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Estimated 2020 CO_2 Emission Reductions in Virginia's Transportation Sector from COVID-19

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ABSTRACT

The initial lockdown phase of the COVID-19 pandemic presented an unfortunate opportunity to observe how abrupt, large-scale changes in traffic volume can reduce greenhouse gas emissions. This study explores how carbon dioxide (CO_2) emissions from Virginia's transportation sector may have been affected by the changes in activity stemming from COVID-19 to inform more carbon-neutral policies as the state recovers from the economic downfall. Emission savings were calculated by multiplying the percent change from 2019 to 2020 in traffic volume from the Virginia Department of Transportation with the business-as-usual 2020 U.S. Environmental Protection Agency estimate of CO_2 emissions for Virginia's transportation sector. We estimate Virginia's 2020 COVID-19 transportation CO_2 emissions reduction is around 15.0% (14.2 to 15.7%), with reduced passenger vehicle traffic making up the bulk of the inferred reduction. This study highlights the utility of reimagining our current transportation sector as a way to implement sustainable, state-level carbon reduction policies, such as the Clean Car Standards.

Keywords: Climate Change, CO2 Emissions, COVID-19, Transportation, Virginia

INTRODUCTION

Climate change is one of the most pressing environmental issues we are faced with today. Global temperatures have warmed by ~1.0°C since preindustrial times due to human activities, mostly as a result of burning fossil fuels (IPCC, 2014; USGCRP, 2017). The Paris Climate

Agreement has set an ambitious warming tolerance of 1.5°C in order to mitigate the worsening effects of climate change and prevent catastrophe (IPCC, 2018). To meet this target, global emissions need to be reduced by ~7.5% every year until net-zero emissions are met (Matthews and Caldeira, 2008; IPCC, 2018; UNEP, 2019). This will require systematic change driven by international, national, state, and even local policies to reduce emissions in such a stringent period (Rogelj et al., 2015; Davis et al., 2018).

Virginia emits the 35th highest amount of emissions per capita compared to the other states in the country (U.S. EIA, 2019). The state needs to eliminate its emissions by 2050 to aid the rest of the world in keeping global temperatures from warming more than 1.5°C. The benefits of doing so will extend beyond helping to reduce global temperature changes but will also help mitigate the local impacts related to climate change. Virginia is already experiencing more extremes in weather, with an increase in intense periods of precipitation (Allen and Allen, 2019) causing inland flooding, extended and intensified extreme heat events, and longer periods of prolonged drought (EPA, 2016). Sea level along Virginia's coast is rising at a much faster rate compared to the global average, increasing the frequency of tidal flooding and causing communities to be more vulnerable to storm surges (Ezer and Atkinson, 2015). The most important impact is how climate change is affecting human health. Summer temperature highs, in Richmond for example, are over several degrees hotter today than 50 years ago, and many places in the state are already experiencing more extreme heat days (Dahl et al., 2019). This leads to an increase in heat-related illnesses (Constible, 2018), particularly troublesome for our most marginalized communities who are exposed to higher summertime temperatures due to urban design (e.g., Hoffman et al., 2020). Runoff from heavy rains and intrusion of saltwater are polluting waterways, increasing water- and food-borne illnesses (Constible, 2018). Allergy season is longer (Anenberg et al., 2017) and there is an increase in tick- and mosquito-borne illnesses (Brownstein et al., 2005). Lastly, there is a strong correlation between fossil fuel emissions and air quality (WHO, 2006), which has been linked to asthma and many other respiratory conditions (e.g., Constible, 2018; Guarnieri and Balmes, 2014) as well as autism spectrum disorder (ASD), depression, and premature death (e.g., Penn et al., 2017; Calderón-Garcidueñas et al., 2015).

In April 2020, Virginia made progress towards committing to reducing greenhouse gas emissions by passing the Virginia Clean Economy Act (2020), which moves to shut down fossil fuel power plants, mandates for energy efficiency, and requires Virginia's major power suppliers, Dominion Energy and Appalachian Power, to be 100% carbon free by 2045 and 2050, respectively. Although the Virginia Clean Economy Act is a bold statement that illustrates the state's desire to adopt clean carbon-free energy sources, all while creating economic development through generating jobs, it leaves out Virginia's transportation sector. There is no specific policy to date that addresses emissions from the state's transportation sector, despite the fact that it contributes the majority of Virginia's overall carbon emissions (Fig. 1) and causes the formation of air pollutants that are harmful to public health.

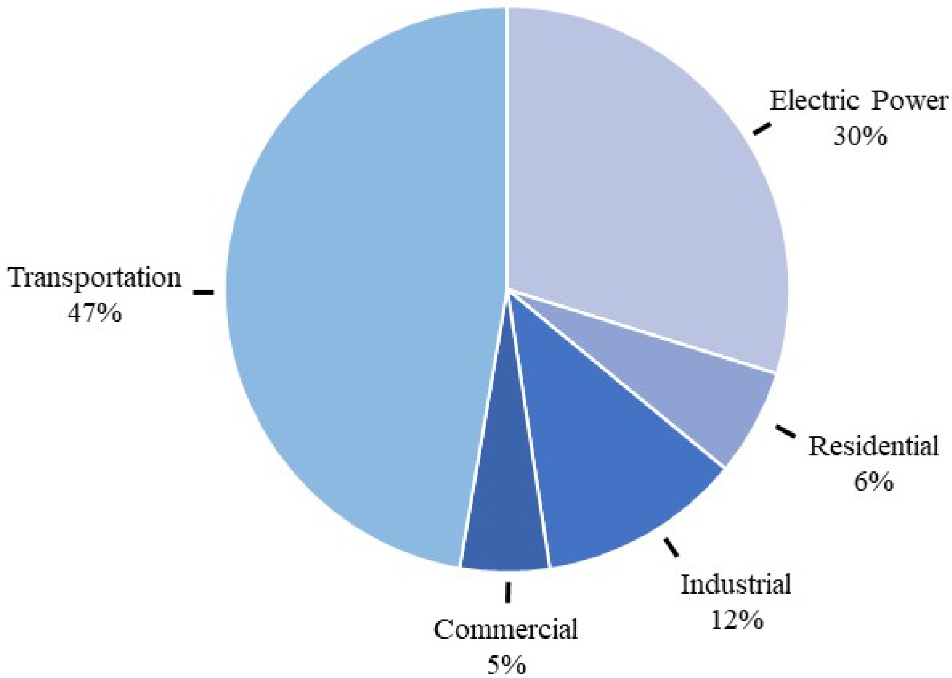


FIGURE 1. The five energy sectors of Virginia and their relative contributions to greenhouse gas emissions from 2010 to 2017. Data from the U.S. EIA.

In 2020, the global health crisis caused by the SARS-CoV-2 novel coronavirus, referred to here by its disease COVID-19, halted global economies as most developed nations went into confinement to prevent the spread of the virus (Sohrabi et al., 2020). This change in activity affected global energy demand in all sectors, especially air and ground transportation. Over the period of January 1−April 30, 2020, Le Quéré et al. (2020) estimated daily emission reductions on average of 26% for individual countries during their peak confinement, attributing most of the change to reduced ground transportation and energy demand from the power sector. Alongside global carbon emission reductions, remotely-sensed estimates of other pollutants saw concomitant and equally ephemeral reductions. In China, where the outbreak first occurred, nitrogen dioxide (NO_2), a major pollutant from gasoline-powered vehicles, dropped by almost 40%. Western Europe and the U.S. saw a 20-38% average decrease in satellite NO_2, compared to the same time period in 2019 (Bauwens et al., 2020). Monitoring stations on the ground in China reflected a 60% decrease in NO_2 as well as a 35% decrease in particulate matter smaller than 2.5 micrometers ($PM_{2.5}$), another major pollutant derived mostly from gasoline-powered vehicles (Shi and Brasseur, 2020). Although there have been many global and country-level studies of major pollutant reductions during the COVID-19 lockdowns, research into emission changes related to COVID-19 specific to the Commonwealth of Virginia has not yet been done.

Prior to the 2020 COVID-19 pandemic, Virginia's carbon dioxide (CO_2) emissions were decreasing slightly on average relative to the past, mostly due to the state's energy sector-driven transition from coal to natural gas (U.S. EIA, 2019). New natural gas power plants, though initially responsible for reducing the state's emissions, may ultimately hinder the state's carbon goals and make it more difficult to achieve net-zero emissions as outlined in the Virginia Clean Economy Act. In fact, some research suggests that no new carbon-emitting power plants should be commissioned if we are to meet the Paris Climate Agreement's goals globally (Tong et al., 2019).

During the early stages of the pandemic, Virginia similarly followed the rest of the world and the country when Governor Ralph Northam issued Executive Order 53 on March 23, 2020 restricting businesses and closing schools, and mandated Executive Order 55 on March 30, 2020 requiring people to stay at home. The state remained in confinement until most areas moved to Phase II on June 2, 2020 and then to Phase III on June 30, 2020, which allowed most businesses to reopen and operate under strict social distancing guidelines. This study aims to quantify Virginia's 2020 CO_2 emission savings stemming from the Commonwealth's reduced traffic volume, resulting from the COVID-19 stay-at-home orders. Our motivation stems from the observed traffic volume reductions around the world and the country, work focusing on large-scale greenhouse gas emissions, and inferred improvements in air quality. Because Virginia's transportation sector is its largest CO_2 emission source (U.S. EIA, 2019), the goal of this work is to highlight how the transportation sector in Virginia was impacted by COVID-19 policies to help inform the systematic changes needed to both reduce greenhouse gas emissions from transportation and improve local air quality.

DATA AND METHODS

Carbon emissions for the state of Virginia were divided into five sectors – transportation, electric power, industrial, commercial, and residential (Fig. 1) (U.S. EIA, 2019). The transportation sector, which accounted for almost half of Virginia's 2010-2017 average CO_2 emissions at 47%, consists of all vehicles whose primary purpose is to transport people or goods. According to the Virginia Department of Transportation's (VDOT) COVID-19 Traffic Trend Tool (Table 1), passenger vehicles accounted for 92% of the vehicles used in this sector while freight trucks made up only 8% in 2019.

TABLE 1. List of data sources used in the 2020 COVID-19 emission calculations

Source	Purpose	URL Link
VDOT - Virginia COVID-19 Traffic Trend Tool	Quantify reduction in traffic activity	https://public.tableau.com/profile/simona.babiceanu#!/vizhome/shared/GXW4B5FK3
EPA State CO_2 Emissions Projection Tool	Estimate BAU 2020 CO_2 emissions	https://www.epa.gov/statelocalenergy/download-state-inventory-and-projection-tool
U.S. EIA Energy Sales	Estimate emissions from the residential, commercial, and industrial sectors	https://www.eia.gov/electricity/data.php
U.S. Electric System Operating Data	Estimate emissions from the electric power sector	https://www.eia.gov/realtime_grid/

State-level annual CO_2 emission calculations from the U.S. Energy Information Administration (EIA) State Energy Data System (SEDS) are not published until at least two years after the annual energy data is published. Thus, real-time CO_2 emissions data were not available for Virginia at the time of writing. Changes in CO_2 emissions from the transportation sector were estimated using traffic counts collected by VDOT, provided through the Virginia COVID-19 Traffic Trend Tool. This tool measured traffic volumes, which were expressed as a percent difference from 2019, and distinguished between passenger vehicles and freight truck traffic. Thus, estimates are based off percent change from one year to the next. This approach does not account for if there were more electric and hybrid vehicles travelling during 2020 relative to the recent past. However, Virginia's current policy landscape makes it unlikely that there was a significant increase in these low or zero-emission vehicles on the road. The tool also does not differentiate between older, less efficient vehicles and newer, more efficient vehicles, which makes comparing emissions through time less accurate.

This 2020 COVID-19 transportation CO_2 estimate is based off the percent change in transportation activity from 2019. The Environmental Protection Agency's (EPA) projected transportation emissions for 2019 and business-as-usual (BAU) 2020 represent what emissions would have been if the pandemic lockdowns had never happened. The projected transportation emissions came from the EPA's CO_2 projection tool that estimates future state emissions based on historical energy trends through 2017 (Table 1). Because 2019 and 2020 transportation emissions were similar, BAU 2020 traffic volumes are assumed to be the same as 2019 and the 2019-2020 percent change in state-wide daily traffic volumes were averaged for each of the 12 months in the year. These months were then averaged to obtain an annual percent change for 2020. The annual percent change was multiplied with the EPA's BAU 2020 transportation emissions projection to calculate the total annual CO_2 emissions reduction in $MMTCO_2E$, which is million metric tons of CO_2 standardized with other greenhouse gases. VDOT reported a 5% error in traffic counts, which were applied to estimate uncertainty bounds indicated in parentheses. The following equation summarizes the calculation used:

$$\text{CO}_2\text{ emissions reduction (MMTCO}_2\text{E)} = \frac{\text{BAU 2020 projection (MMTCO}_2\text{E)} \times \text{2020 annual \% traffic volume change}}{100}$$

RESULTS

Traffic volumes were slightly higher in January and February of 2020 relative to 2019 (Fig. 2). After Governor Northam issued Executive Order 55, traffic volume was reduced from 17.2% in March to a peak of approximately 45.7% in April. Traffic volume then rebounded through September to a reduction of about 10% and stayed relatively steady for the remainder of 2020. The EPA's BAU Virginia transportation CO_2 emissions estimate for 2020 was 49.97 $MMTCO_2E$. Based on annual traffic volume reductions, it is estimated that transportation CO_2 emissions for 2020 were 42.48 $MMTCO_2E$ (42.11 to 42.86 $MMTCO_2E$) for Virginia due to COVID-19 lockdowns (Table 2). This is a reduction of 7.5 $MMTCO_2E$ (7.1 to 7.9 $MMTCO_2E$) or 15.0% (14.2 to 15.7%) from 2019. Transportation emissions in Virginia have not been this low since 1995 (Fig. 3).

This study finds passenger vehicle transport had the largest influence on emission reductions during the lockdown period. Vehicle type data from the Virginia COVID-19 Traffic Trend Tool revealed that passenger vehicle traffic, which accounted for 93% of vehicles on Virginia's roads in 2020, saw a 16.2% (15.4 to 17.1%) average reduction over the year, while freight truck traffic saw only a 1.94% (1.85 to 2.04%) average reduction for the same period (Table 3; Fig. 4).

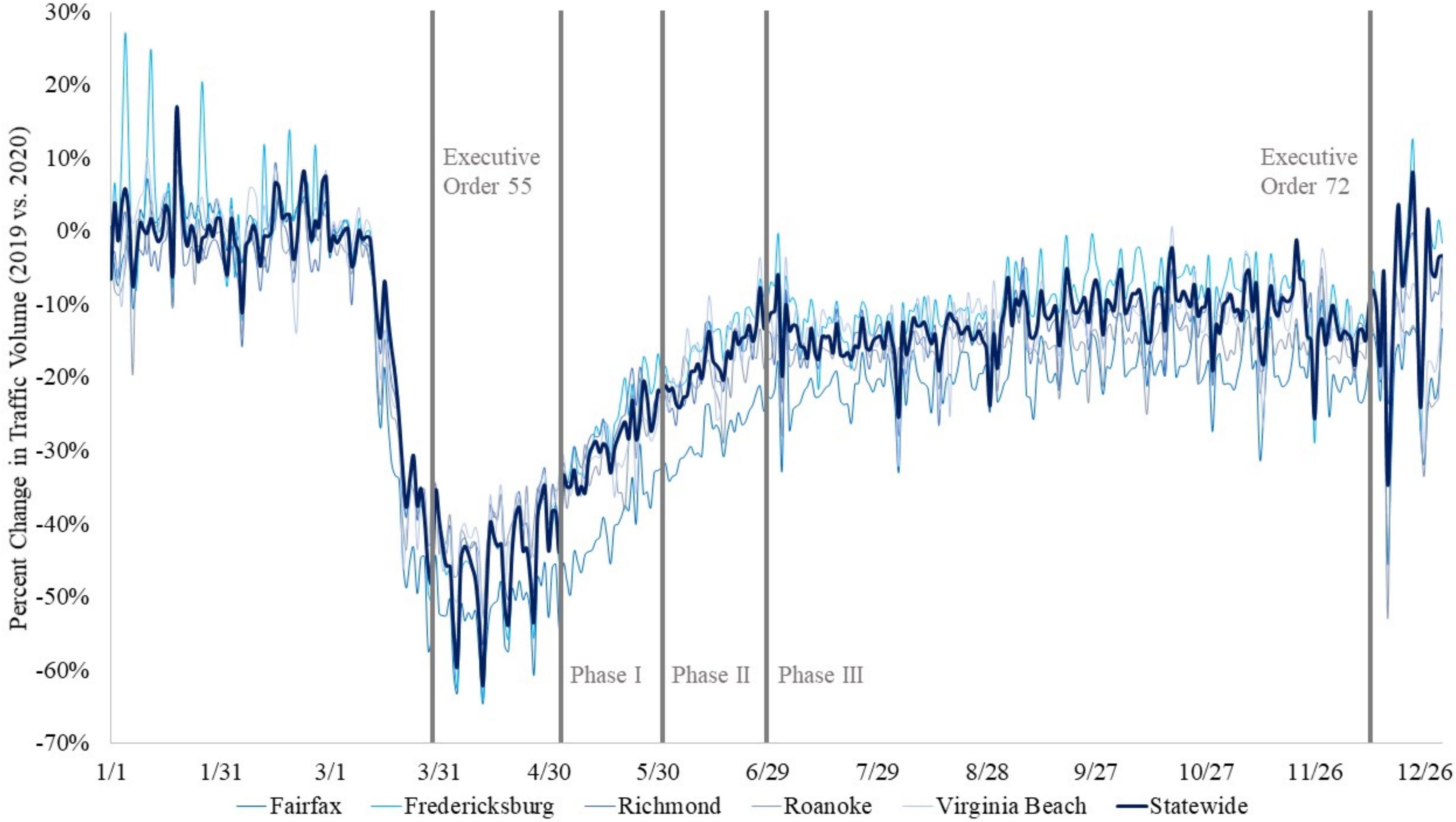


FIGURE 2. Percent change in transportation volume from 2019 for the state of Virginia (bold dark blue line) and select cities (thin blue-shaded lines). Gray vertical bars denote when Executive Order 55, the first stay-at-home order, was issued by the Governor (March 30, 2020), when the state subsequently entered Phase I (May 8, 2020), II (June 2, 2020), and III (June 30, 2020) of reopening, and Executive Order 72 (December 10, 2020), which introduced a "modified stay-at-home order" to slow the surging winter COVID-19 cases. Note: Fairfax and the City of Richmond delayed entering Phase I until May 29, 2020 and Phase II until June 12, 2020.

TABLE 2. Estimated 2020 CO_2 emissions reduction due to COVID-19 for Virginia's transportation sector

2020 BAU CO_2 emission estimate ($MMTCO_2E$)[a]	Estimated annual change (% change)[b,c]	CO_2 reduction ($MMTCO_2E$)	2020 COVID-19 CO_2 emission estimate ($MMTCO_2E$)
49.97	**-14.99** (-14.24 to -15.74)	-7.49 (-7.11 to -7.86)	**42.48** (42.11 to 42.86)
Estimated monthly change (% change)			
January	February	March	April
0.64 (0.61 to 0.68)	0.48 (0.46 to 0.51)	-17.46 (-16.59 to -18.34)	-45.74 (-43.45 to -48.03)
May	June	July	August
-29.96 (-28.46 to -31.46)	-17.16 (-16.30 to -18.02)	-14.71 (-13.79 to -15.44)	-14.83 (-14.09 to -15.57)
September	October	November	December
-10.51 (-9.98 to -11.03)	-9.81 (-9.32 to -10.30)	-10.84 (-10.30 to -11.38)	-9.95 (-9.46 to -10.45)

[a]Estimates from the EPA's CO_2 projection tool available at https://www.epa.gov/statelocalenergy/download-state-inventory-and-projection-tool
[b]Annual change is calculated by taking the average percent change from January through December.
[c]Error ranges of 5% as reported by VDOT are indicated in parentheses.

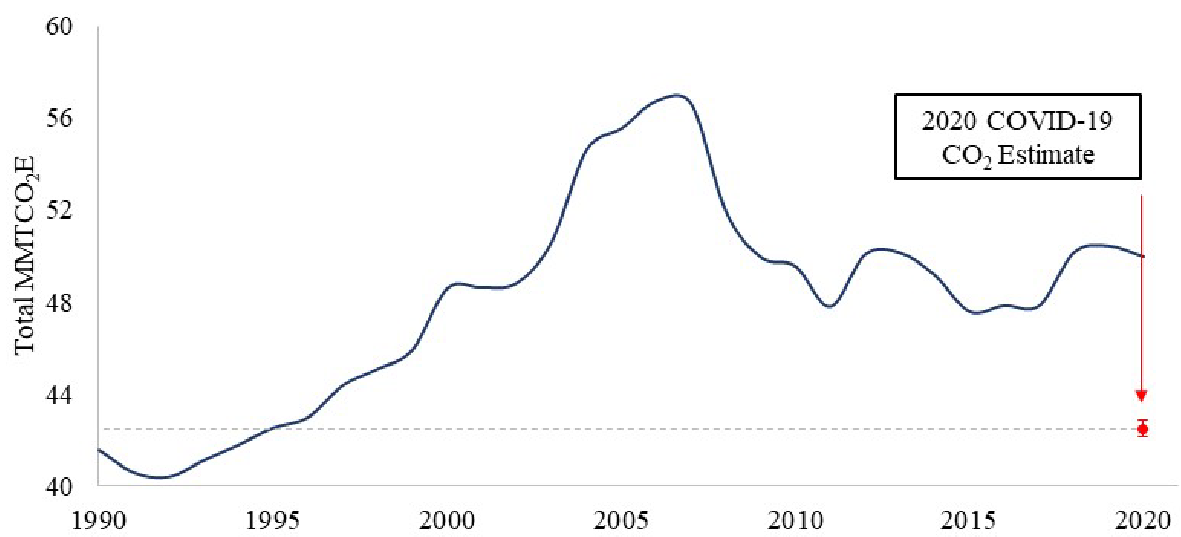


FIGURE 3. Virginia's transportation annual CO_2 emissions from 1990 to BAU 2020 (dark blue line) with the 2020 COVID-19 annual CO_2 estimate (red dot).

TABLE 3. Change in passenger vehicle and freight truck traffic volumes from 2019 to 2020

Passenger Vehicles		Freight Trucks	
Estimated monthly change (% change)			
January	July	January	July
0.42 (0.40 to 0.44)	-15.17 (-14.41 to -15.93)	-0.39 (-0.37 to -0.25)	-3.85 (-3.66 to -4.04)
February	August	February	August
0.93 (0.89 to 0.98)	-15.87 (-15.07 to -16.66)	-0.24 (-0.22 to -0.25)	0.63 (0.60 to 0.66)
March	September	March	September
-19.39 (-18.42 to -20.36)	-12.69 (-12.05 to -13.32)	-1.52 (-1.44 to -1.60)	0.55 (0.52 to 0.58)
April	October	April	October
-45.21 (-42.95 to -47.47)	-12.15 (-11.54 to -12.75)	-16.23 (-15.42 to -17.04)	3.79 (3.60 to 3.98)
May	November	May	November
-31.56 (-29.98 to -33.14)	-12.29 (-11.68 to -12.91)	-8.52 (-8.10 to -8.95)	5.62 (5.34 to 5.90)
June	December	June	December
-18.74 (-17.80 to -19.68)	-13.10 (-12.45 to -13.76)	-3.72 (-3.53 to -3.91)	0.58 (0.55 to 0.61)
Annual change (% change)[a]			
-16.23 (-15.42 to -17.05)		-1.94 (-1.85 to -2.04)	

[a]Annual change is calculated by taking the average percent change from January through December.

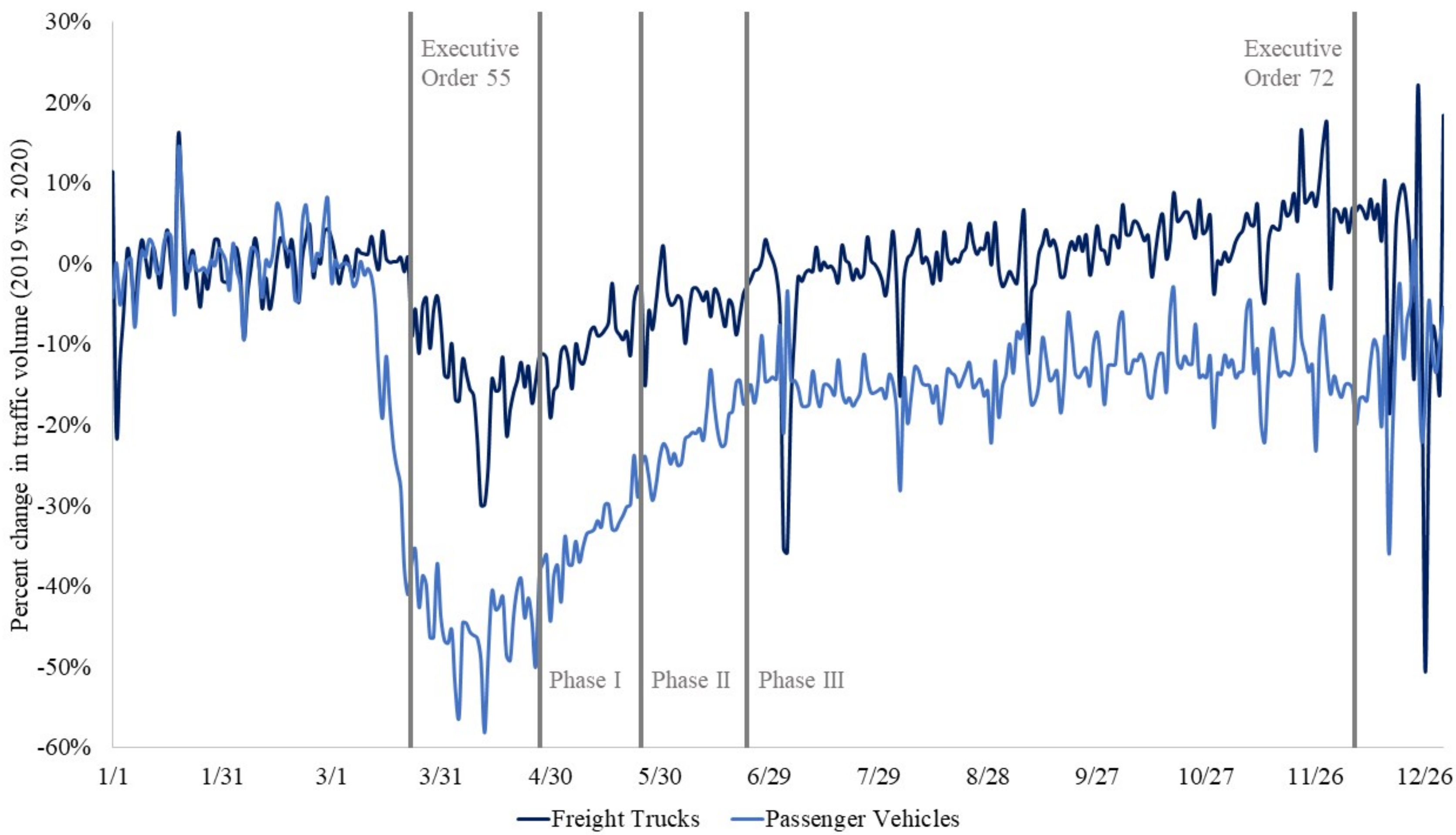
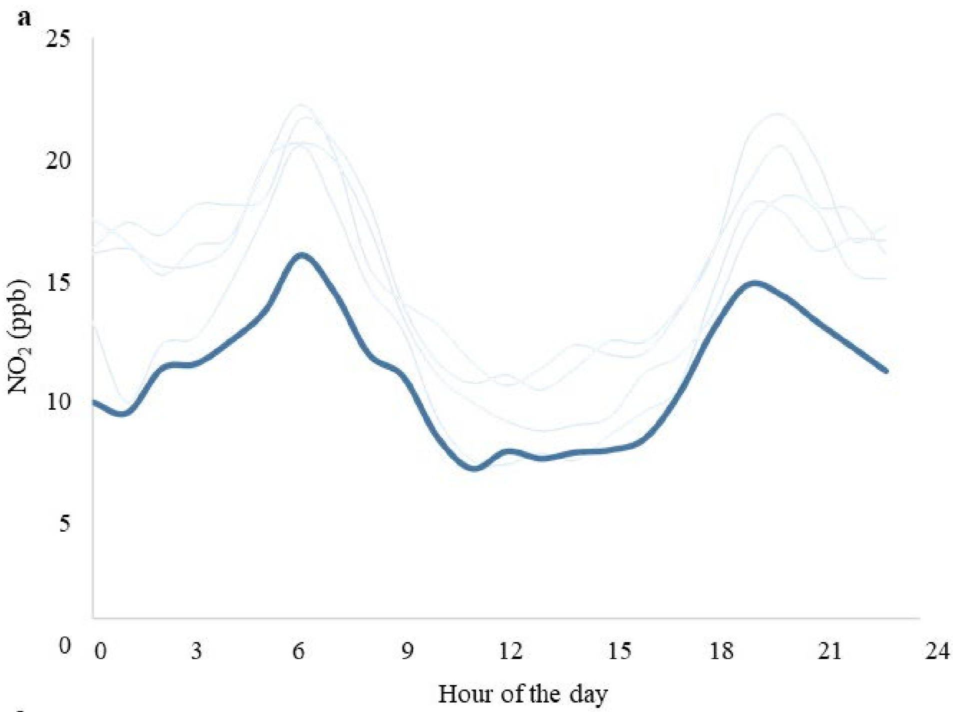


FIGURE 4. Percent change from 2019 in freight truck traffic (dark blue line) and passenger vehicle traffic (lighter blue line) for the state of Virginia in 2020.

DISCUSSION

Virginia's stay-at-home order had a considerable effect on the transportation sector, with the estimated CO_2 emission reductions equivalent to taking approximately 1.6 million passenger vehicles off the road for one year, according to the EPA's greenhouse gas equivalencies calculator. The COVID-19-related reduction in traffic volume in Virginia are similar to reductions in traffic across the U.S. and around the world. Our estimated 15.0% reduction for Virginia over the whole year is close to the Rhodium Group's U.S. estimate of 14.7%; however, their estimate is only based on January through October data (Larson et al., 2021). Virginia's peak monthly reduction in traffic volume in April of ~46% is similar to the estimated 50% reduction of average global traffic volumes during peak confinement (Le Quéré et al., 2020) and U.S. estimates of max reductions of 48% in early April (Schuman, 2020). Reduced traffic volumes were seen in all cities across the state but the more urbanized cities, particularly Northern Virginia, saw the largest reductions (Fig. 2). Additionally, overall ridership on public transit was significantly reduced during the confinement period (De Vos, 2020), further highlighting the impact that the stay-at-home order had on communities. Interestingly, the largest daily reductions occurred on weekends (Fig. 2), suggesting that people with more traditional working schedules were following Executive Order 55. However, while passenger vehicle traffic saw large reductions, there was little change in freight truck traffic volumes in Virginia, indicating that goods were still being ordered and delivered (Pishue, 2020).

Implications for reduced traffic extend far beyond reducing greenhouse gases, leading to quick and dramatic short-term improvements in air quality, as has been seen around the world in both satellite and ground measurements of NO_2 and $PM_{2.5}$ (Bauwens et al., 2020; Shi and Brasseur, 2020; Li et al., 2020). Even in Virginia, roadside ground measurements of NO_2 and $PM_{2.5}$ from the Virginia Department of Environmental Quality (DEQ) taken at Bryan Park in Richmond from mid-March to mid-April, when traffic volumes were most reduced, show reductions on average of 25% and 65%, respectively, during peak rush hour traffic on weekdays compared to the same period in previous years (Fig. 5). This suggests that locally, surface-level air quality near high-traffic road networks positively responded in real time to reductions in emissions driven by reductions in passenger traffic volumes at peak commuting hours (Kendrick et al., 2015). However, there is a complex, regional relationship between $PM_{2.5}$, NO_2, and weather, as seasonality in temperature, humidity, and wind can lead to inaccurate results. These air quality data must be normalized for these factors before drawing conclusions between these observed improvements in air quality and traffic volumes (Grange and Carslaw, 2019). Trends between weather-normalized ground-monitored air pollution and traffic volume over the last several years should be explored in more detail to fully quantify how the reduced traffic from COVID-19 affected air quality in several of Virginia's largest cities.



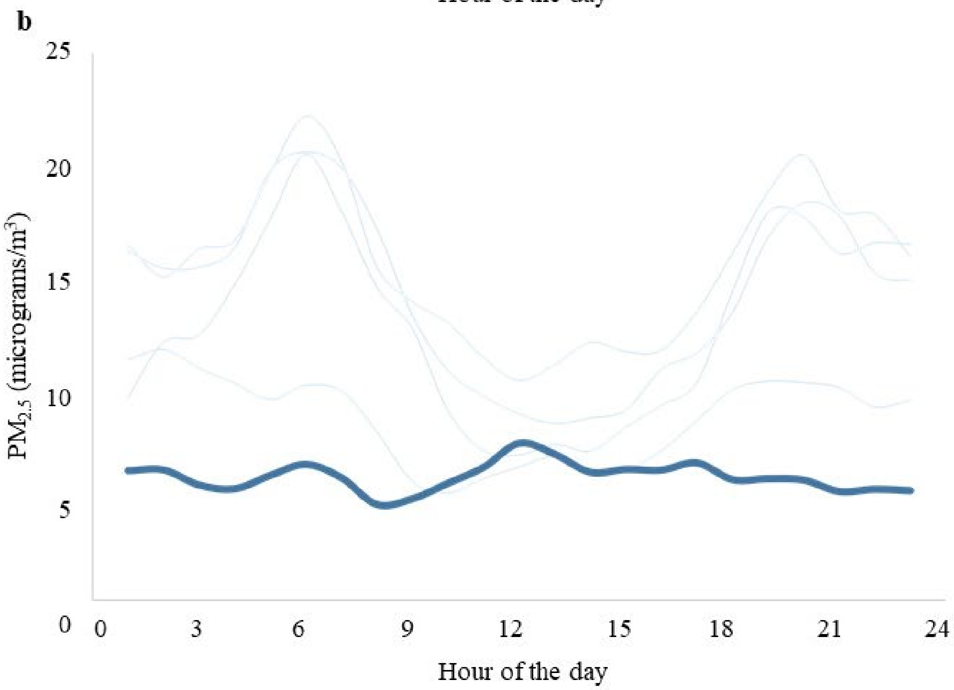


FIGURE 5. Hourly time series of A) NO_2 and B) $PM_{2.5}$ ground surface air quality measurements collected by DEQ from Bryan Park, Richmond, Virginia. Time series are hourly weekday averages from March 14 to April 14, 2020. The dark blue line denotes March 14 – April 14, 2020 and the gray lines denote the same time period for the years 2016 – 2019.

Poorer air quality related to proximity to burning fossil fuels and traffic emissions of $PM_{2.5}$ has major implications for human health (WHO, 2006), and those from lower income communities and communities of color are consistently shown to be disproportionately exposed to these stressors (e.g., Hooper and Kaufman, 2017). Air pollution from NO_2 not only increases respiratory problems, such as asthma, wheezing, and coughing, but also reacts in the atmosphere to form ground-level ozone (Sillman, 1999), leading to additional health problems related to the airway and lungs (WHO, 2006). Particulate matter, especially $PM_{2.5}$, accumulates deep inside the lungs, further aggravating respiratory symptoms, but can also lead to cardiac problems, lung disease, and even premature death (WHO, 2006; Anderson et al., 2012). Additionally, new research has shown that localities with poorer air quality are at greater risk for contracting (due to socioeconomics), suffering more severe cases, and/or dying from COVID-19 (Wu et al., 2020; Zoran et al., 2020; Hendryx and Luo, 2020; Conticini et al., 2020), as COVID-19 is a respiratory disease (Sohrabi et al., 2020). These connections between improved air quality and health related to reduced COVID-19 fossil fuel emissions are only beginning as researchers untangle the complex relationships between the two.

A 15.0% reduction in traffic emissions for the whole year is considerable. However, if it is the only energy sector that saw significant COVID-19-related reductions, the state's overall emissions for 2020 would only be reduced by around 7.45% (7.08 to 7.83%), saving 7.49 $MMTCO_2E$ (7.11 to 7.86 $MMTCO_2E$). However, studies suggest that other energy sectors experienced changes related to COVID-19 as well (Larson et al., 2021; Le Quéré et al., 2020). The Rhodium Group study covering the whole U.S. from January to October found 10.3% and 7.0% reductions for the electric power and industrial sectors as well as a 6.2% reduction for building emissions (Larson et al., 2021). If we assume that Virginia's other energy sectors experienced similar emission changes to what has been estimated more broadly by the Rhodium Group, the state would expect a reduction of 11.8 $MMTCO_2E$ (11.4 to 12.2 $MMTCO_2E$), or ~11.7%, assuming the EPA's 2020 pre-COVID-19 emissions estimates as BAU (Table 1). We acknowledge that Virginia's emissions behavior may not be reflected in the patterns of the U.S. more generally; thus, we explored state-level trends in energy sales and energy demand from the U.S. EIA from March through June, the peak of the confinement period (Table 1). We suggest that Virginia's total emission reductions estimated here (~8.54% decrease from 2019), while based on broader geographical patterns, may actually be more limited than the U.S.-wide emission reduction estimates. If this lower-end estimate is true, this equates to an emission savings of ~8.58 $MMTCO_2E$ and puts Virginia's annual CO_2 emissions for 2020 below 1990 levels. However, the available data for the other energy sectors contains different spatial scales and does not account for emission coefficients, which creates additional uncertainty. Thus, we caution that these are only a range of estimates that puts into perspective how widespread public activity changes can significantly impact carbon emissions at the state scale.

RECOMMENDATIONS

This study indicates that Virginia's transportation sector carbon emissions can respond rapidly to policy changes. The Virginia Conservation Network (VCN) has outlined several policies that Virginia legislators could take to reduce emissions and air pollution from passenger vehicles (available at: http://www.vcnva.org/curbing-vehicle-pollution/), and they include two pathways. One path would aim to shift the transportation system away from depending so heavily on passenger vehicle transportation and its related infrastructure. This could include incentives for teleworking or ride sharing, multi-year investments in transit expansion between urban areas and further into rural areas, smarter planning of communities around reliable and frequent public transportation hubs, better trail and protected urban systems for biking and walking, and more research – including public health impacts – on the emission-related effects of new road projects like lane expansions before they are approved and/or implemented. The second pathway would be to improve fuel emission standards while transitioning Virginia's electrical grid to accommodate more electric vehicles. This second pathway – which would largely swap the current dependency on fossil-fueled cars (and the accompanying sprawl of population centers) with electric ones – would do little to realize the additional environmental, public health, and socioeconomic co-benefits of living in more connected, less sprawling, and largely healthier communities (Stone, 2008).

Overall, Virginia has made limited progress toward reducing transportation sector carbon emissions over the last decade. However, many Virginia cities are using incentives, such as Power Purchase Agreements, to add solar panels to school and government buildings, which require little to no money invested but come with large energy savings that can then be invested back into the cities and schools. This model could also support more efficient transportation system changes, such as implementing more electric vehicle (EV) charging stations across the state to increase driving range. Policies supporting renewable energy have shown to reduce greenhouse gas emissions (Le Quéré et al., 2019) and therefore, it is important for Virginia to continue improving these types of policies while also addressing transportation.

There are arguably more detrimental transportation policies than environmentally friendly ones in the state right now. Consumer Reports analyst Jeff Plungis (2019) explains that existing and proposed EV fees aimed at being equivalent to gas taxes are up to 61% higher than those for gas-powered vehicles in Virginia. However, there are bills currently on the table to improve Virginia's transportation policies. The Virginia Clean Car Standards bill would set two new requirements. The first would be the Low Emissions Vehicle (LEV) standard, which would require manufacturers to reduce emissions for the new gas-consuming vehicles they seek to sell in Virginia markets. The Zero Emissions Vehicle (ZEV) standard would add more electric and hybrid vehicles to the pool of purchasable vehicles in Virginia each year. Most car manufacturers send the majority of their EVs to states that already have Clean Car Standards in place, such as Maryland (Generation180, 2020), leaving little inventory for Virginia-based consumers. As the impacts from climate change and air pollution disproportionately affect historically marginalized communities, adopting policies like the Clean Car Standards that control CO_2 emissions and air quality is one critical step forwards for environmental equity and social justice as well (e.g., Clark et al., 2014). While these proposed standards are a daring start, further and decisive action will still be required to curb state emissions from the transportation sector.

CONCLUSION

This study estimates that Virginia's 2020 transportation CO_2 emissions were reduced by 15.0% (14.2 to 15.7%) from 2019 levels because of the abrupt traffic volume decrease stemming from COVID-19 public health interventions. Of course, strict public confinement is not a permanent solution to addressing transportation emissions and these changes do not reflect the systematic change in transportation types that would ultimately drive down emissions permanently each year. However, this study shows that the transportation sector, which makes up almost 50% of Virginia's CO_2 emissions on average, is responsive to policies that mandate transportation changes. Thus, transportation should be considered as a primary target for reducing Virginia's carbon emissions as well as further improving air quality. Even as new Federal leadership strengthens or reinstates environmental policies, state and local policies remain critical in addressing the root cause of present-day climate change. Although promising progress has been made in the electric power sector with Virginia's Clean Economy Act, policies for reducing transportation-related emissions are currently lacking. We recommend the state, alongside cities and counties, work with proposed VCN policy measures to lay a path towards attainable goals to reduce greenhouse gas emissions from the transportation sector. This will be critical to 1) help the country meet its commitment to the IPCC 1.5°C warming target to limit the economical, ecological, and human health impacts from climate change, and 2) better the people of Virginia's well-being through improved air quality, more community-oriented infrastructure, and improved economic and social equality. We acknowledge that the COVID-19 pandemic has been and continues to be disastrous for communities and families, especially those that have been historically marginalized through discriminatory public policy. We do not assert here that the pandemic has yielded positive effects. Rather, this work highlights that COVID-19 has provided a momentary glimpse at geophysical phenomena, useful toward envisioning a fairer future where reductions in emissions and improvements in air quality are permanent in Virginia as well as globally. Our findings underscore the fact that Virginia must support robust and equitable policies as the state recovers from the pandemic to reduce greenhouse gas emissions, especially from the transportation sector.

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Statement of Responsibility: P. Grothe (corresponding author) and J. Hoffman formulated the project. E. Rakes collected the traffic, energy, and emission data. E. Rakes and P. Grothe analyzed the data and wrote the manuscript. J. Hoffman collected and analyzed the air quality data and provided feedback on the manuscript.

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