Title
Measuring Carbon Dioxide (Co2) As A Proxy For Air Pollution Exposure At Los Angeles Elementary Schools Located Near Major Roadways

Author
Joshi, Tanisha

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MEASURING CARBON DIOXIDE (CO2) AS A PROXY FOR AIR POLLUTION EXPOSURE AT LOS ANGELES ELEMENTARY SCHOOLS LOCATED NEAR MAJOR ROADWAYS

By

Tanisha Joshi

A capstone project submitted for Graduation with University Honors

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APPROVED

Dr. Francesca Hopkins
Department of Environmental Sciences

Dr. Richard Cardullo, Howard H Hays Jr. Chair
University Honors

ABSTRACT

Witnessing natural consequences such as tornadoes, floods, and irregular weather, climate change has never been more apparent in action than it has been in these past few decades. The greenhouse effect has been spurred into action mostly due to the excess of fossil fuels burned for daily life activities such as transportation, heating, and power generation. These sources most prominently emit the greenhouse gasses carbon dioxide and methane. Vehicles especially emit greenhouse gases which can be hard to measure as they are reacting in the lower atmosphere. Recently, electrifying transportation has been a popular solution to reducing carbon emissions, but it also has an influence on emissions from the tailpipe. There continues to be a lack of good understanding of the distribution and relative contribution of the sources of these gases in cities, where decisions to control emissions are often made. My research focuses on examining data collected at sites across the greater Los Angeles (LA) area to better understand the contribution of different sources to emissions in the region. Specifically, I will examine the ratio of carbon dioxide to methane, and carbon dioxide to carbon monoxide, to explore spatial and temporal patterns in emissions across the LA basin, specifically around elementary schools that are in close proximity to major freeways. Exposure to the air pollution produced by freeways has been linked to higher childhood asthma rates, so it is important to understand the distance these pollutants can travel, and how much children are exposed. As CO_2 can be measured quickly and efficiently, we are trying to determine whether CO_2 is a good proxy for air pollution exposure at schools. With more detailed, local information on greenhouse gas sources, this research can help inform local actions to reduce emissions driving climate change.

ACKNOWLEDGEMENTS

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INTRODUCTION

In California, concentrated mainly in Los Angeles (L.A.), freeways are an integral part of transportation due to the high velocity of traffic throughout the city. There are 38 freeways in Los Angeles County and according to the Los Angeles Almanac, approximately 2,882,784 trips are taken on weekdays between seven to eight a.m. alone. This intricate route system allows a large number of people to travel daily for work but can pose a public health hazard with the mass amount of air pollutants escaping the motor vehicles at a given time. The most common pollutants that escape vehicles are carbon monoxide, nitrogen dioxide, and PM 2.5 (a specific type of particulate matter). At low levels, these pollutants have less chance of causing serious health issues but at high levels, have been confirmed to be linked to respiratory diseases. The combination of tall buildings, including skyscrapers and high-rises, with excessive air pollution leads to wind patterns potentially spreading damaging fumes over nearby neighborhoods and local schools. Children and adult pedestrians in these freeway-adjacent areas are exposed to higher concentrations of pollutants, which may lead to increased rates of asthma and decreased lung function. More at risk of permanent lung damage is children, who breathe in more air relative to their body weight than adults do in addition to their weak immune systems (*This Map Shows How Many Millions of Children Are Exposed to Dangerously High Levels of Pollution*, 2016).

Measurements of CO2 in urban regions have become more widespread given the increasing availability of sensors to measure CO2 alongside policies to reduce CO2 emissions. Similar trends have increased the availability and number of air pollution sensors. The most significant source of CO2 and air pollutants in Los Angeles (and most other urban areas globally) are transportation, namely, the combustion of carbon-based fuels in vehicles. This produces CO_2, and air pollutants CO, NO_x, and contributes to the formation of the air pollutants most impactful for health, PM2.5 and ozone. California and the city of LA have committed to reducing their CO_2 emissions. Yet there are still severe air pollution problems and disparities in air pollution exposure in the state and city. One of the policies the state has in place to reduce CO_2 emissions is to provide subsidies for electric vehicles. Electric vehicles do not combust carbon-based fuels and hence do not emit CO_2, CO, or NO_x. However, they still may contribute to pollutants like PM2.5 through tire and brake wear and road dust emissions. Here, we are interested in studying spatial patterns of air pollution exposure at schools. Air pollutants like NO_x and ozone have short atmospheric lifetimes, and pollutants such as PM2.5 have complicated source profiles. We chose to avoid these challenges by studying carbon emissions from vehicle combustion, CO_2 and CO. We wanted to see if CO_2 and CO would be good predictors of air pollution exposure at schools located near major roadways, where we expect air pollution levels to be elevated. We examined data from the BEACO2N network, which measures CO_2 and air pollutants and is already located at several school sites in the region. We also took measurements closer to ground level over the course of a school day to look at students' exposure to pollutants while in the schoolyard. Since CO_2, CO_2, and other pollutants originate from the tailpipe, they follow similar dispersion patterns in the environment.

Current Regulations

California has one of the strict air pollution regulations in the United States. The California Clean Air Act (CCAA) and the California Air Resources Board (CARB) are two high-profile measures in place with the goal of reducing air pollution from a variety of sources, including cars and trucks. After California Senate Bill 352 was passed in 2003, the new law mandated that school buildings could not be built closer than 500 feet to a freeway. However, many residents do not agree that this distance is far enough from the freeway, and in addition, schools built before this law was enacted are still allowed to serve students. Seen more prominently in lower socioeconomic neighborhoods in L.A., children can be seen walking to school in the early mornings around the time of morning traffic. In California, children from households with an annual income below $25,000 are nearly three times more likely to walk or bike than those from families with an annual income above $75,000 (Banerjee et al., 2014). Additionally, inequitable air pollution exposure has been studied with African American, Latino, and Asian Californians being more exposed to PM2.5 than white residents (Reichmuth, 2019). Public transportation is not always a convenient option, as California does not require schools to provide school bus transport for students, especially those who live within a certain distance away.

Respiratory Diseases

Along with pollutant exposure on the walk to school, air pollution that gathers over freeways is carried through Southern California wind patterns to settle in open-air playgrounds of elementary schools. Outdoor playgrounds are common in the Sunshine State, permitting another possibility for kids to breathe in polluted air while playing. Exercise leads to an increase in heart and metabolic rate as well as dilated bronchial tubules, which leads to children inhaling more pollutants than normal during this time frame. Two studies performed at USC in 2004 and 2007 revealed reduced lung function in students who attended schools within 500 feet of the freeway between the ages of ten and eighteen (Fernandes et al., 2018). Further research has concluded that children who are more physically active in an area with worse air quality have a greater risk of developing respiratory health issues (Center for Health Reporting, 2022). The immune system finishes developing when children are about eight years old and overall development finishes when puberty ends, around fifteen to sixteen years of age (Kloc et al., 2020). Children who are exposed to air pollutants in early life can have long-term effects such as cardiovascular diseases, childhood cancer, and a higher chance of developing asthma (World Health Organization: WHO, 2018), which is our primary focus of study.

Our study focuses on the different types of pollutant precursors that come from the combustion of fossil fuels in transportation, such as carbon dioxide, carbon monoxide, and nitrogen oxides. Pollutant precursors combine to form other pollutants - for example, nitrogen oxides when combined with volatile organic compounds form ozone and fine particulate matter (*Inhalable Particulate Matter and Health (PM2.5 and PM10)*, n.d.). A commonly known and researched pollutant is fine particulate matter (primarily PM2.5 and PM10) which was not measured in this experiment despite its proven detriment to human health through numerous air quality studies. In addition, uncovering which pollutants are the most common and during which times of the day they are at their highest and lowest concentrations is a point of focus. Research on this topic can help school administrators implement policies on children's playtime that will lower the latter's exposure to air pollutants.

METHODS + MATERIALS

Summary

The experiment consisted of driving a mobile laboratory (a retrofitted van containing air pollutant-detecting instruments) to measure carbon dioxide, carbon monoxide, and methane concentrations in real-time. The instrument is calibrated at the beginning of each round of data collection with gas cylinders. The mobile laboratory is driven to the site which in this experiment, was chosen based on the intersection of a specific age group and geographical location. Being that asthma rates in kids are the key focus, the research site is an elementary school located relatively close to a freeway. The van is driven early in the morning to the site and parked in the playground while still running. The mobile laboratory is collecting data all day, including pickup and drop-off times which are known to be times of high-volume traffic at schools. At the end of data collection, the lab is driven back to Riverside during peak traffic hours. The instruments are re-calibrated and data is collected from the survey on a USB drive.

Sampling Strategy

Eight schools were chosen for their proximity to popular freeways in the LA basin, ranging from elementary to high schools. After careful consideration, the school options are narrowed down to focus on children whose respiratory systems are more immature. Children who develop asthma most commonly develop symptoms around five years old, narrowing down the schools to elementary options only (*Childhood Asthma*, 2023). The five potential sites are officially Castelar Elementary, Tenth Street Elementary, Murchison Elementary, Wilshire Crest Elementary, and Ninth Street Elementary. CO2 data about these sites from January 2021 to January 2022 is collected from BEACO2N, Berkeley's Environmental Air-quality & CO2

Network. The purpose of this project is to collect greenhouse gas data from nodes placed at street level in order to get more accurate readings of the pollutant concentrations people live in day to day. Out of the five options, Tenth Street Elementary is chosen as the school of focus. There are two factors that play into this choice. First, this location has the second lowest distance to the freeway being 1665.52 feet away (Table 1). Second, the administration's cooperation with the survey requirements made Tenth Street the ideal choice.

Instruments

The mobile laboratory (a 2016 Mercedes Sprinter cargo van) contains dozens of instruments but only a certain few were used in this experiment due to their individual purposes. Starting with the carbon dioxide sensor, the purpose is to measure carbon dioxide in ppm units. The carbon monoxide sensor measures carbon monoxide concentration in ppm units. The nitrogen oxide sensor measures nitrogen oxide concentrations in ppm units. The Picarro G240 measures carbon dioxide, carbon monoxide, and methane concentrations. As for the BEACO2N instruments, a BEACO2N node is a single instrument per site that is essentially an aluminum box designed to withstand the outdoors. The node contains sensors that collect multiple types of data, including CO2, NO, NO2, and CO (*Cohen Research - University of California Berkeley*, n.d.). These instruments contribute to making temporal and spatial measurements for this experiment.

BEACO2N

The BEACO2N nodes are placed several feet above the rooftop in order to sample flowing air. The data is collected and uploaded every five seconds to the network from each site and there are currently over two dozen nodes placed in different sites in the Oakland metropolitan area. The full extent of data collected is CO2, NO, NO2, O3, CO, aerosol, temperature, pressure, and relative humidity. UC Berkeley's research acts as a starting point for this experiment, both in a scientific and community aspect. The data collected by them that they currently share is used as the average baseline for our measurements and variations are deduced from that. Additionally, the schools that are already working with the university that are of importance to us (as seen in Map 1) are open to more collaboration and more research being done at their sites. This pre-established connection helped secure the relationship between our lab and Tenth Street Elementary's administration. The use of community resources and the application of community research is an important aspect of this project. BEACO2N's goal is to use the data collected from their sites to help create better air pollution laws and air quality management policies (*Cohen Research - University of California Berkeley*, n.d.). This feat can only be undertaken with the participation of others aside from researchers. BEACO2N serves as a model for this project to involve community members and hopefully for future research as well.

Data Collection

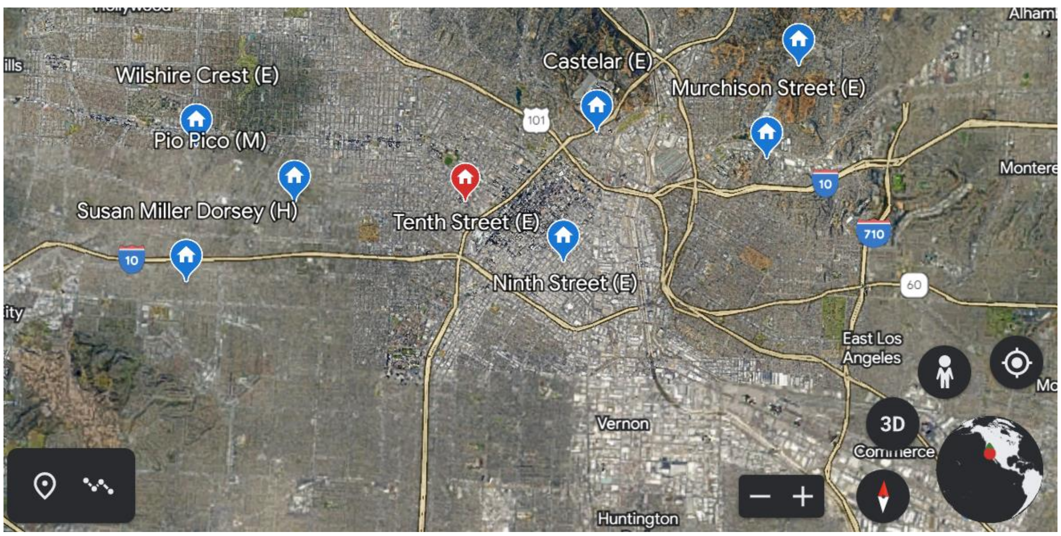
To start off a full day of data collection, the van is turned on at 5:00 AM, and instrument times were synchronized in universal time (UTC). The instruments are calibrated using gas cylinders that contain CO2 mixing ratios which have been corrected against the NOAA WMO-CO2-X2007 scale. When calibrating an instrument, the inlet sampled air from the gas cylinders with known mixing ratios of CO2 for three minutes. The instruments are left to run for ten minutes to allow the instruments to warm up and create a baseline on all the air pollutant levels. On the road, the instruments are constantly collecting data from the freeway and surrounding car emissions. In addition, it is important to note any unusual spikes and jot down any potential factors correlated with the surroundings. An example of a surrounding factor that occurred is a heavy diesel truck passing by emitting dark heavy gases from its radiator. After the truck passed by, the spike returned to the average measurements.

After reaching the school thirty minutes before classes started, the van is parked on the side of the playground asphalt and left running to ensure the instruments continue recording climate data. Drop-off times in the morning for schools are times of high-volume traffic in a small area. This could potentially lead to an increase in pollutant concentration that the mobile laboratory can pick up on. In this survey, it is key to record data from before and after school starts and ends respectively. The instruments do not need to be altered at any point during the day to continue working. Hourly checks are conducted on the mobile laboratory's laptop which is connected via Bluetooth to the instruments and can actively show that the instruments are functioning well. After eight hours of data collection, the school day will pull to a close around roughly 2:30pm for this location. The van is moved to the front main parking lot to record the change in air pollution from pickup time. After pickup time is concluded in about thirty minutes, the mobile laboratory is driven back to its starting location, which in this survey is Riverside. In order to get the broadest amount of data from different freeways in the LA basin, a different freeway than the one the van came on in the morning is taken back. For this survey, the CA-60 is taken to the LA basin and the CA-91 is chosen to drive back on. After reaching Riverside, the mobile lab is parked, and the instruments are kept running for a little while longer. Final data measurements are taken, and data is transferred from each machine before being turned off along with the van. Data is manually transferred onto a USB drive from the instrument itself.

In this experiment, we assume that observed pollutant concentration spikes are due to on-road emissions. These spikes can be influenced by climate conditions and others that are not solely on-road such as biosphere fluxes and/or wildfire emissions which had been uncommonly high at the time. However, for the purpose of this experiment, we expect that these influences are relatively small and do not affect the results.

School Name	Latitude	Longitude	Distance to Freeway (feet)	Average CO2 (ppm)	Standard Dev
Castelar Elementary	34.065	-118.24	864	440	2
Tenth Street Elementary	34.049	-118.273	1666	436	1
Lincoln High School	34.081	-118.189	2260	440	3
Murchison Street Elementary	34.061	-118.196	2422	N/A	N/A
Pio Pico Middle School	34.047	-118.317	3438	440	3
Susan Miller Dorsey High School	34.029	-118.344	3532	423	10
Ninth Street Elementary	34.037	-118.247	4397	441	3
Wilshire Crest Elementary	34.058	-118.343	5764	449	9
			Average	437	

Table 1. Initial CO2 data taken from BEACO2N between Jan. 2021 and Jan. 2022



Map 1. Locations of the eight schools initially chosen due to their proximity to freeways in Los Angeles. The red pin is the survey location.

RESULTS

BEACO2N

Before conducting the experiment, it is important to understand the relative averages of pollutants at the chosen list of schools. BEACO2N gives spatial patterns while mobile sampling gives temporal patterns. This sets a baseline for the conditions we expect to see during the survey and helps identify significant changes in pollutant concentrations. Looking at the BEACO2N data from August 2021 to January 2022 will give a potential clue about the trend in March 2022 which is when the survey was conducted. The ratio between the school's distance to the freeway and the average pollutant amount is an additional key focus. Nationally, air quality trends have shown cleaner progress with declining national air pollutant emissions since 1990 (Radiation, n.d.). Therefore, we expected to see overall lower averages of pollutant concentrations and an inverse relationship between pollutant concentration (ppm) and distance to the freeway (feet).

Based on data from Table 2, we plotted the distance to the freeway compared to the averages of each pollutant for each school. Looking at Graph 1, there is a gradual incline trend signifying that for most schools, a larger distance from the freeway resulted in higher concentrations of CO2. In Graph 2, the trend is not as clear. Some schools have higher CO levels being closer to the freeway while schools that are farther from the freeway also have relatively high levels. Lastly, in Graph 3, the majority of schools have higher PM2.5 levels being closer to the freeway distance wise but some schools demonstrate the opposite. The difference in trends can be due to multiple factors including the prevalence of certain pollutant emitters near a specific school, weather conditions, and the existing Coronavirus restrictions. Research has shown that light-duty vehicles emit more carbon monoxide while heavy-duty vehicles emit more nitrogen oxides (Badshah et al., 2021). Diving deeper into weather patterns and climate conditions, the five elementary schools showed a spike in carbon dioxide concentrations in December 2021 but overall, remained at a steady average around the low end of 400 ppm. The low temperatures in the winter season prompt a higher usage of fossil fuels, such as defrosting cars or keeping them warm. In addition, particulate matter and carbon monoxide concentrations increase due to wood burning from chimneys and smokestacks (Education, n.d.). As for the global pandemic, a new variant of Omnicron had been discovered in late November 2021, which led to increased restrictions that limited travel (Katella, 2023). These new restrictions were expected to have resulted in lowered emissions which conflicts with the data collected by BEACO2N.

Survey

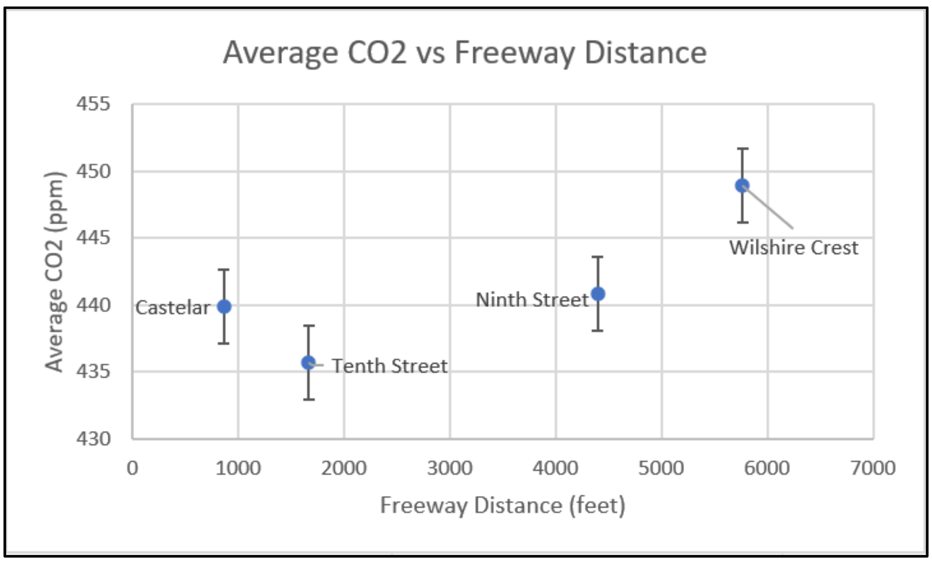
The goal of the survey is to understand temporal patterns of CO2 and CO over the course of the school day at the playground level. Looking at the data collected from Tenth Street Elementary in March 2022, the instrument in use is the Picarro G240 which collected data on carbon dioxide, carbon monoxide, and methane levels. Therefore, comparisons can be made between data from 2021 and 2022 about CO2 and CO while new CH4 measurements will be compared through previously published research. The average concentrations of all three pollutants from the survey are 457.26 ppm for CO2, 0.31 ppb for CO, and 2.01 ppm for CH4. According to the EPA, clean air is classified as having a CO concentration of 0.01 ppb which means Tenth Street conditions could adversely affect children's health as carbon monoxide is an asphyxiate (*Carbon Monoxide Levels and Risks*, 2014). Graph 4 highlights a significant rise in carbon dioxide emissions from around 4:30:00am to 7:00:00am, as indicated by the red arrow. CO2 concentrations rose from the average to almost 600 ppm during this time. In general, a concentration of carbon dioxide below 350 ppm is considered safe for humans and the environment, indicating severely harmful conditions for children. During this time period, the mobile laboratory was being driven to the survey site during early morning traffic which is the most likely source of this spike in emissions.

There are no correlating significant spikes in CO and CH4 which remain at steadily similar levels throughout the day as seen in Graph 5 and Graph 6. Both pollutants share a minor spike at 6:00:00am which may be the result of a polluting vehicle passing by while driving on the freeway. Methane emissions have been steadily declining over the past few years in California due to greenhouse gas emission reduction goals (Yadav et al., 2023). As the survey is conducted over a one-day time period, a reduction will most likely not be seen throughout the day. However, average methane concentrations are seen to be much lower than carbon dioxide and similar to carbon monoxide. These steadily low levels throughout the day correlate with literature and previous research. As of 2021, Tenth Street Elementary is classified as located in a methane buffer zone where it borders an area that has a high number of outputs that naturally produce methane (Geo Forward, 2021). The lack of spikes in methane concentrations means evidence of no significant emitter in the area around the school by any stationery or mobile source. In this experiment, asthma records of each school were not available, including the number of students who were diagnosed with asthma or the severity of their conditions. Methane is not directly linked to asthma rates, but methane can increase asthma symptoms. Being a main driving gas of climate change, methane's role in trapping heat in the atmosphere can lead to reduced lung function and increased asthma flare-ups (*Allergy & Asthma Network Provides Testimony on EPA's New Methane Standards*, n.d.).

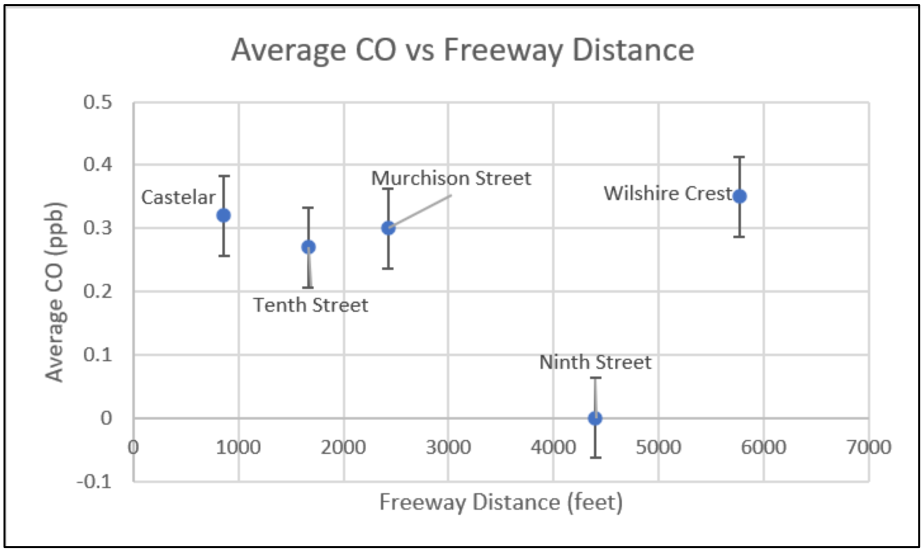
The data collected and averages taken are variable as well. We examined previous data from BEACO2N as well as temporal and spatial patterns. Since the nodes are located on rooftops, the conditions are different than the air at the playground level which is where we measured. Previous work has shown that on-road CO_2 mixing ratios are sensitive to certain traffic conditions such as the distance between cars, the speed of the vehicle, and the grade of the road grade (Maness et al., 2015).

A	D	E	F	G
School Name	**Distance to Freeway (feet)**	**Average CO2 (ppm)**	**Average CO (ppm)**	**Average PM2.5 (ug/m3)**
Tenth Street Elementary	1665.52	435.72	0.27	15.63
Castelar Elementary	864.07	439.87	0.32	12.41
Ninth Street Elementary	4396.81	440.79	-	8.80
Wilshire Crest Elementary	5763.96	448.91	0.35	12.37
Murchison Street Elementary	2422.14	-	0.30	16.05

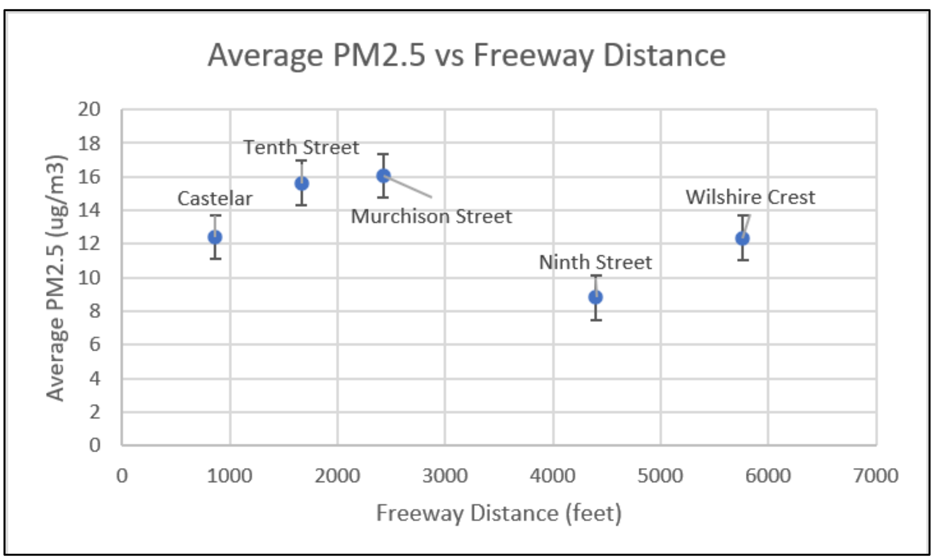
Table 2. The average pollutant concentrations of the five elementary schools over a six month period from August 2021 to January 2022. The original eight schools have been narrowed down to five due to the age range of the target group.



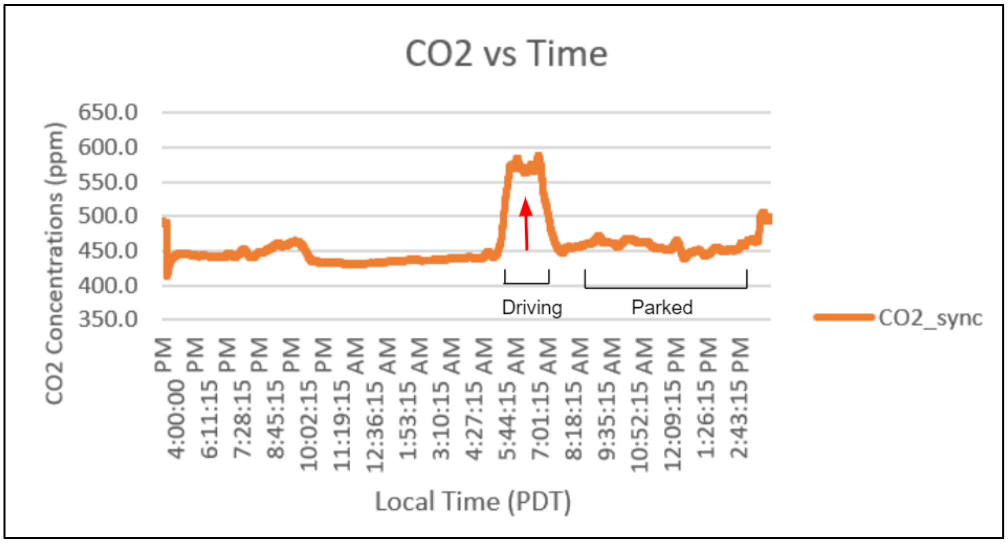
Graph 1. A time series from August 2021 to January 2022 depicting the CO_2 levels at five elementary schools. Murchison Street is excluded due to the lack of CO_2 data available from that site in this time period.



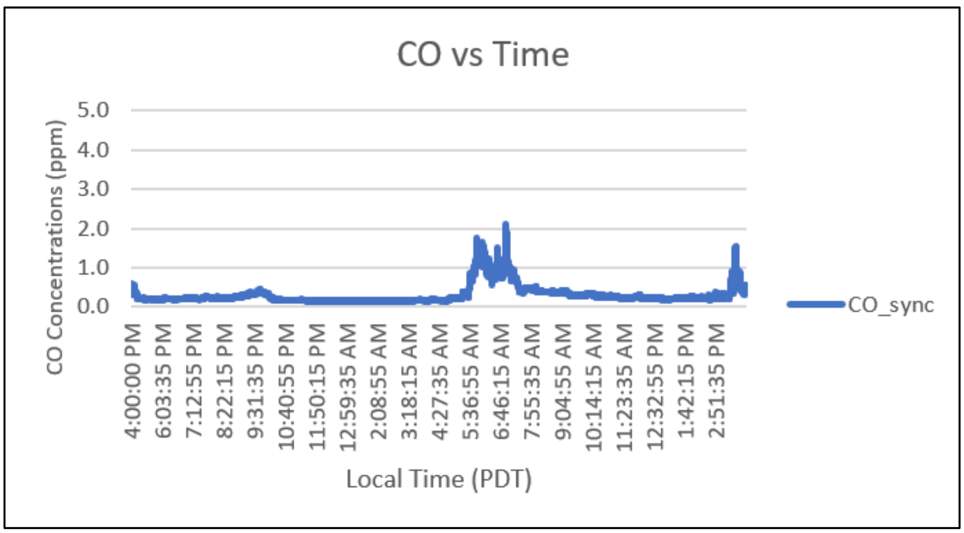
Graph 2. A time series from August 2021 to January 2022 depicting the CO levels at five elementary schools. Ninth Street is excluded due to the lack of CO2 data available from that site in this time period.



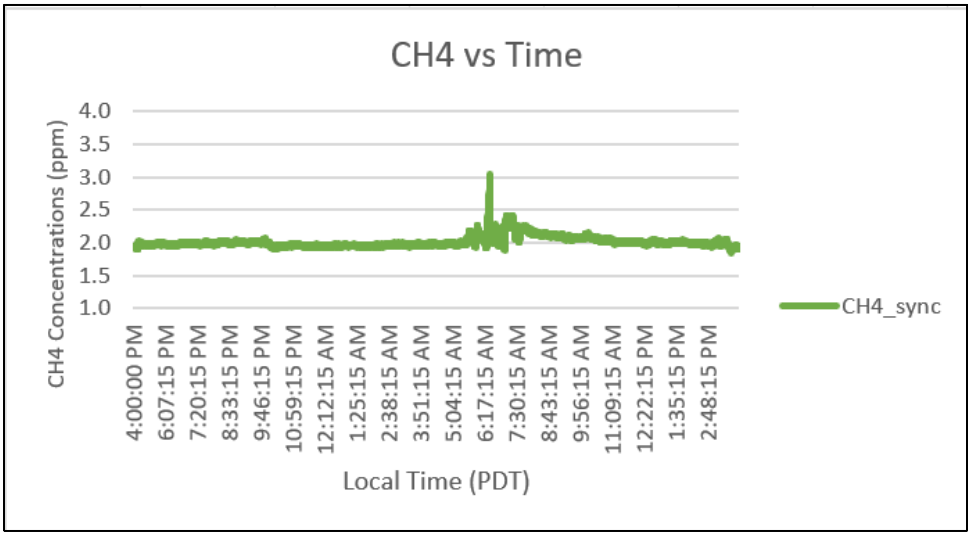
Graph 3. A time series from August 2021 to January 2022 depicting the PM2.5 levels at five elementary schools.



Graph 4. March 2022 survey time series of CO2 concentrations throughout the day. Red arrow indicates an abnormal spike in CO2 concentration.



Graph 5. March 2022 survey time series of CO concentrations throughout the day.



Graph 6. March 2022 survey time series of CH4 concentrations throughout the day.

DISCUSSION

This experiment conducted an examination of the ratio of carbon dioxide to methane, and carbon monoxide emissions at elementary schools located near major freeways and how this has an effect on children's asthma rates. The survey yielded surprising results, with pollutant and freeway distance relationships being less straightforward than initially hypothesized. Out of the three pollutants of focus, only carbon dioxide had significant numbers as well as any changes to the average indicating that there is more going on than what meets the eye. The spike in carbon dioxide concentration only during driving time is unexpected. Regulations for different pollutants are about the same in California with there being an overall decline annually of the average concentrations of air pollutants other than carbon dioxide. In addition, the correlation between pickup time and the spike is based on inductive reasoning from the spike happening to occur during pick-up time. However, since this experiment is conducted outside of a lab with controlled variables, there is a large number of potential explanations for the spike that are not associated with pick-up time.

With more time and resources, we would like to expand our sample group and survey more schools that are still relatively close to freeways, starting with Castelar Elementary and Murchison Elementary. A larger survey will allow for more accurate predictions of the causes of any spikes and average levels of pollutant concentrations throughout the day. Potential causes include changing wind directions or nearby sources of pollutants. Additionally, acquiring asthma rates from these schools would be ideal for comparing unsafe concentrations of any pollutant and possibly linking it to increased or decreased rates of diagnosis. This would be difficult to acquire since human subject permission is required but it is still a route that can potentially be explored. In the future, we aim to conduct experiments that focus on linking exposure to specific pollutants to different respiratory diseases. The experiment would use 2B Tech NOx and a new instrument to collect NOx and PM2.5 data with the mobile laboratory respectively. These two pollutants have been heavily researched on the role they play in respiratory diseases, namely asthma.

In addition to continued research, we would like to give back to the community by educating families with children about the health impacts of the area they live in and the schools their children attend. We would advocate for the implementation of solutions that reduce greenhouse gas emissions as well as reduce exposure to them. Potential solutions include switching over to electric vehicles, participating in carpooling, and opting for public transport more often. A higher percentage of electric vehicles during pick-up time could drastically reduce the children's immediate exposure to car exhaust pollutants. With an ever-growing population, electric vehicles offer a long term solution that sets clean air trends up for success. For example, the least efficient type of electric car still emits 37% less carbon dioxide than petrol (*How Clean Are Electric Cars?*, 2022). Secondly, schools and/or parents can set up a carpooling program, reducing the number of cars gathering in one area for pick-up time and lowering overall emissions on the road. The numerous other benefits of this solution can be stressed, such as saving time and gas money. Third, the increased use of public transportation is a solution that is the most convenient and practical for families to start using but is least likely to be implemented due to the inconvenience of public transportation in the United States. Compared to private automobiles, heavy rail, light rail, and bus transit produce 76, 62, and 33 percent less greenhouse gas emissions, respectively (*Federal Transit Administration*, 2023). These three solutions have the potential to save the developing respiratory systems in kids until a time when overall emissions are reduced to clean air standards.

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