Staying Grounded: COVID-19 Impact on CO_2 Emissions from Transportation in the United States

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Contents

I. Introduction

When the COVID-19 pandemic spread throughout the United States in March 2020, cities and states locked down, national borders closed, school and work moved online, and health experts recommended against traveling. The virus thereby brought a slowdown to people's need and desire to use cars and airplanes, not to mention an economic crash that left many people unable to afford travel even if it were safe. One year later, the virus continues to spread and people's travel patterns remain far from "normal." A major consequence of this travel restriction is an accompanying opportunity to reduce the carbon dioxide emissions associated with transportation. A number of studies have shed light on the extent to which COVID-19 has reduced transportation related-emissions, finding that, at least toward the beginning of the pandemic, carbon dioxide emissions significantly decreased (He et al., 2020; Huang et al., 2020; Le Quere et al., 2020; Le et al., 2020). As carbon dioxide is the greenhouse most responsible for anthropogenic climate change, these reductions could be an essential step in reaching the goals laid out in the Paris Climate Agreement and holding off the worst effects of global warming. Because cars are major emitters of carbon dioxide, these changing travel patterns also present opportunities to explore the ways in which society can use lessons from the pandemic to mitigate climate change. In order to combat climate change, a similarly global and deadly threat, with the same seriousness that much of the world has brought to COVID-19 policies, climate policymakers should understand what measures can most quickly and effectively create behavioral change during a time of crisis.

The relationship between COVID-19 policies, their impact on transportation, and the resultant effect on emissions reduction in the United States is not straightforward. There are a number of variables that mediate this relationship. For example, government-ordered lockdowns can legally prevent people from going to work or retail locations, in which case the change in transportation-related emissions would be dependent on the length and strictness of the lockdown, which in turn is controlled by the number of cases and the political climate of the jurisdiction. Individuals' perceptions of the threat posed by COVID-19 is also highly variable, which may lead to differential responses with regard to travel even when no shutdown exists. Finally, the impact of COVID-19 on travel reduction was also mediated by the dominant economic sector of a state (e.g., proportion of critical workers). The extent to which these factors mediate the relationship between COVID-19 and transportation-related emission reduction is largely unknown. Based on prior events of similar threat scale, it is still difficult to predict if these declines will last long-term or if human resilience and desire for a recovery from disasters will revert any changes that occurred during the pandemic.

This paper will investigate how the COVID-19-related behavioral change that resulted in carbon emission reduction can apply to climate change. Behavioral response to a disturbance from the "normal order" can vary on both the individual and societal level, as seen in the enforcement of and response to lockdowns and stay-at-home orders in the USA. In the context of COVID-19 and CO_2 emissions, behavioral change manifests as shifts in the amount of miles people travel, the means they use to travel, and the locations they travel to and from. The COVID-19 pandemic has presented evidence that large-scale events that disrupt routine human behavior and demand abrupt changes, such as lockdowns, can decrease emission levels of carbon dioxide, the greenhouse gas most responsible for anthropogenic global warming. However, these behavioral changes that limit carbon dioxide-producing activities often will not occur unless an uncontrollable pressing factor, like government orders, enforces them. This research closely examines three main interactions: how the pandemic has disturbed human-driven "normal" CO_2

emission levels due to traveling, what specific behavioral changes contributed to this disturbance, and what other variables can determine these behavioral changes on a regional level.

The main goal of this paper is to understand how changes in people's travel behavior have impacted carbon dioxide emissions and ultimately could mitigate climate change if these effects are extended by further efforts. On the national level, we examine both changes in transportation and emissions patterns to determine the scale of the change that occurred. On the regional level, we present a case study of the states of Minnesota and Louisiana to understand some of the variables that determine behavioral change. Specifically, we examine COVID-19 lockdown policies as well as economic variables such as primary industry and unemployment and how the pandemic has influenced these variables. Understanding how these variables impact human behavior can help contribute to the development of effective climate mitigating strategies. The findings from this research will provide insights for future efforts to lower CO_2 emissions, which could prevent a rise in global temperature that, after crossing a threshold, ultimately would be as alarming as a pandemic. The results from this study could improve policy-makers' understanding of human perception of disasters with the hope that they can craft meaningful climate policies to reduce carbon emissions and make substantial impacts on global climate change even in the absence of a pandemic.

In this study, we present three main hypotheses. First, we hypothesize COVID-19 preventative measures have considerably altered people's travel patterns, as measured by an increase or decrease in mobility. Secondly, we expect that the magnitude and length of these behavioral changes depends upon the economy and policies of the region in question. Finally, we predict that the changes in travel patterns associated with COVID-19 correspond to a decrease in CO_2 emissions, providing us with insight into future climate change mitigation strategies.

II. Literature Review

Air pollution is a major concern of the Anthropocene and one of the most difficult climate and health issues to address due to the many pollutants and sources for these pollutants. The EPA has six different categories of criteria air pollutants: carbon monoxide, lead in particulate matter, nitrogen oxides, ground-level ozone, particulate matter, and sulfur oxides (National Center for Environmental Health, 2019). Most of these air pollutants are formed during the burning of fossil fuels in cars, power plants, and industrial facilities (National Center for Environmental Health, 2019). Carbon dioxide is not considered to be a classic air pollutant, because it does not adversely affect human health directly when people inhale higher levels of it in the air. Although it has not been officially included in the list of most harmful air pollutants, carbon dioxide is the biggest contributor to the greenhouse effect, hence a primary cause of global climate change.

Road and air traffic play a large role in this pollution: they are responsible for over 55% of U.S. NO_x emissions, less than 10% of U.S. volatile organic compound emissions, and less than 10% of US PM2.5 and PM10 emissions (US EPA, 2015b). Transportation produces 28% of U.S. greenhouse gas emissions (US EPA, 2015a). As such, a decrease in the amount of car and air travel would reduce these pollutants, particularly in developed countries where transportation is the main source of emissions. Recent studies have found that lockdowns and the decrease in transportation due to COVID-19 have brought levels of many pollutants down.

Improved air quality, even if only temporary, can significantly impact public health. Air pollution results in 3.3 million deaths annually worldwide (Lelieveld, n.d.). Air pollution commonly causes cerebrovascular disease and ischemic heart disease which can lead to strokes and heart attacks respectively, and respiratory diseases like asthma and lung cancer (Lelieveld, n.d.). In addition directly causing cardiac and respiratory problems, air pollution aggravates climate change, generating many other health issues related to heat stress, food insecurity, and insect-borne disease (which is caused and spread by species' climate migration). Combined with a global pandemic, air pollution can be even more deadly. One of the factors that accounts for higher risk of death from COVID-19 is higher levels of $PM_{2.5}$ (Coker et al., 2020; Wu et al., 2020). Even before the COVID-19 pandemic, a study of the 1918 Spanish Influenza found higher mortality rates associated with locations with poor air quality (Severnini et al., 2015). There are certainly many other factors at play in these mortality studies, as locations with poor air quality tend to be cities. However, these studies still make clear that worse air quality is associated with higher mortality, indicating that improved air quality can offer significant health benefits.

Clearly, the pandemic has had a marked effect on air quality. The pandemic has also shown an effect on greenhouse gas emissions, with CO_2 levels dipping notably during lockdown, particularly in the month of April 2020, although already these CO_2 emissions seem to be rising again once states and countries started lifting restrictions (Kanitkar, 2020; Le Quere et al., 2020; Liu et al., 2020). The average maximum decrease in CO_2 emissions per country was 26% (Le Quere et al., 2020). Hubei Province, China (which includes Wuhan) potentially had a decrease of 44.4% in CO_2 emissions (Han et al. 2021). The pandemic has not, however, impacted each CO_2 source evenly: 72.5 % of pandemic-related emissions in the Hubei Province reductions can be attributed to secondary industry, which includes the mining industry, the manufacturing industry, the electricity, heat, gas and water production and supply industries, and construction, while about 25% of the decrease can be attributed to ground transportation (Han et al., 2021).

Transportation emissions are 32.4% of the US's total greenhouse gas emissions compared to China where they are 12.05% (Fig S1) (Ritchie & Roser, 2020). Airports saw a significant reduction in passenger flights as countries closed their borders; passenger flights decreased by 89% in the EU in April 2020 (Nižetić, 2020). States with larger contact-intensive sectors of their economy had greater decreases in CO_2 emissions (Lee, 2021). Many of those jobs could not be switched to online work, providing a likely explanation for why this pattern occurred. As transportation constitutes a major source of greenhouse gas emissions, it is expected that countries would see a decline in emissions when people do not travel as far or frequently, even if emissions from other sectors remain constant.

Knowing that reduced travel has lowered CO_2 emissions, it is next important to ask what motivates people to travel less during a crisis and how long this change in travel behavior will remain. There are many factors dictating how people respond to both the climate crisis and the COVID-19 pandemic. These factors include threat perception, culture, social norms, political polarization, communication, leadership, group think and many others (Bavel et al. 2020). An assessment of lasting behavioral change will need to consider these factors and not simply the magnitude of the threat. Though it has been a long time since the world has seen a lockdown of this magnitude, the collateral economic crises usually come with a shift toward a less carbon-intensive economy. During the 2008-2009 financial crises, a period of rising CO_2 emissions was marked by a decrease in emissions from developed nations in just the year 2009. However, this recession also provides an example of how emissions shoot up again after the crisis has ended (Peters et al., 2011). With the COVID-19 pandemic, emissions have decreased from the combined effects of the virus and the recession. If the pattern holds, greenhouse gas emissions and air pollution will return to their previous patterns once the threat of COVID-19 is contained. However, longer restrictions are likely to elongate the length of the decrease in emissions (Le Quere et al., 2020).

Despite the amount of data showing declines in air pollution and greenhouse gas emissions during stay-at-home orders and mass unemployment, a gap in our understanding of how much the decline in emissions due to changes in travel behavior make up for the need for fundamental change in our energy supply still remains. Since a disruption of this magnitude and length of time has not occurred anytime in the recent past, it is difficult to predict how long behavioral changes adopted during the pandemic will last once the pandemic has ended. An understanding of what changes in human behavior lead to the decrease in emissions, specifically with regard to transportation, will lead to a better ability to make policy recommendations to make those behavioral changes permanent, so that the world can combat climate change more effectively.

III. Methods

A. Case Study State Selection

To understand the different responses to the pandemic, we performed a case study comparing two states. In order to select the states for this case study, we collected data on CO_2 emissions, lockdown policies, and mobility change for each state in the USA. The mobility data measured change in frequency of travel to various types of destinations (grocery stores, parks, etc.) compared to January 2020 based on cell phone location data and was acquired from the Google Mobility Report (*Google COVID-19 Community Mobility Reports*, 2021). In this context, mobility change refers to the percent change in travel to different types of locations. Each state--with the exception of California, Hawaii, and Washington, D.C.--fell in to one of five general trends (Fig. 1, Fig. 2). As every state's emissions similarly declined in the spring, these trends are based on how mobility patterns evolved over the summer and fall. A data point at zero means that the amount of people traveling to that type of location remains the same as the January 2020 baseline. Type A trends return to zero in the summer and remain flat, indicating a state with very short-term changes. Type B trends remain below zero and level out, suggesting that people continued to travel less than normal even after lockdowns lifted. Type C trends return to zero at the beginning of the summer but decrease again for the rest of the year. Type D and E trends follow similar patterns as Type C, but Type D graphs go above zero at the beginning of the summer and Type E graphs do not ever reach zero.

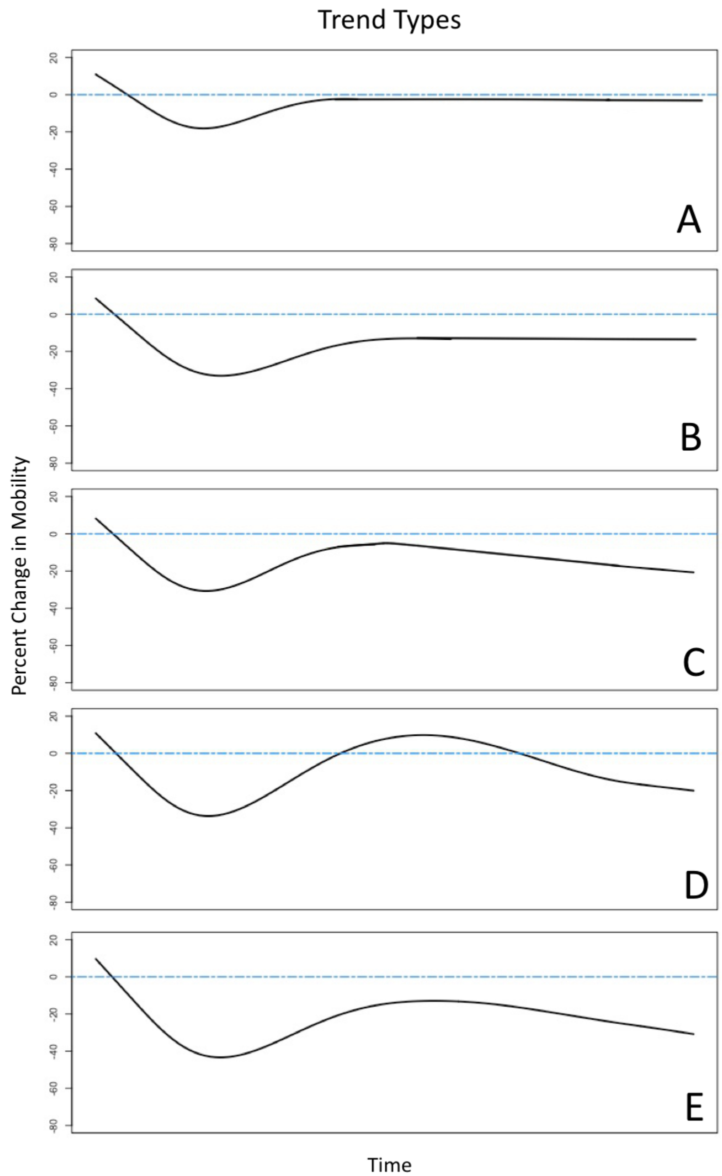

Figure 1. The five categories of mobility trends are shown above. When a trend line is at zero this means that the amount of people traveling to a type of location is the same as the January 2020 baseline. Type A trends return to zero in the summer and remain flat. Type B trends remain below zero and level out. Type C trends return to zero at the beginning of the summer but decrease again for the rest of the year. Type D and E trends follow similar patterns as Type C, but Type D graphs go above zero at the beginning of the summer and Type E graphs do not ever reach zero. Mobility data comes from Google Community Mobility Reports.

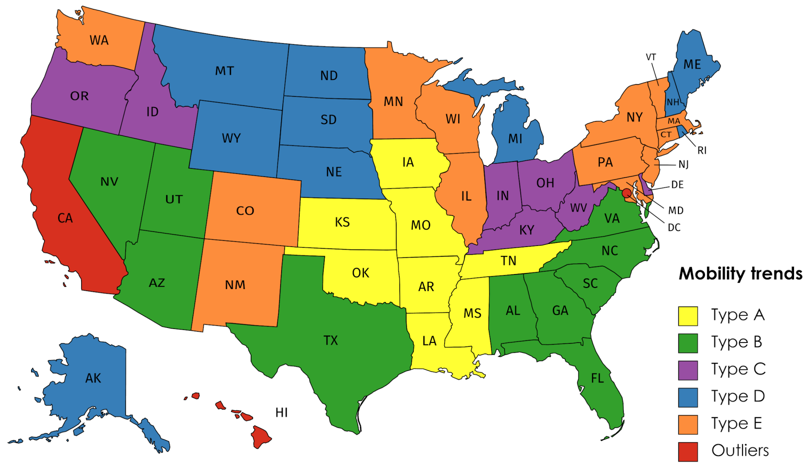

Figure 2: Map of state mobility according to the five trends displayed in Fig. 1. Three states--California, Hawaii, and Washington, D.C.--did not fall into any of the five categories. State-by-state mobility data comes from Google Community Mobility Reports. Map from Lemos (2021).

Conducting this case study started by obtaining the mobility data broken down by type of destination for the two selected states, to understand which reasons for travel most explain the changes. In addition to explaining reasons for travel behavior, obtaining the breakdown of CO_2 emissions by sector provided a way to see if there is a connection between transportation-related emissions and total emissions. We then collected data for each state to determine factors that could potentially be responsible for the observed mobility and emissions trends. Because we hypothesized that lack of commuting to work could account for many of the observed changes, many of these factors were employment-related: they included change in unemployment, highest-employing industries, and change in proportion of the population that works remotely (Table 1). Since these are not the only factors that explain travel behavior, we also found demographic and geographic information, and travel patterns and pre-pandemic CO_2 emissions trends.

B. Variable Selection

Several variables provided a way to understand how people's travel behavior changed during the pandemic. Changes in mobility are a measurement of how people's travel patterns have changed during the pandemic: this study examines changes in frequency of travel and what types of destinations (retail, workplaces, etc.) have increased or decreased in frequency over the course of the pandemic.

The main dependent variable was CO_2 emissions, for which we acquired data both nationally and on a state-by-state basis. State-by-state CO_2 estimates provide information about the change between 2019 and 2020. For national emissions, we obtained estimates for ground transportation emissions for each day between 2019 and 2020. Since regular CO_2 emissions estimates from prior to 2019 are not readily accessible, fuel consumption acted as a proxy to determine whether or not 2020 displayed an observable change compared to the last several years. Because this study was concerned specifically with emissions associated with transportation, which produces CO_2 through fuel combustion, a change observed in fuel use patterns in 2020 compared to numerous prior years would be indicative of a comparable change in CO_2 emissions associated with transportation. Though more detailed research would be necessary to precisely quantify how fuel use corresponds to emissions, a statistically significant decrease in fuel consumption means that there would have been a decrease in CO_2 emitted from fuel use. The Carbon Monitor estimates for ground transportation emissions is based on the EIA petroleum data as well as the Bureau of Transportation Statistics data for distance traveled; therefore, using EIA fuel consumption data provides an idea of what CO_2 emissions trends looked like in the years without CO_2 emissions estimates (Liu et al. 2020).

C. Data Sources

Mobility data: Mobility data comes from Google Community Mobility Reports, which compiles mobility data based on phone location data (*Google COVID-19 Community Mobility Reports*, 2021). These reports analyse mobility changes on the county, state, and national levels. Reports compare pre-COVID mobility to current COVID mobility, providing a way to measure behavioral change due to the pandemic. Using these data allows us to look at the change in frequency of people going to certain locations (grocery stores, parks etc.). It will also be useful for comparing how effective lockdown policies were in changing mobility behavior. People who had the location history turned off on their phones and people who did not own a mobile phone would have been excluded from this dataset. These data also present a limitation in that they do not include the means of transportation--it is impossible to determine when the movement came from gas-guzzling vehicles versus when it came from low-carbon walking, biking, and hybrid or electric vehicles. However, the detailed nature of these data still provides a way to explain motivations behind travel behavior, whereas road traffic data cannot provide information about what drives people to go places during a pandemic.

CO_2 data: State-by-state estimates for changes in CO_2 levels come from the Global Carbon Project (GCP) (Le Quere et al., 2020). This dataset includes change in megatons of CO_2 emitted from various sectors for each day from January 1st through October 31, 2020. The breakdown of emissions for the ground transportation sector will be most relevant to this project. For national emissions, data came from the Carbon Monitor, which provided data in megatons of CO_2, as opposed to change in emissions, per day for each sector for each day of 2019 and 2020 (Liu et al., 2020). The fuel use data came from the Energy Information Administration (EIA), which catalogues monthly petroleum consumption since 1945. The data of relevance for this study is the EIA's motor fuel consumption data since 2017 (*U.S. Product Supplied for Crude Oil and Petroleum Products*, 2020). This motor fuel includes all types of conventional gasoline but does not include aviation gasoline.

D. Statistical Analysis

We conducted t-tests to determine if the difference in emissions and fuel use between 2020 and other years was statistically significant. To visualize the changes in national CO_2 emissions, we graphed Carbon Monitor's daily emissions data using Excel. We visualized the Google mobility trends and GCP state-by-state emissions using R. Using the mobility graphs, we classified each state's trend into one of five categories as shown in Figure 1. Using these five categories, we calculated the mean and standard deviation for lockdown length, start date, and end date for each trend we observed.

IV. Results

A. National Carbon Dioxide Emissions

We examined changes in CO_2 emissions from transportation between 2020 and previous years to determine whether or not a significant change occurred. Due to the difficulties in finding detailed CO_2 emissions data for short timescales, CO_2 emissions estimates came in three main forms. The Global Carbon Project data provided breakdowns for each state; however, their estimates only provided the change in CO_2 emissions compared to the previous year rather than absolute numbers. Their estimates are useful for visualizing the drop in emissions in each state and allowed us to determine not only which states had the largest decrease in emissions, but also the extent to which each state's emissions increased again as the pandemic progressed. Because these data were broken down by sector, we were able to determine how much total CO_2

emissions reductions are due to transportation-related emissions. Every state had a sharp drop in emissions early in the pandemic, around late March and April, but the magnitude of the decrease as well as the post-April trends vary between states. State-level trends for the case study of Minnesota and Louisiana are discussed further below. For national emissions estimates, we used the Carbon Monitor data to compare daily 2020 emissions with daily 2019 emissions for the ground transportation sector (Figure 3). In this dataset, we observed that emissions remained relatively consistent throughout the year of 2019. In contrast, 2020 started similarly flat, then dropped in mid-March and gradually rose over the rest of the year while still remaining below 2019 levels. The year as a whole brought an observable change in emissions from transportation: the t-test comparing ground transportation emissions between 2019 and 2020 found a two-tailed p-value of 6.7×10^{-60}, indicating a very strong statistically significant difference between 2019 and 2020 emissions. The mean for the first two months of each year (the pre-pandemic part of 2020), was actually even higher for 2020 than for 2019--4.53 $MtCO_2$/day compared to 4.25 $MtCO_2$/day--suggesting that this clear decrease across the year can be attributed to the COVID-19 pandemic response.

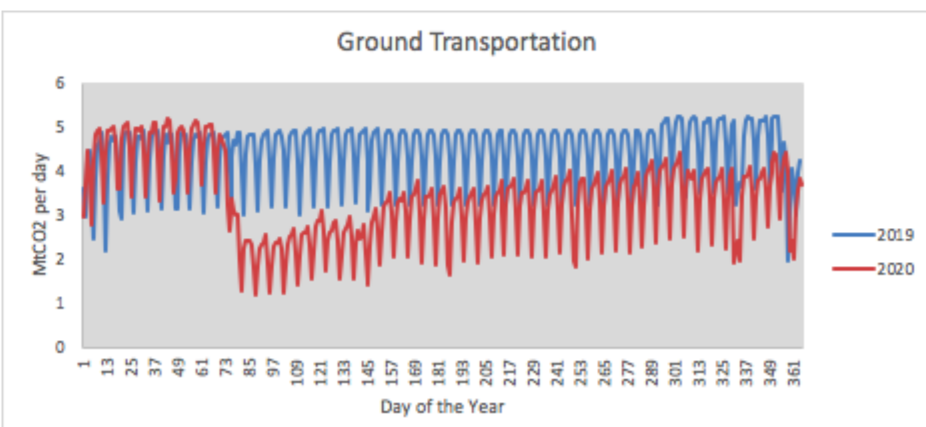

Figure 3. Daily CO_2 emissions from ground transportation throughout the years 2019 (blue) and 2020 (red). Each data point represents the estimated emissions for a given day; both years have a large range due to the decreased road travel on weekends and holidays. Day-by-day emissions estimates came from the Carbon Monitor.

In a comparison of the U.S. motor fuel supply data from 2017-2020, we observed a visible decrease in 2020 compared to the three previous years (Fig. 4). The decrease in supply of motor fuel indicates a drop in gasoline consumption--meaning that gasoline-powered (and therefore CO_2-emitting) cars were driving fewer miles. Though this drop is most dramatic in April, it continues through the end of data collection in October.

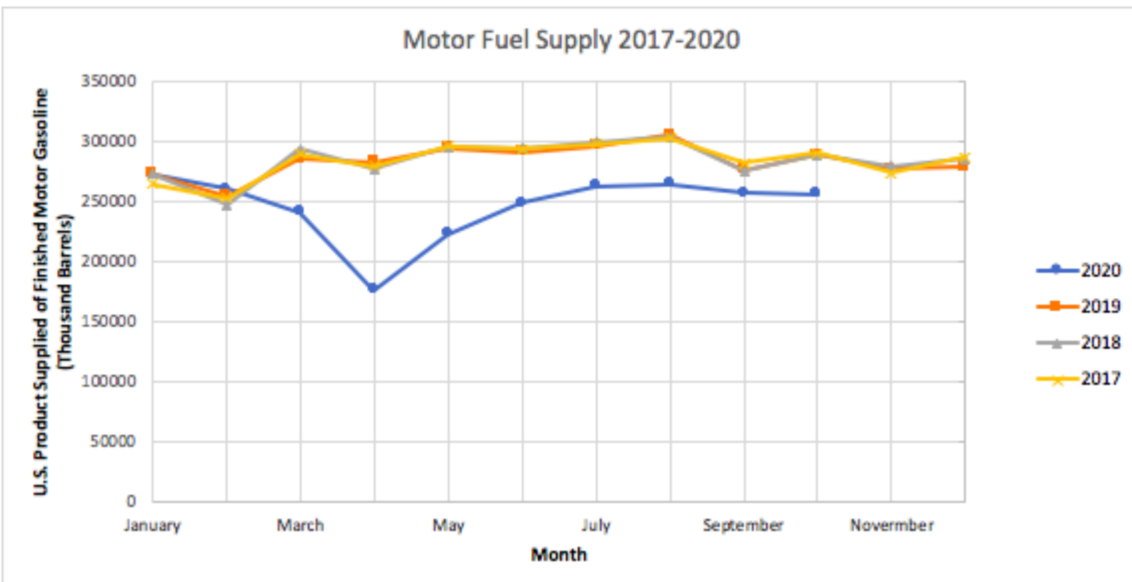

Figure 4. Monthly motor fuel consumption over the years 2017 (yellow), 2018 (gray), 2019 (orange), and 2020 (blue). Each point represents fuel use for the month. Monthly fuel consumption data came from the EIA.

A t-test comparing the data for 2020 with the average of the previous years found a p-value of 0.00247, indicating a strong statistically-significant difference between 2020 and all other years. This difference in motor fuel supply in 2020 compared to relatively unchanging previous years indicates an abrupt disruption in gasoline combustion.

B. Two-State Case Study

Based on mobility and emissions patterns for each state, Minnesota and Louisiana became the focus for this case study. We selected these two states because they had similar lockdown lengths yet provide strong contrasting responses to the COVID-19 pandemic. In addition to being a rational choice due to being the state where the authors are currently located, Minnesota represented a Type E mobility graph, indicating a longer term change in people's movements. However, there was not a large decrease in CO_2 emissions, with a dip in the spring followed by a return to almost pre-pandemic levels (Fig. 5). Louisiana exhibited a Type A mobility trend, indicating a return to relatively normal mobility patterns after the spring drop. But despite the lack of change in mobility, Louisiana displayed a clear change in emissions, with a -20% decrease in CO_2 levels that remained at -10% below pre-pandemic emission levels. Therefore, understanding the behavior and emissions outcomes in these two states could provide guidance for future policy to reduce CO_2 emissions.

Louisiana's mobility to non-essential businesses most closely resembled the type A trend. That is, it experiences a dip in mobility in April before recovering to zero. Louisiana's CO_2 emissions dipped in April with a maximum decrease of 20.6%, a large decrease compared to other states who averaged at a 7.5% ± 9.6% decrease in emissions (Fig 5). After the dip in April, CO_2 emissions rose but remained below their March levels, at around 10% (Fig 5). Industrial emissions decreased by 12.5% in March. In May, industrial emissions rose to 7% below the emissions of the previous year. Emissions from transportation had a maximum decrease of 5.7% in April and stabilized at a 1.13% decrease by July. Based on these numbers, decreases in industrial emissions should account for 60.7% of the total decrease in emissions, while transportation accounts for 27.7%.

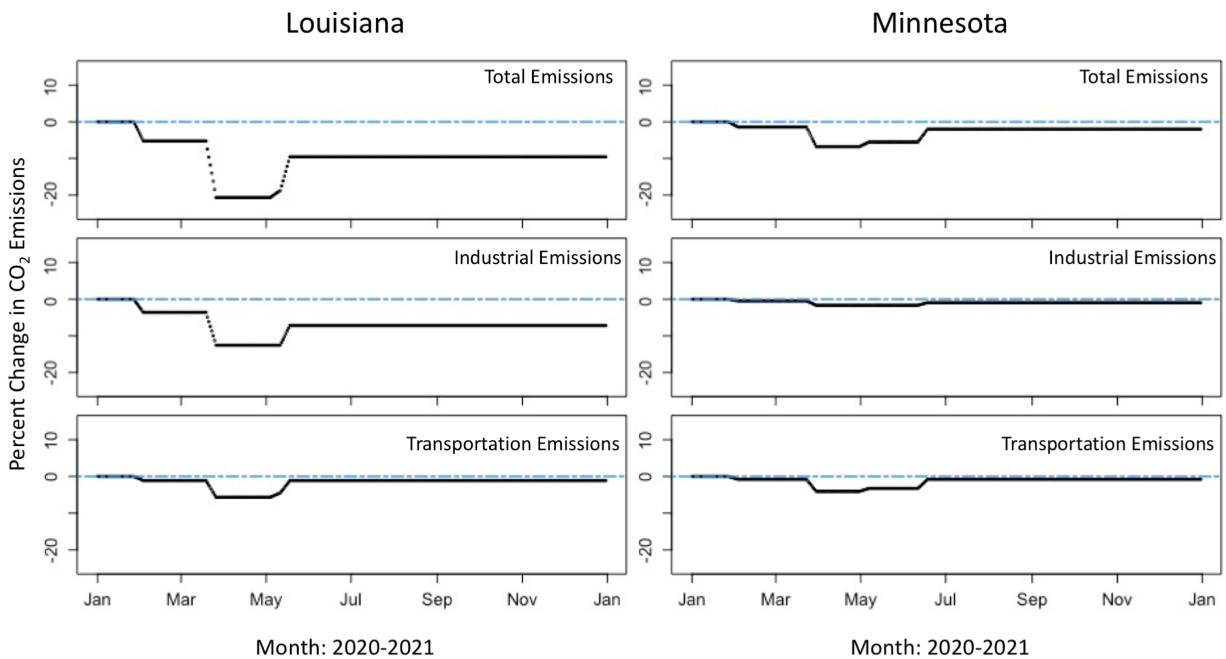

Fig. 5: CO_2 emissions for Louisiana (left) and Minnesota (right) in 2020, broken down by total emissions (top), industrial emissions (middle), and transportation emissions (bottom). The dashed blue line represents no change from the previous year. CO_2 emissions estimates come from the Global Carbon Project.

As seen in Figure 6, travel to retail and recreation initially dipped by -41.2% ± 4.21% in early April before stabilizing at -16.0% ± 9.51% from July to January (Fig 6). Travel to transit stations initially decreased by 45.16% ± 5.81% in April and stabilized at -19.18% ± 6.85% from July to January. Travel to workplaces initially decreased by 42.53% ± 5.57% in early April, but stabilized at -27.03 ± 9.3% from July until November when it started to slightly decrease. The two separate trends for workplaces that appear in the graph likely come from reduced travel on weekends and holidays. The upper trend likely represents weekends. Since fewer people work on weekends, fewer people would be commuting to work on weekends pre-COVID, hence less people would be changing their mobility behavior on weekends.

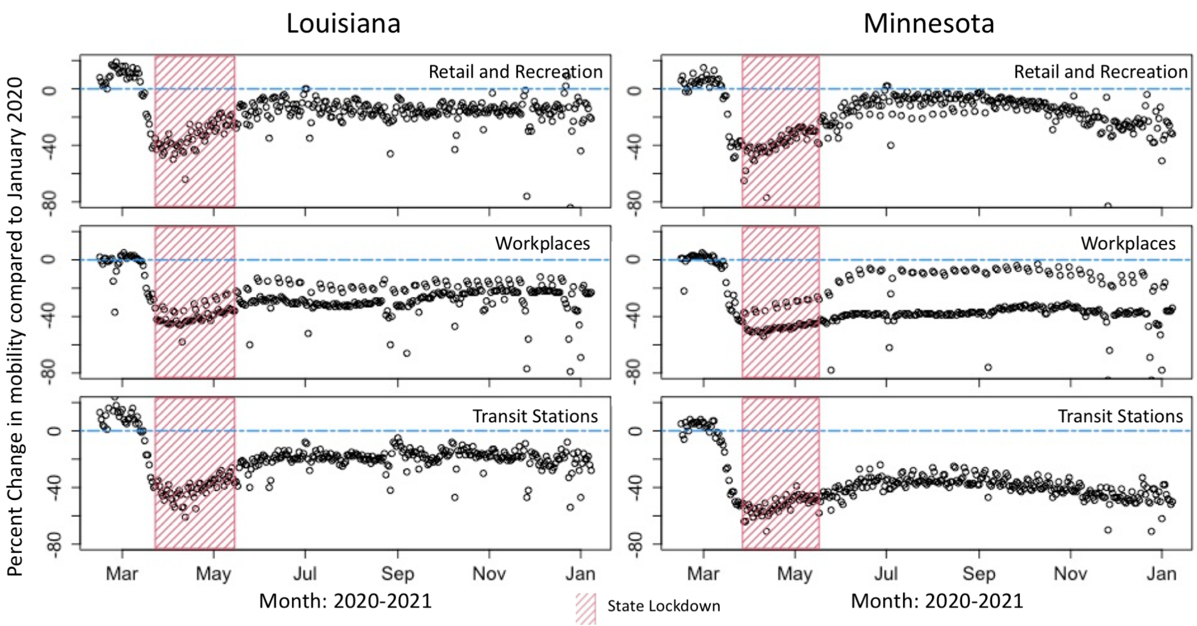

Figure 6: Changes in mobility for Louisiana (left) and Minnesota (right) from February 2020 to January 2021, broken down by movement to and from Retail and Recreation (top), Workplaces (middle), and transit stations (bottom). The red box indicates the time of each state's statewide stay-at-home order. The dashed blue line represents zero change from the previous year. Mobility data obtained from Google Community Mobility Reports.

Mobility to non-essential businesses in Minnesota resembled a type E trend. A type E trend is one that dips in April then slowly recovers (but does not reach 0) before gently sloping downwards again. As seen in Figure 5, Minnesota had a maximum 6.8% decrease of total CO_2 emissions in April, before rising to a 1.9% decrease in July. Minnesota saw a maximum decrease of 1.65% in industrial emissions in April, before rising to a 0.9% decrease in July. Transportation emissions decreased by 4.09% in April and rose to - 0.8% in July. Based on these numbers, decreases in industrial emissions account for 24.3% of the total decrease in emissions and transportation emissions account for 60.1% (Fig 6). Travel to retail and recreation facilities initially decreased by 46.71% ± 7.13% in early April, by July that decrease had lessened to 7.15% ± 6.26% (Fig 6). By December, travel to retail and recreation facilities had decreased by

26.43% ± 2.59%. Travel to transit stations decreased by 57.28% ± 4.00% in early April, by July it was 35.85% ± 3.50% and by December it had decreased to 47.57% ± 2.82%. Travel to workplaces decreased by -49.5% ± 0.76% by early April, excluding weekends. Travel to workplaces remained low but slowly increased to -37.6% ± 0.97% by December.

This case study also included political, geographic, and economic variables that could potentially explain patterns in CO_2 emissions, mobility, and transportation (Table 1). Several of these variables are similar between the two states: Minnesota and Louisiana had approximately the same length of lockdowns (51 and 53 days, respectively). Their workers also had approximately the same average commute lengths to work (23.7 and 25.7 minutes, respectively). Both have governors who are members of the Democratic party.

Demographically, Minnesota has a greater percentage of white people (83.8%) compared to Louisiana (62.8%). Minnesota has a larger population than Louisiana by approximately one million people, but Louisiana is more densely populated with 104.9 people per square mile compared to Minnesota's 66.6 people per square mile. Louisiana is also a larger emitter of CO_2 than Minnesota (53.04 and 31.06 million metric tons of CO_2 ($MMTCO_2$) per year, respectively).

In Louisiana, construction and manufacturing were the highest employing non-service industries employing 156,229 and 134,292 people respectively (Edwards and Dejoie, 2018). Much of Louisiana's economy (4.7% of GDP) was dedicated to mining, quarrying, and oil/gas extraction. Meanwhile, Minnesota's largest employers were in health care and social assistance. Apporximently 42% of households have switched to teleworking in Minnesota, compared to Louisiana where about 26% of households have switched to teleworking.

Prior to the pandemic, Louisiana was a much greater emitter of carbon dioxide compared to Minnesota, producing 211 $MMCO_2$ in 2018 compared to Minnesota's 92.7 $MMCO_2$ (Table 2).

However, most of Louisiana's emissions were industrial; transportation emissions, the main focus of this study, were proportionally higher in Minnesota (33.5% compared to Louisiana's 23.1%).

Table 1: Comparison of differences between Minnesota and Louisiana. Climate information was obtained from NASA. Demographic information was obtained from the U.S. Census. Transportation statistics came from BTS and unemployment statistics came from the Bureau of Labor Statistics.

Variable	Minnesota	Louisiana
Land area in square miles	79,610	43,562.00
Climate	continental	subtropical
Average temperature in the Summer (°F)	83	92
Average temperature in the Winter (°F)	9	47
Population	5,639,632	4,648,794
% Over 65 y/o	16.30%	15.9
% White	83.80%	62.8
Population per square mile	66.6	104.9
%Urban population	70	68
Income per capita	37,625	27,923
Total household numbers	2,185,603	1,739,497
Median Household Income	71,306	$49,469
% Persons in Poverty	9	19
% Unemployment in July 2020	7.6	9.4
% Unemployment in December 2020	4.4	7.2
% Gas Tax	28.6	20.01
Public Airports	142	77
Mean travel time to work (min)	23.7	25.7
All public roads (miles)	132,250	60,900
Automobiles registered (milion)	2.6	2
Commuting vehicles carrying one worker	77.3	79.8
Commuting vehicles carrying more than one	10.1	11.4

Table 2: Breakdown of carbon dioxide emissions in Louisiana and Minnesota. The data comes from the EIA. Table obtained from Lemos (2021).

Source (MMT CO_2/year)	Minnesota	Louisiana
Commercial	7.3	2.5
Electric Power	26.7	33.9
Residential	9.9	2.2
Industrial	17.7	123.7
Transportation	31.1	48.8
Total	92.7	211

Source (Percent of Total CO_2 Emissions)	Minnesota	Louisiana
Commercial	7.90%	1.20%
Electric Power	28.80%	16.10%
Residential	10.70%	1.00%
Industrial	19.10%	58.60%
Transportation	33.50%	23.10%

V. Analysis

A. Conclusions

As scientists learn more about the climate crisis and Earth's future becomes ever more desperate, national climate goals consequently become more ambitious, with many politicians calling for net-zero emissions by 2050 or even 2030 (Times, 2019). Though the pandemic has caused observable changes in emissions, we have learned from the national emissions and fuel consumption results, as well as state-by-state mobility and emissions data, that the presence of crisis and lockdown regulations by themselves are not enough to create lasting, drastic change. Based on the results above, we present several conclusions regarding the relationship between COVID-19, transportation, and CO_2 emissions. From our study of national emissions, we can conclude that emissions fell at the same time the pandemic started but began recovering toward their prior level over the course of the rest of the year. For each data set, we found a strong decline in April with a quick return by July. Though the rest of 2020 remained below pre-pandemic levels for emissions (Fig. 3), fuel consumption (Fig. 4), and many states' mobility patterns (Fig. 1) with a statistically significant change for the year as a whole, the rise after April still indicates that, while there may be a small lasting change, the drastic change that we seek cannot be found from lockdowns such as those due to COVID-19 alone. The threat of COVID-19 did not end in the spring, yet the sharp decline in emissions and mobility did, demonstrating that concern about the virus cannot solely explain behavioral patterns relating to transportation. Though lockdowns may have had an effect on mobility, we found that mobility patterns were not completely dependent on lockdowns, as the states without any lockdown had similar patterns as those with lockdowns.

The findings from the two state case study informed potential explanations for variations in emissions and mobility patterns for each state, working towards the goal of creating policy recommendations to continue lowering CO_2 emissions. Of the two states, we found a larger, more lasting drop in emissions in Louisiana and present several possible explanations: 1) Louisiana had higher emissions pre-COVID which gave it more room to cut emissions during the pandemic; 2) Minnesota had more people working from home and taking public transportation pre-COVID so there wouldn't have been as much of a change when everything went online; 3) Louisiana unemployment was higher than Minnesota unemployment so there are even more people not traveling to work; 4) industrial CO_2 emissions contributed more to decreases in Louisiana whereas transportation had a greater contribution in Minnesota. We see evidence for our first explanation in pre-pandemic emissions data, which indicate that Louisiana's emissions had already been much higher than Minnesota's (Table 2). Our second and third explanations also align with the mobility report, which shows that the largest decline in Louisiana was travel to workplaces while the largest decline in Minnesota was to transit stations. Transportation accounts for a large portion of emissions in Minnesota, while most of Louisiana's emissions came from industry--transportation there does not have as strong a role, indicating that a change in transportation behavioral patterns would have a larger impact on CO_2 emissions in Minnesota (Lemos, 2021).

Most Americans work service based jobs (since much of the manufacturing has moved out of the country) (Fig S2) (Lee, 2021). By their nature, service-based jobs involve interactions with other people. States that had higher percentages of people employed in the service sector had the largest decrease in emissions since those non-essential employees either lost their jobs or transitioned to working from home and no longer commuted to the office (Lee, 2021). Based on our comparison of Minnesota's and Louisiana's economies, Minnesota has more people employed in the service sector, yet it had a smaller percent decrease than Louisiana (Edwards & Dejoie, 2018; *Getting to Know Greater Minnesota's Economy*, 2019). Contrary to our expectations, Minnesota had a higher percentage of the population teleworking, but a smaller decrease in CO_2 emissions compared to the previous year's baseline. Louisiana's decrease in total CO_2 emissions had other contributing factors such as larger decreases in industrial emissions than Minnesota. In our results, we observed that a higher percentage of Louisiana's employment comes from manufacturing and construction (compared to Minnesota), which provides an explanation for a drop in CO_2 emissions that wasn't related to transportation and mobility changes. Therefore, an analysis of the impact of reduced transportation on CO_2 emissions will need to consider the extent to which transportation accounts for a given region's carbon footprint. For states like Minnesota, without high industrial emissions, driving less and using more efficient vehicles can cut a larger proportion of emissions. For states like Louisiana, driving less can reduce emissions significantly, but concentrating on improving the environmentally-friendliness of industry and manufacturing can create a larger change.

B. Policy Positions

The COVID-19 pandemic brought a decrease in road transportation use and the corresponding CO_2 emissions in response to efforts to keep people separated to prevent the spread of the virus. The question then becomes how to keep emissions low, and even to lower them further, to mitigate climate change even when it is safe for people to travel to indoor spaces and gather in groups. We present several potential changes for future climate change policy inspired by the transformation that occurred during the pandemic.

Because such a large proportion of the mobility decrease occurred in traveling to and from places of employment, future policy to encourage less driving would have a greater impact specifically when it addresses travel to work. Encouraging continued remote work activities could be one way to limit travel. However, this approach may often prove impractical due to the many jobs that cannot be performed remotely, such as health and sanitation workers and grocery store cashiers. Even if it were possible to move these jobs online, requiring people to work remotely permanently can be undesirable because of difficult work environments at home and the increased difficulty forming connections between coworkers. Therefore, our research also supports policies that limit the need for using cars to get to workplaces. These policies include structuring city planning to place workplaces within walking distance of residential locations. It would also include making public transportation options available between homes and workplaces so that when people do return to completely in-person work, they do not need to take a car.

Our research also supports policies that support more sustainable industries. In our case study, we observed that Louisiana suffered greater job loss partly due to the oil industry presence, which suffered during the pandemic due to the lack of demand for oil when people weren't driving and flying.

Even though aggressive climate action will require addressing every sector, the findings from the two-state case study indicate that prioritization for different climate action depends on the economy, geography, and culture of each state or country. For a place like Minnesota, where many emissions come from commuting to and from workplaces, the above policies related to creating shorter and greener commutes should hold greater priority. For a place like Louisiana, addressing commuting is still important, but the state would also have a greater need to address heavily-emitting industries to ensure that the economy itself is sustainable. Understanding which CO_2 sources produce the largest change when eliminated or reduced will allow governments to create a swifter, more effective transition to a sustainable future.

VI. Limitations and Future Research

Though transportation and associated CO_2 emissions declined during the pandemic, they are far from the only sources of greenhouse gases that threaten our climate. Though people have decreased their driving, they have not stopped needing heat and light, producing waste, and eating food produced by intensive agriculture. While economic declines are usually associated with decreases in emissions from power and industry sectors, this pandemic has resulted in an emissions drop almost completely in the transportation sector (Nguyen et al., 2021). Even if every gasoline-fueled car ceased to exist immediately, the U.S. would still have a long way to go in order to achieve the emissions reductions necessary to avoid the worst impacts of climate change (Storrow, 2020). Within transportation, this study specifically researched the impact on passenger cars--further research is necessary to understand whether or not the pandemic had a similar impact on trucking. Life being moved online comes with an increase in computer, phone, and internet usage, which produces CO_2 emissions as well, indicating that the pandemic may not have been as environmentally-friendly as it appears when only looking at transportation data. The next steps for continuing research into the pandemic's effect on CO_2 emissions would need to address these other sources of greenhouse gases and how to most efficiently reduce them.

As many of our results have already shown, when the total CO_2 emissions did drop significantly, these changes started reverting back within two months. Studies that have come out as we write this paper have found that some locations, such as China and India, even had increases in emissions in recent months compared to last year (EIA, 2021). We conducted our research while still in the midst of the pandemic and have yet to witness how the traveling patterns will progress as the virus continues its spread. Clearly, in order to reach net-zero emissions any time in the foreseeable future, further research is needed to halt other sources of greenhouse gases.

The COVID-19 pandemic presents a picture of how the world responds to an urgent, life-threatening crisis. Though each country and state had a different response with varying success at controlling the spread of the virus, the world nevertheless saw a complete transformation in order to manage the pandemic. Climate change poses a similar threat: just as COVID-19 brought us stories of overflowing hospitals and painful last breaths taken alone, climate change brings us stories of lives lost in devastating floods and fires and heat waves. Yet the complete societal transformation necessary to manage climate change remains frustratingly slow. Governments need to learn from this experience and start actually treating the climate crisis as a crisis.

VII. Acknowledgements

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VIII. References

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IX. Supplemental Figures

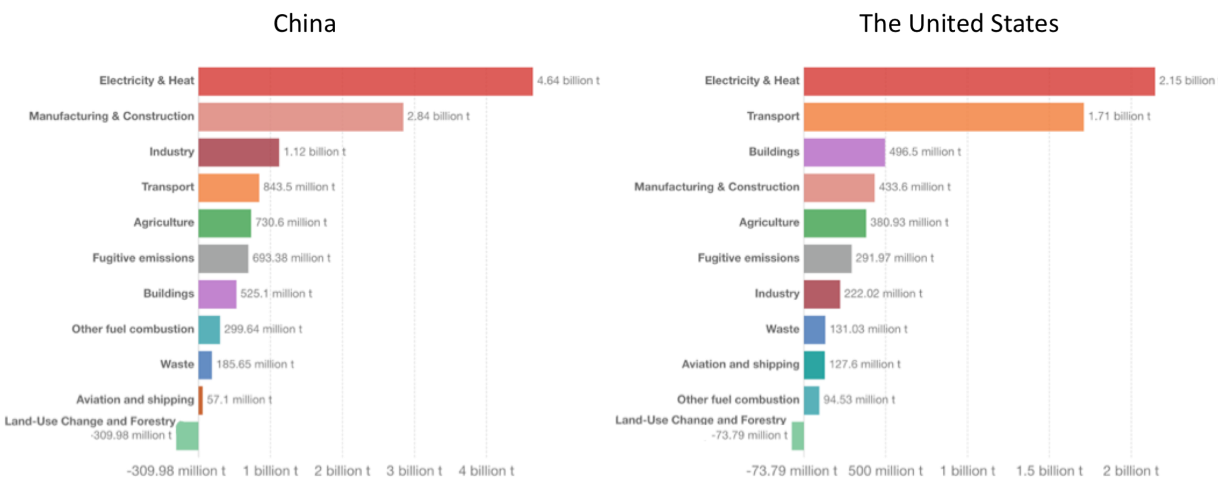

Figure S1: Greenhouse gas emissions measured in metric tonnes of CO_2 equivalents for China (left) and the United States (right) from 2016, broken down by sector. Axises are proportional to each country's total greenhouse gas emissions. Figures obtained from Our World in Data (Ritchie & Roser, 2020).

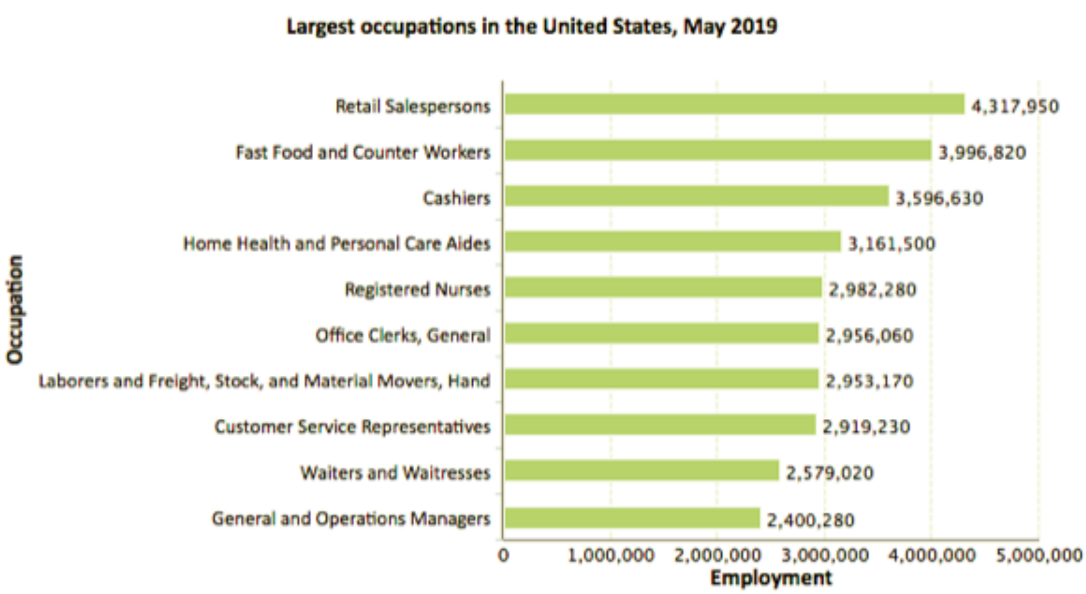

Figure S2: Largest occupations in the United States in May 2019. Most of these occupations are in the service sector. Figure obtained from the Bureau of Labor Statistics (*Occupational Employment Statistics*, n.d.).