbonizing largely by shifting from coal to natural gas (green curve in Fig. 3A), and that decarbonization continued during the COVID-19 pandemic.

Yet progress varies considerably among states. GDP in 2020 decreased by 3-6% in most (39) states (Fig. 4G), but CO_2 emissions per unit GDP dropped by 12-18% in states such as Montana, Hawaii, Washington, Illinois, New Jersey, Massachusetts, Georgia, Arkansas, and Indiana (where total emissions also declined substantially; Figs. 4B and 4H) but increased by 1-7% in states such as Alaska, Mississippi, Delaware, Louisiana and Wyoming (states with relatively small shares of the nation's GDP and small decreases in their emissions; Figs. 4B and 4H). While the decarbonization progress continued in most states, it has slowed down in a few states (Fig. S5).

Power Generation. Changes in power sector emissions in 2020 relative to 2019 reflect changes in both electricity demand as well as the carbon intensity of electricity generation (Fig. 3B). While

U.S. electricity generation/demand dropped by 3%-4% in 2020, electricity generation at fossil fuel-burning power plants decreased by 6% (though fossil fuel power generation did increase somewhat in a few states; Fig. S6C). Importantly, by correcting for differences in daily temperature (see *Methods*), we estimate that weather explained only ~15% of the 2019-2020 decline in annual electricity consumption (Figs. 3D and S6; though its contribution can be higher in particular months). Rather, the COVID lockdowns seem to have caused substantial decreases in commercial and industrial electricity use that were not entirely balanced by increases in residential electricity use (Figs. 3D and S6).

The share of electricity generation from fossil fuels decreased slightly in 2020 than in 2019 (Fig. 3B). But more importantly, as natural gas prices fell[25], the longer-term transition from coal to natural gas continued in first half of 2020, reflected in a 13.1% decrease in the carbon intensity of electricity (blue, green, and red lines in Fig. 3B). However, slowing natural gas production during the COVID lockdown and recession led to a rebound (increases) in natural gas prices in the second half of 2020[25], restoring the share of electricity from coal to 2019 levels (red curve in Fig. 3B) and with it the carbon intensity of fossil fuel and total U.S. electricity (blue and orange curves in Fig. 3B). As a result, the carbon intensity of electricity decreased in many states in the first half of 2020, but then rebounded in the second half of 2020 (Fig. S7). While renewables increased in many states following or even greater than historical trends, the 2020 increases in power sector emissions in New York, California, Connecticut and Mississippi reflect their lack of gains in renewables in 2020 and the associated increases in carbon intensity of electricity (Figs. 2B, S6 and S7).

Road transportation. The decline of road transportation emissions during COVID was mainly from the reduction in distances travelled by passenger vehicles and thereby gasoline consumption, which dropped by 38% in April of 2020 compared to the same month in 2019 and remained 15% lower than in December of 2020 than 2019 (blue bars in Fig. 3C). In contrast, diesel fuel consumption by larger trucks declined by only 15% and recovered to near 2019 levels by December (tan bars in Fig. 3C). As a result of the increased share of heavy-duty diesel vehicles, although the average fuel economy of U.S. cars and trucks has been improving for several years[26], fleetwide carbon intensity per vehicle-miles increased by 17% in April of 2020 (and by 4.3% over the year; Fig. 3C). The maps in Figure S7 show further that increases in fleetwide carbon intensity were widespread.

Residential and commercial sector. Altogether, electricity and natural gas account for >85% of final energy use in U.S. residential and commercial sectors[22]. As discussed in the context of the power sector, residential and commercial energy uses were affected by COVID lockdowns in 2020. Whereas temperature has historically been the main driver of variability in residential and commercial energy use and emissions in the U.S., we find a temperature-corrected increase (+3%) in electricity use and a very small decrease (-0.4%) in natural gas by the residential sector in 2020, consistent with people working from home (blue and black curves at left in Fig. 3D). Contrarily, there were clear reductions in both commercial electricity and natural gas use (both -6% after temperature correction) due to closed offices and businesses (right of Fig. 3D). The maps in Figure S6 show further that increases in residential electricity use were widespread, but were outweighed by the decreases in commercial energy use. Note that changes in emissions related to electricity are assigned to the power sector regardless of the sector in which the electricity is used; changes in residential and commercial emissions reflect direct emissions only, e.g. burning of natural gas for heating.

Discussion

The detailed emissions estimates we present here represent a leap forward in the ability to monitor emissions by key sectors in each U.S. state almost as they happen, and to assess the drivers of changes. The COVID pandemic is a valuable context in which to evaluate such estimates. For example, our results reveal offsetting changes in residential and commercial emissions due to lockdowns; large decreases in passenger vehicle emissions even as emissions from trucks moving freight mostly persisted; and rebounding carbon intensity of electricity in the second half of 2020 as natural gas prices rose. Moreover, such trends and their drivers can be compared across states and evaluated over time to assess the relative effectiveness of climate and energy policies.

For example, we see that the states which imposed more stringent public health restrictions[12] in response to the COVID pandemic ultimately experienced both lower incidence rates of the disease and larger decreases in their CO_2 emissions—yet changes in their GDP that were similar to states with less stringent policies (Fig. 5). In an era of renewed climate ambition, such inter-state comparisons may be used to identify local and state policies aimed at achieving multiple goals such as decarbonization, jobs growth, and environmental justice, and to encourage their broader implementation. Or, equally important, future updates of our results may reveal that a policy is not achieving the desired outcomes and why not, thus supporting more responsive policies and accelerating progress.

Our emission estimates are derived from multiple data sources, each with related uncertainties that are exceedingly difficult to quantify. However, we have made extensive comparisons of our estimates with independent datasets to the extent that they overlap, and found that our results are generally consistent with well-established products such as U.S totals from the U.S. Energy Information Administration[22] and the International Energy Agency[10] (Fig. S8). We also cross-checked our results with multiple data sources and rely more heavily on data whose uncertainties we think are likely to be small. For example, we constrain daily estimates of transportation emissions by monthly fuel consumption data and daily activity. In the future, our methods may be improved to include even more detailed, timely, and redundant data streams, allowing us to more thoroughly validate our estimates.

Despite uncertainties, bottom-up estimates of emissions such as ours which rely on reported energy use and activity data have long been the gold standard of emissions accounting, and our method improves upon the currency and detail of such estimates. Using such results, we will continue to monitor the recovery of the U.S. economy, paying particular attention to outstanding questions such as whether remote work and teleconferencing will have a lasting effect on the distances and modes of transportation[27], and how investments in new energy infrastructure affect emissions throughout the country. Regardless, the detail and timeliness of our emissions estimates can facilitate more agile and adaptive management of CO_2 emissions during both the pandemic recovery and the ongoing energy transition.

Methods

State-level annual and monthly emissions based on EIA's energy data.

Annual total energy-related CO_2 emissions by sector and source in 2018 for all the states in the U.S. are directly obtained from State Carbon Dioxide Emissions Data[3] released by U.S. Energy Information Administration (EIA). We then disaggregate the state-level annual emissions in 2018 into monthly level based on monthly consumption data of key fuels (e.g., motor gasoline, diesel, jet fuel and natural gas) which are updated more frequently at state level from EIA[17,18,28]. We assume that the emission factors remain unchanged for each state in 2019 and 2020 when comparing with 2018. We estimate state-level monthly emissions by sector in 2019 and 2020 based on the change of monthly consumption data of key fuels[17,18,28] in 2019 and 2020 compared to the same period of 2018.

For the power sector, we use state-level monthly fuel-specific consumption data from Electric Power Monthly[28]. For the industrial, residential and commercial sectors, we use state-level monthly natural gas consumption for each sector[18], with each fuel type constrained by the trend of national-level total monthly consumption[22]. For road transportation sector, we use prime supplier sales volumes of motor gasoline and diesel[17]. For the aviation sector, we use prime supplier sales volumes of kerosene-type jet fuel[17].

State-level daily emissions in 2019 and 2020.

For 2019 and 2020, the state-level monthly emissions are allocated to each day by state-level daily indicators for each sector. For the power sector, we use state-level daily electricity generation produced by coal, petroleum and gas by summarizing the electricity produced of 63 balancing authorities from the EIA's Hourly Electric Grid Monitor[13] (representing >93% of US electricity production). We remove the outliers and fill the missing values by using similar methods of Ruggles et al. (2020)[29]. For industrial sector, we use daily natural gas pipeline deliveries to industrial end users from Genscape[14].

For road transportation sector, we use daily distance traveled based on the Trips by Distance data from Bureau of Transportation Statistics[15]. For the aviation sector, we use daily kilometers flown of flights (domestic and international) per state collected from the FlightRadar24 database[16]. We classify the kilometers flown per aircraft class (light, medium and heavy), with the emission factors per km flown of medium and large aircrafts are assumed to be 1.5 and 3 times that of small aircrafts[30]. Emissions are attributed to the state of departure airport and are calculated separately for U.S. domestic flights and international flights departing from each state, with monthly totals rescaled according to jet fuel consumption[17].

For residential and commercial sector, we estimate daily emissions based on heating degree days (HDDs). We calculate daily and monthly population-weighted HDDs for each state based on the ERA5 reanalysis of 2-m air temperature[19]. Residential and commercial emissions are split into heating emissions and cooking emissions: emissions from cooking are assumed to remain independent of temperature; emissions from heating are assumed to be a linear function of the heating demand (HDDs). A regression model based on monthly HDDs and monthly residential and commercial emissions in 2019 is developed to estimate the annual percentage of emissions from heating demand in each state. We then estimate daily emissions in 2019 and 2020 based on changes in daily HDDs.

We have tried to correct the electricity use data and the natural gas consumption data of the residential and commercial sector for the temperature effect, i.e., energy consumption change caused by temperature change from year 2019 to year 2020. This was achieved by establishing linear regressions between monthly energy consumption and HDDs and CDDs (cooling degree days) for each state. Linear regression models are developed based on monthly energy consumption and monthly HDDs and CDDs data in 2019. Similar to previous studies, we include HDDs and CDDs in the regression models of electricity consumption, and CDDs only in the regression models of residential and commercial natural gas consumption[5,7,8]. We then use the linear regression model and the temperature change between year 2020 and year 2019 (i.e., changes in HDDs and CDDs on the same month of these 2 years) to calculate the corrected energy consumption for year 2020.

Data availability

The state-level emission data generated by this study are available at the U.S. Carbon Monitor (https://us.carbonmonitor.org). All data sources for emissions estimates can be found in the *Methods*. The energy data are obtained from EIA (https://www.eia.gov). The GDP data are from U.S. Bureau of Economic Analysis[20] (https://apps.bea.gov/regional/downloadzip.cfm). The VMT data are from U.S. Department of Transportation (https://www.fhwa.dot.gov/policyinformation/travel_monitoring/tvt.cfm). Stringency index scores are obtained from the Oxford COVID-19 Government Response Tracker[12] (https://github.com/OxCGRT/USA-covid-policy). The reported cases and incidence rate of COVID-19 are from the COVID-19 Data Repository by CSSE at Johns Hopkins University[21] (https://github.com/CSSEGISandData/COVID-19).

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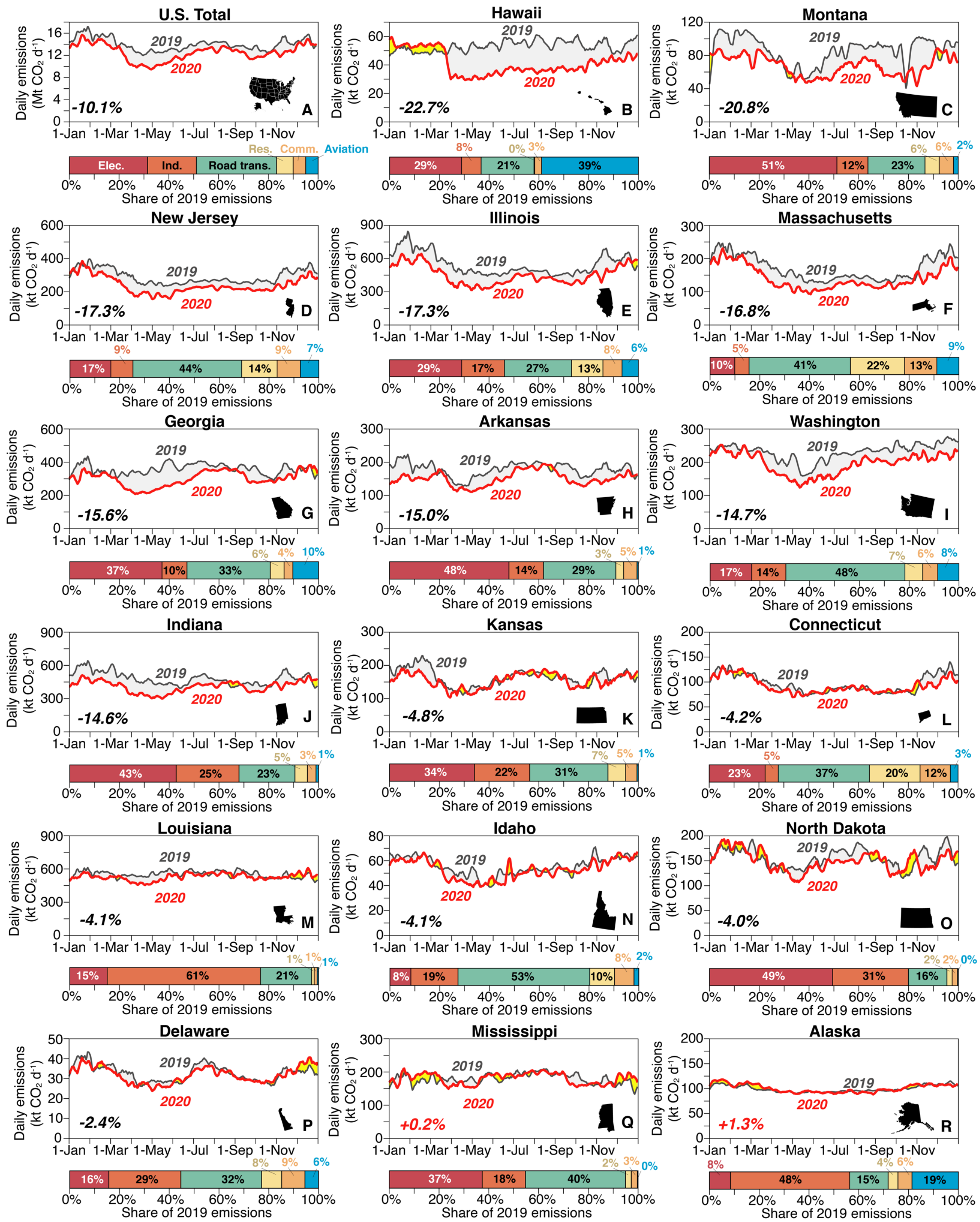


Figure 1. Daily CO_2 emissions for the whole of U.S. (panel A) and selected U.S. states (panels B-R) in 2019 and 2020 (7-day running mean; grey and yellow shaded areas indicate decreases and increases in 2020 emissions, respectively). Bars show the sectoral breakdown of annual emissions in 2019, and the percentages in the lower left of each panel reflect the relative change of total annual emissions in 2020 compared with 2019. See Supplementary Figure 1 for all other states.

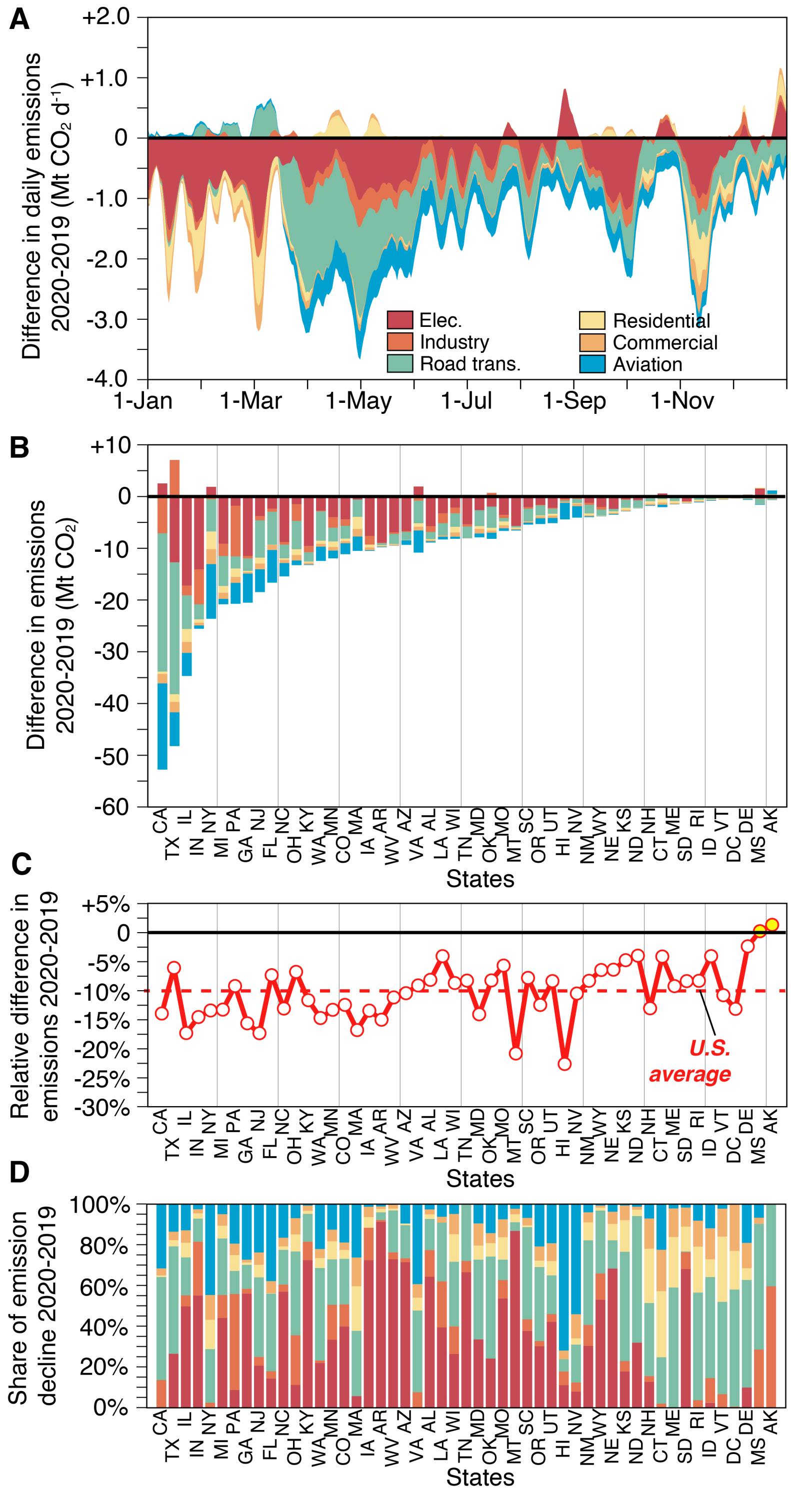


Figure 2. Sectoral contribution to changes in CO_2 emissions. **A,** Sectoral contribution to daily changes in the U.S. total CO_2 emissions, shown as the 7-day running mean of daily differences between January 1st and December 31th of 2019 and 2020. **B,** Changes in annual emissions by sector in each of U.S. states in 2020 as compared to 2019. **C,** Relative change of annual total emissions by state in 2020 compared with 2019. **D,** Sectoral contribution to the total decline of CO_2 emissions in each state.

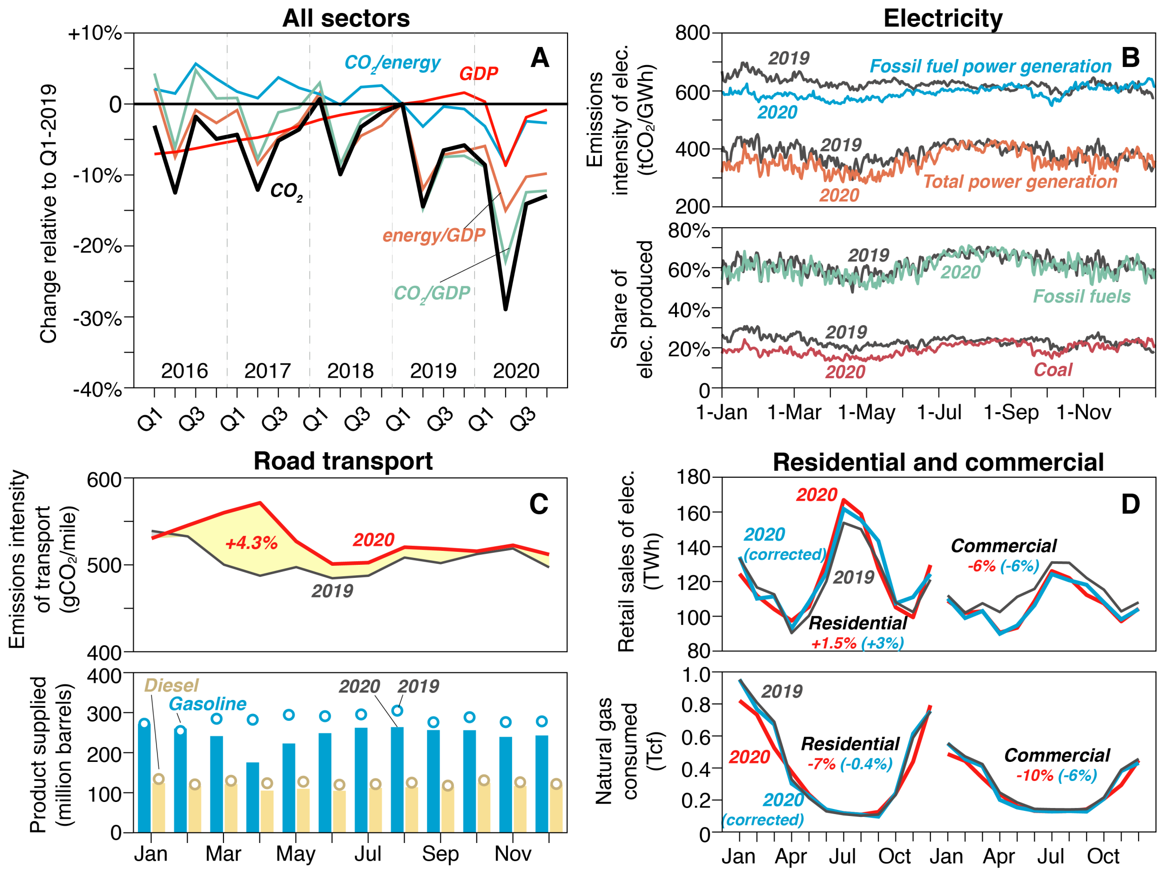


Figure 3. U.S total changes in drivers and carbon intensity by sector. **A**, Changes in total energy-related CO_2 emissions, GDP, energy intensity and carbon intensity in each quarter from 2016 to 2020 (relative changes to the first quarter of 2019 are shown). **B**, Daily changes in carbon intensity of power generation and the shares of power generation by source in 2020 as compared to 2019. **C**, Monthly changes in carbon intensity per vehicle-miles and product supplied of motor gasoline and distillate fuel oil in 2020 as compared to 2019. **D**, Monthly consumption of electricity and natural gas by the residential and commercial sector in 2019 (black curves) and 2020 (red curves). We corrected the temperature effects for residential and commercial energy consumption in year 2020 by using temperatures in year 2019 (blue curves).

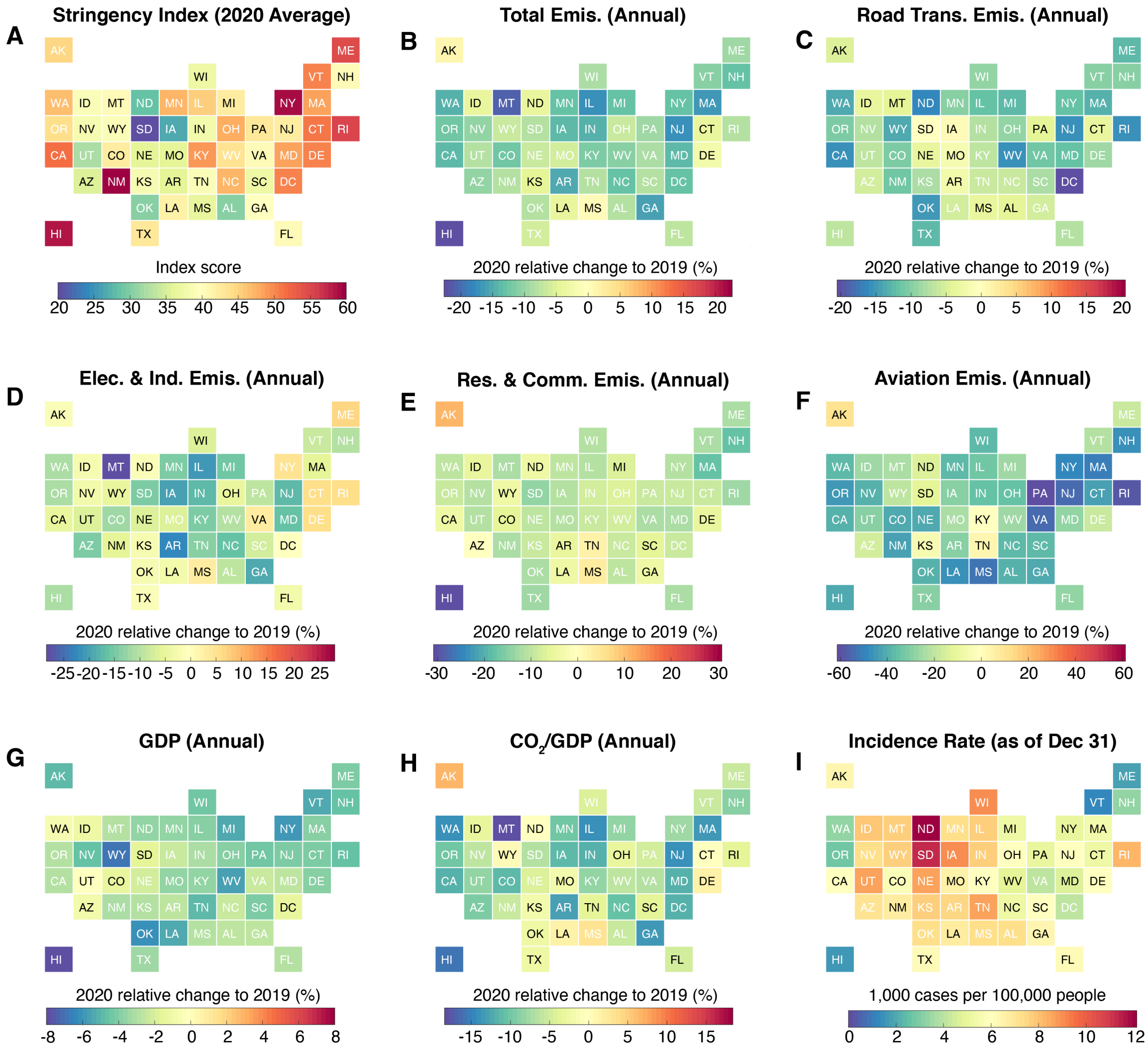


Figure 4. State-level indicators and changes in CO_2 emissions and drivers. **A,** Average stringency index score in 2020. **B-F**, Changes in annual emissions by sector in 2020 compared with 2019. **G-H**, Changes in GDP and carbon intensity in 2020 compared with 2019. **I**, Incidence rate of COVID-19 by December 31, 2020.

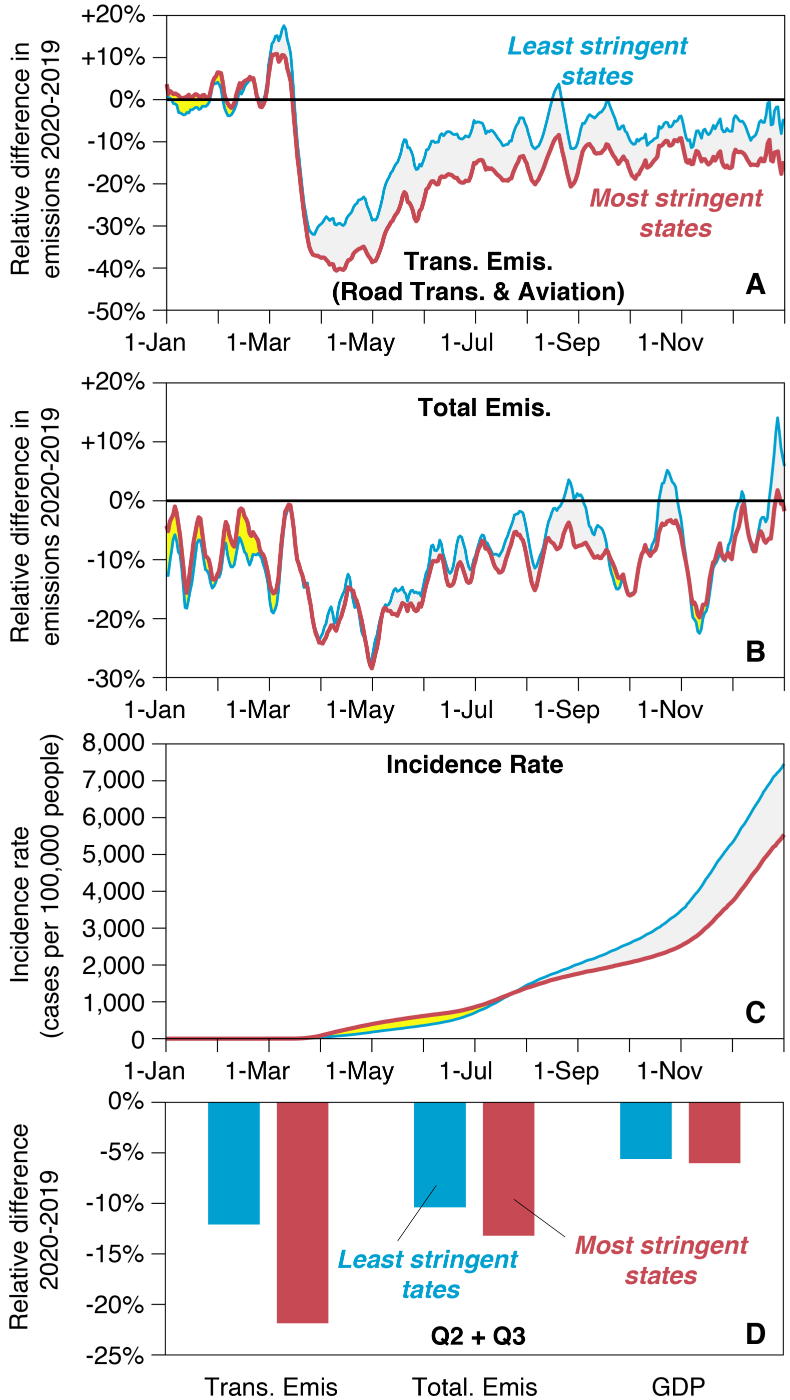
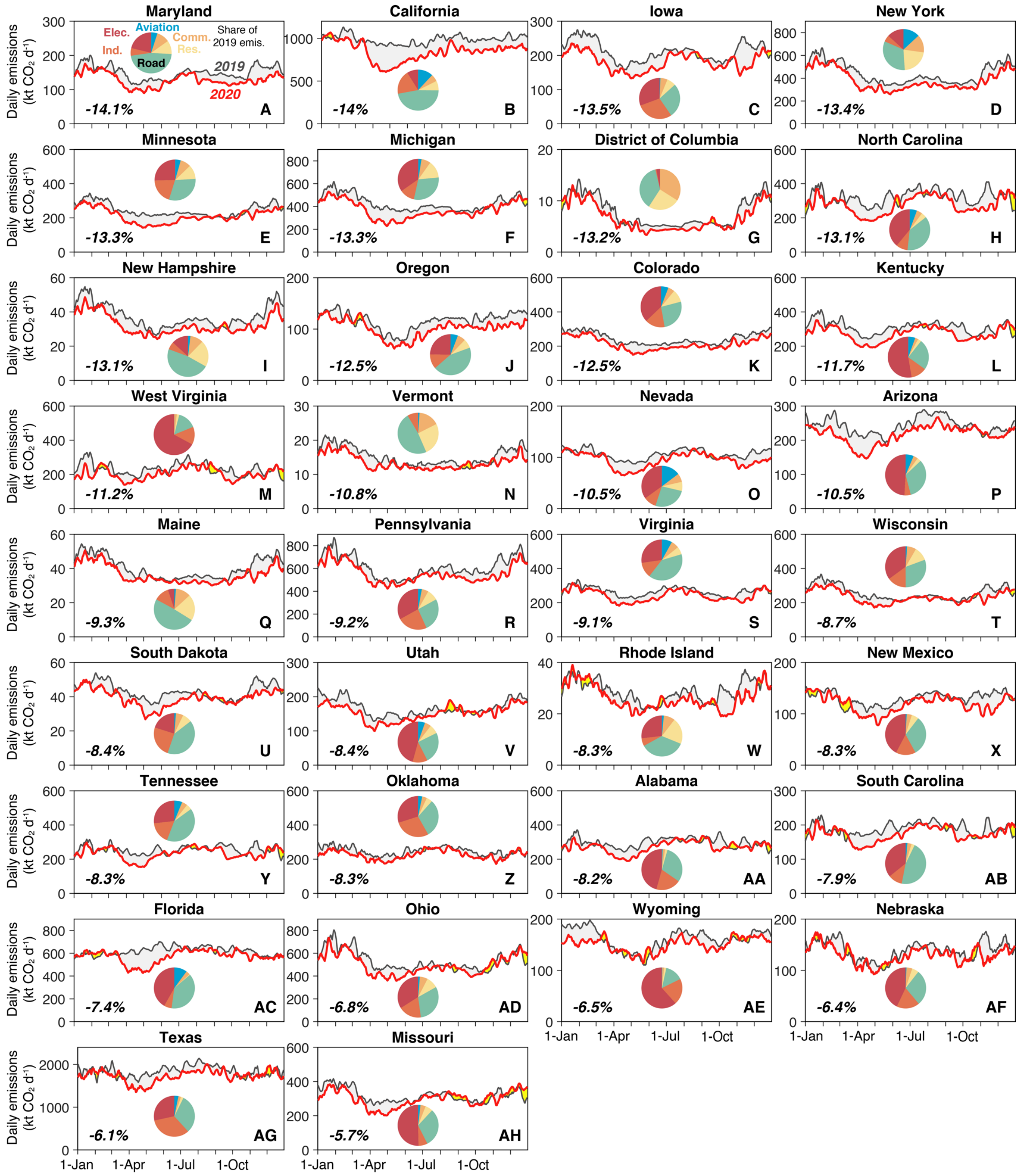
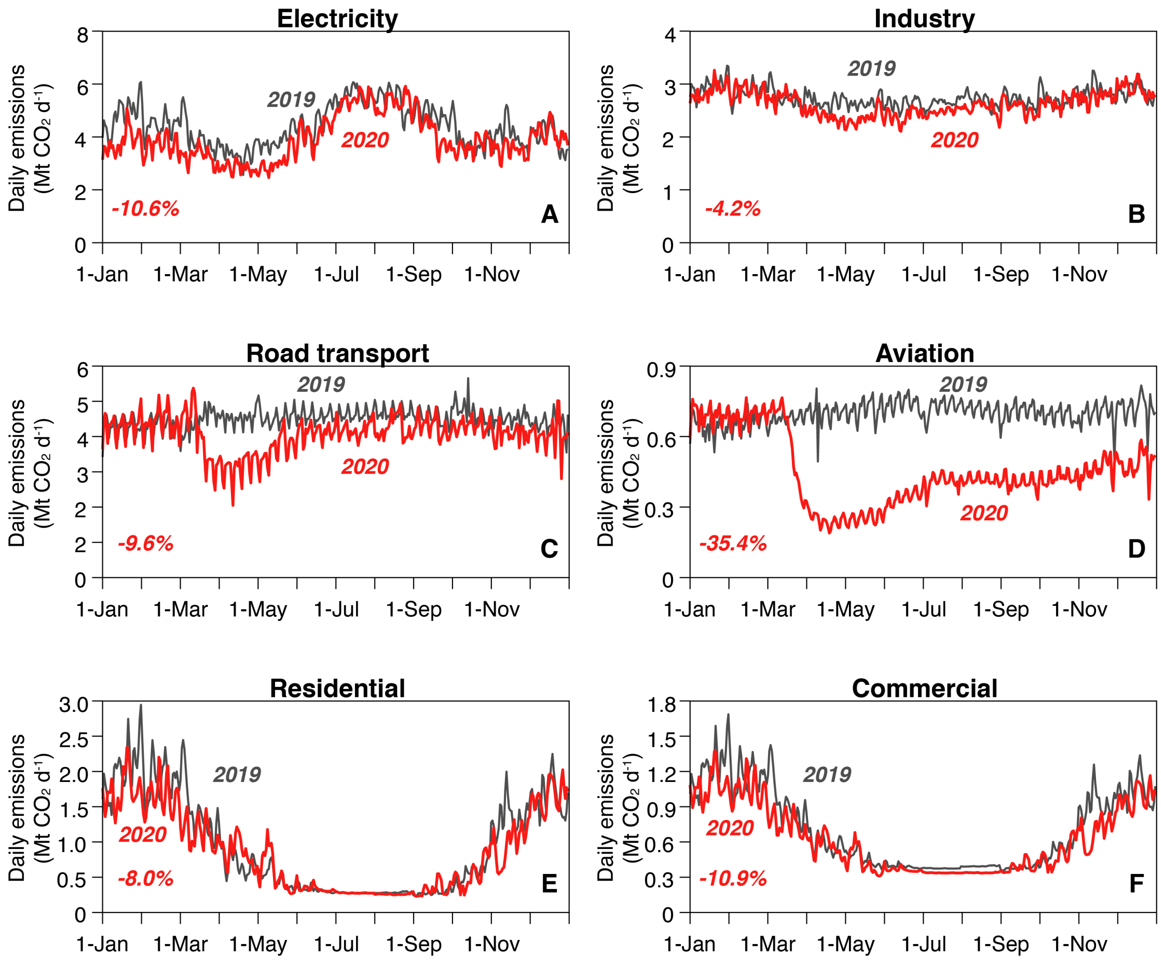


Figure 5. Changes of emissions, incidence rate of COVID-19 and GDP in two groups of US states. Daily changes of transportation emissions (**A**) and total emissions (**B**) in 2020 as compared to 2019. **C**, Cumulative incidence rate of COVID-19 in 2020. **D**, Relative changes of emissions and GDP in the second and third quarters in 2020 as compared to 2019. All the U.S. states are divided into two groups: least stringent states (stringency index < 40) and most stringent states (stringency index ≥ 40), by average stringency index score in 2020 (Fig. 4A).

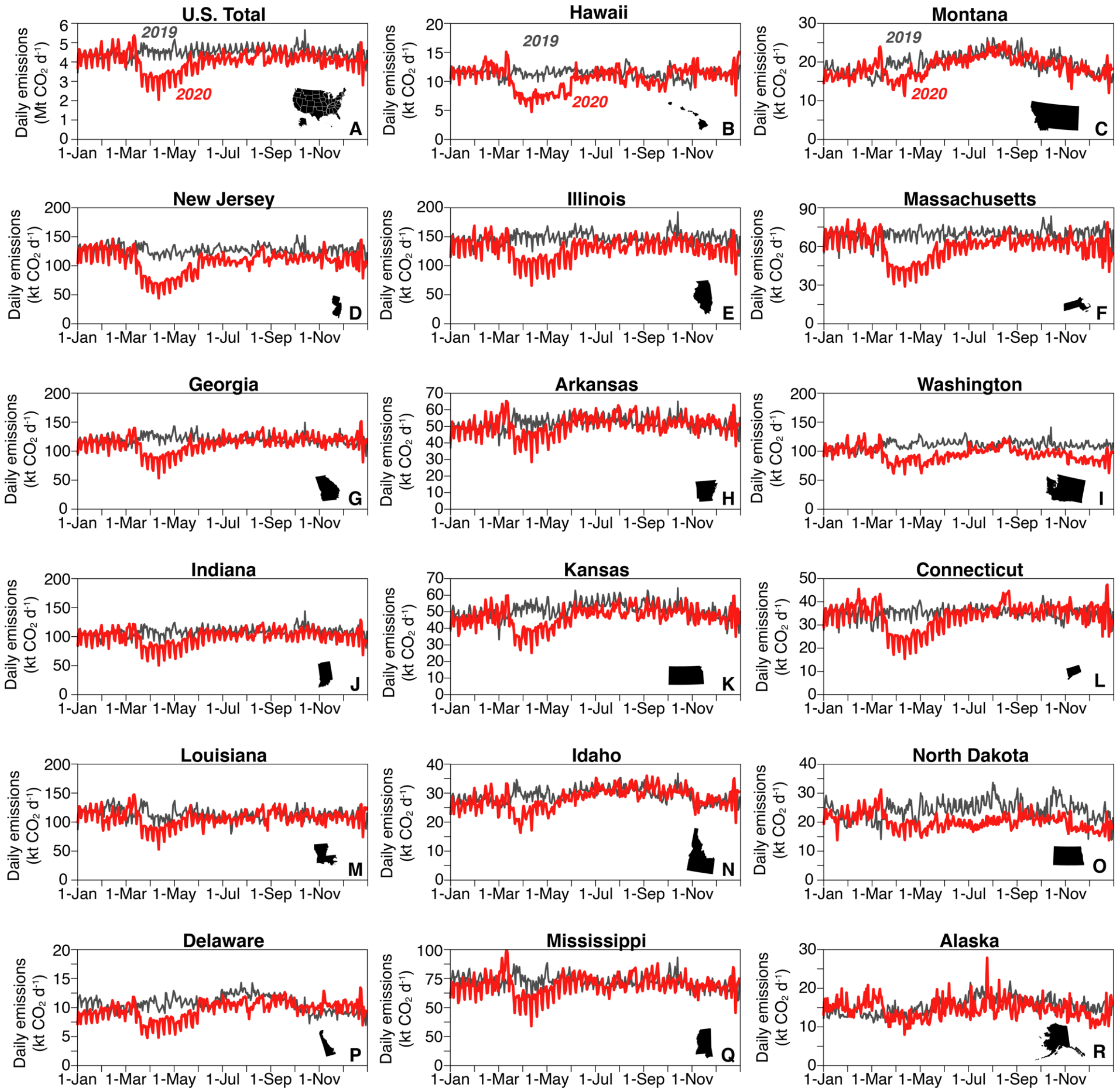
Supplementary Information



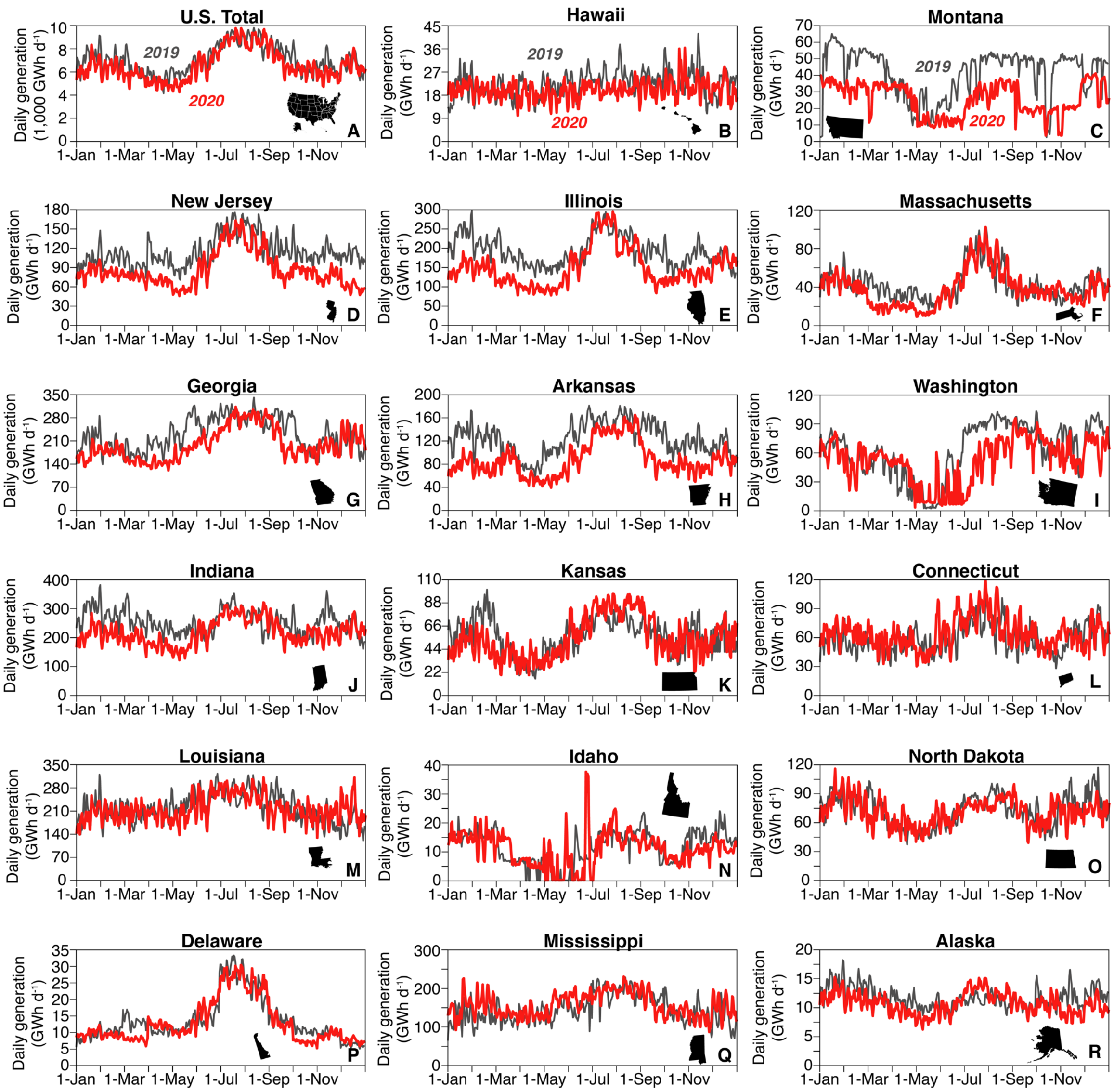
Supplementary Figure S1 | Daily CO_2 emissions for selected U.S. states in 2019 and 2020 (7-day running mean; grey and yellow shaded areas indicate decreases and increases in 2020 emissions, respectively). Pies show the sectoral breakdown of annual emissions in 2019, and the percentages in the lower left of each panel reflect the relative change of total annual emissions in 2020 compared with 2019.



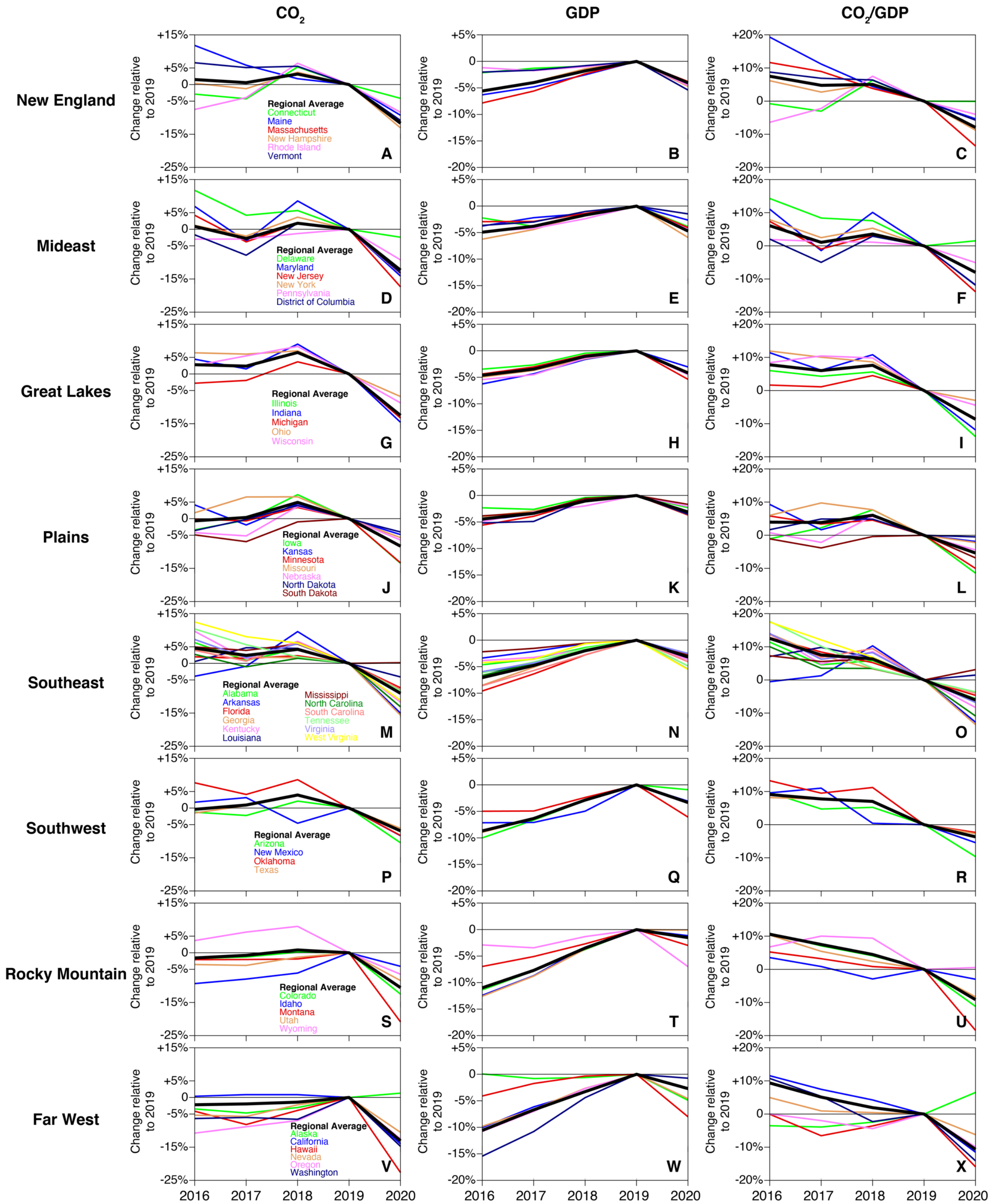
Supplementary Figure S2 | Daily U.S. CO_2 emission by sector. U.S. emissions in 2019 (black) and 2020 (red) from the electric power (A), industry (B), road transportation (C), aviation (D), residential (E), and commercial (F) sectors.



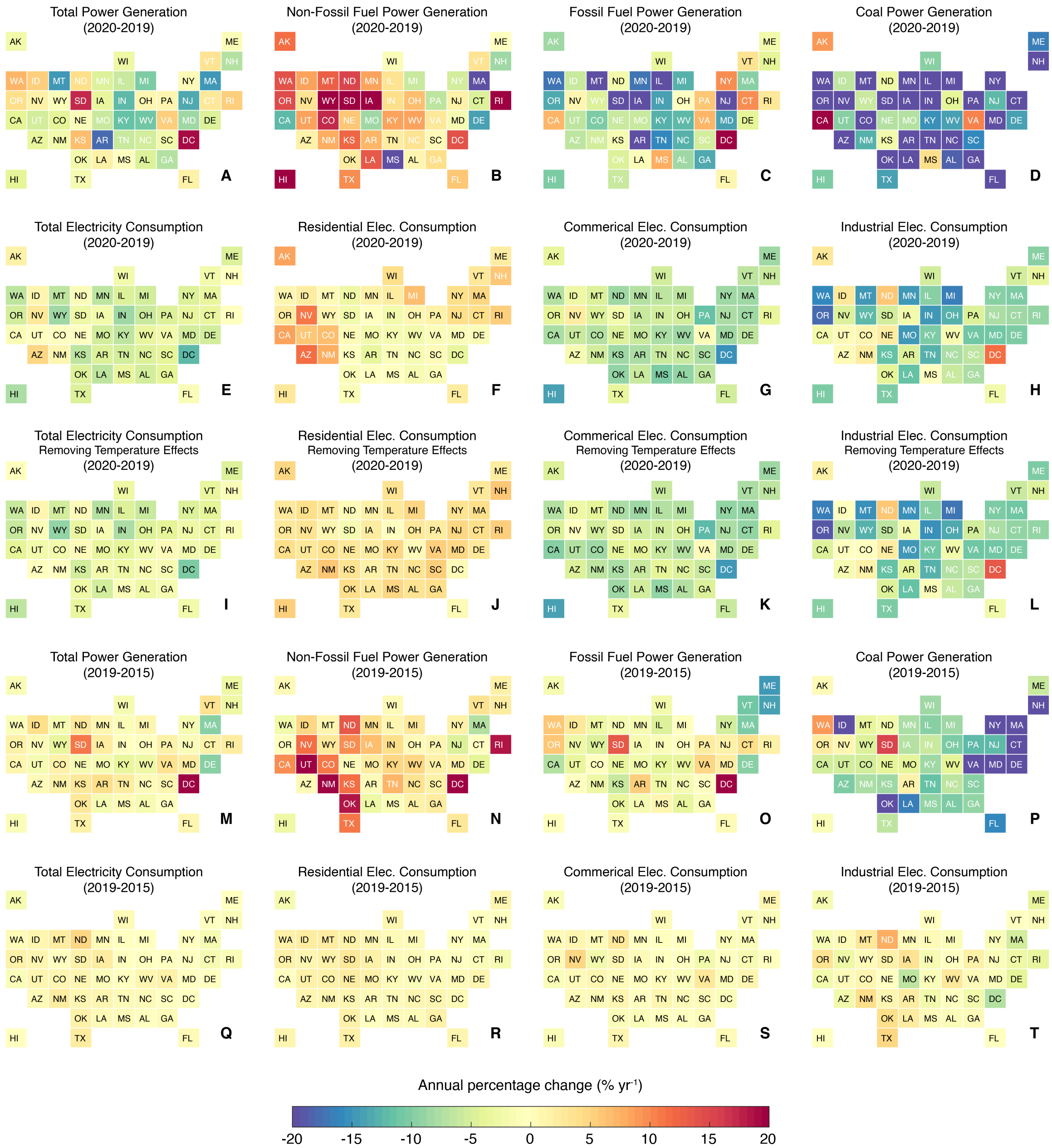
Supplementary Figure S3 | Daily CO_2 emissions from road transportation in selected states. Road transportation emissions in 2019 (black) and 2020 (red) in the U.S. (A) and states with the largest and smallest relative decreases in total emissions (B-J and K-R, respectively).



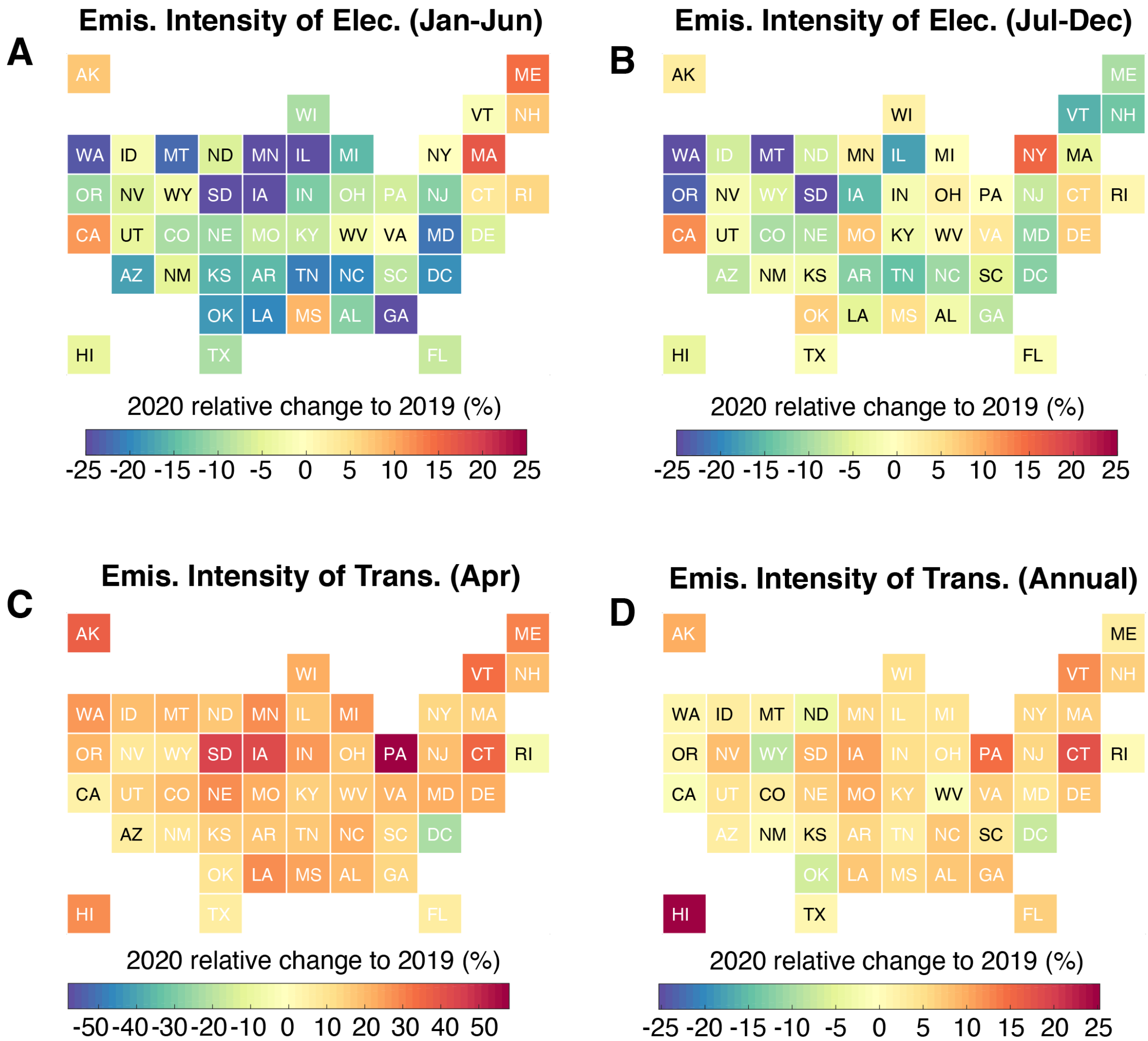
Supplementary Figure S4 | Daily electricity generation from fossil-fuel burning power plants in selected states. Electricity generation from fossil-fuel burning power plants in 2019 (black) and 2020 (red) in the U.S. (A) and states with the largest and smallest relative decreases in total emissions (B-J and K-R, respectively).



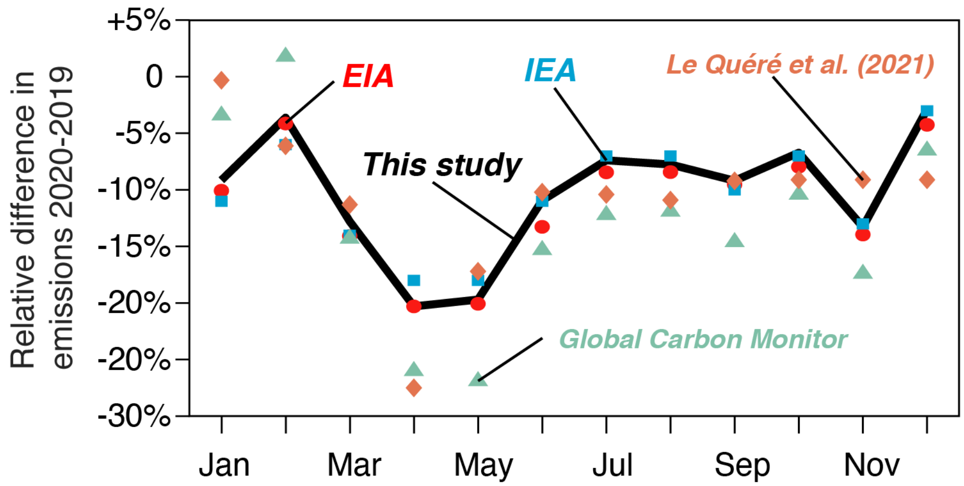
Supplementary Figure S5 | Changes in CO_2 emissions, GDP and carbon intensity by region since 2016. Relative changes to 2019 (in %) are shown. Each state is shown by the thin line, and regional averages are shown by the bold black line.



Supplementary Figure S6 | State-level changes in the power sector. State-level changes in the power sector in 2019-2020 (A-L) and 2015-2019 (M-T).



Supplementary Figure S7 | State-level changes in emissions intensity. State-level changes in emissions intensity of electricity (A-B) and transport (C-D; emissions per vehicle-miles) in 2020 relative to 2019 (in %).



Supplementary Figure S8 | Comparison of changes in the U.S. total emissions by month. Changes in the U.S. total CO_2 emissions by month in 2020 relative to 2019, estimated by this study, EIA[22], IEA[10], Global Carbon Monitor[5], and Le Quéré et al.[31].

5 Liu, Z. *et al.* Near-real-time monitoring of global CO2 emissions reveals the effects of the COVID-19 pandemic. *Nat. Commun.* **11** (2020).

10 *Global Energy Review: CO2 Emissions in 2020* (IEA, 2021); https://www.iea.org/articles/global-energy-review-co2-emissions-in-2020

22 *Monthly Energy Review* (EIA, accessed 26 March 2021); https://www.eia.gov/totalenergy/data/monthly/

31 Le Quéré, C. *et al.* Fossil CO 2 emissions in the post-COVID-19 era. *Nat. Clim. Chang.* **11**, 197-199 (2021).