Effects of Changes in Operations at Power Plants on Local Air Quality in Colorado Springs, CO

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Abstract

Over the course of their lifetimes, the two coal-fueled power plants in Colorado Springs, Martin Drake and Ray Nixon, have undergone a series of changes, finally culminating in the complete closure of Martin Drake in September 2022. Many of these changes were motivated by the desire to reduce air pollution in the city and its surroundings. This study explores the effects of changes at the two power plants on four different air pollutants. Data collected by the Environmental Protection Agency are split into ten periods characterized by changes at each plant, including plants being partially or entirely shut down, the addition of pollution control equipment, and fuel changes. The changes are found to have had profound effects on levels of sulfur dioxide, but negligible effects on other pollutants. Mean levels of sulfur dioxide have decreased by approximately 2.73 ppb since before the changes to the two plants began. There is substantial evidence to suggest that changes at the plants were the primary contributors to this effect. There is also some evidence to suggest that spikes in sulfur dioxide levels may be caused by plumes of pollution being carried by the wind from other counties and states. Changes in carbon monoxide have not been linked to any type of event, but the 95th percentile of yearly concentrations of carbon monoxide is decreasing significantly. Finally, El Paso County is approaching unlawfully high concentrations of ozone, although no statistically significant trends were found in ozone data. Altogether, the data suggest that local power plants are an important contributor to Colorado Springs air pollution, but they are not the only contributor. Furthermore, they are not necessarily linked with levels of ozone, which is the pollutant most likely to exceed the standards set by the Environmental Protection Agency in El Paso County.

1. Introduction

The United States harbored a steadily growing electricity industry and heavy reliance on fossil fuels from 1950 to approximately 2007. Despite this beginning, the country has since begun to vary the sources of its electricity, level out its overall electricity production, and decrease its use of fossil fuels, especially coal (US Environmental Protection Agency, 2022g). A major part of the reasons for, and benefits of, this change is the decrease in many kinds of pollutants that are primarily emitted by coal plants (US Government Accountability Office, 2008).

In addition to directly encouraging decreases in fossil fuel use, the United States government has passed a variety of regulatory laws to ensure that levels of air pollutants remain safe. The Clean Air Act encompasses a few of these laws. Notably, it established the National Ambient Air Quality Standards, or NAAQS, in 1970 (US Environmental Protection Agency, 2022e). These standards govern levels of six different air pollutants: carbon monoxide (CO), lead (Pb), particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2), with the goal of protecting public health and the environment (US Environmental Protection Agency, 2022d). Under this law, every state must monitor ambient concentrations of the six criteria pollutants, and, if concentrations are found to be in nonattainment of the standards, must submit and implement a plan to return to attainment or face sanctions from the federal government (US Government Publishing Office, 2013). The criteria pollutants are all caused by various anthropogenic activities, and all have harmful effects on human health at high concentrations.

Carbon monoxide emissions come primarily from vehicles on roads (Office of Air Quality Planning and Standards , 2010). Elevated CO levels have been proven to lead to decreased oxygen availability in the blood due to the CO binding to heme proteins, inhibiting their ability to carry oxygen (Office of Air Quality Planning and Standards , 2010). Limited evidence also suggests possible effects on developing fetuses, newborn infants, the central nervous system, and the lungs (Office of Air Quality Planning and Standards , 2010). The CO NAAQS state that levels must not exceed 9 ppm averaged over eight hours, and 35 ppm averaged over one hour, more than once per year (Colorado Air Pollution Control Division, 2021).

Particulate matter is divided into two categories: PM_{10} and $PM_{2.5}$, representing particles with diameters less than or equal to 10 μm (micrometers) and particles with diameters less than or equal to 2.5 μm, respectively (Colorado Air Pollution Control Division, 2021). $PM_{2.5}$ is associated with a variety of adverse effects on human respiration (National Center for Environmental Assessment, Office of Research and Development, US EPA, 2006). PM_{10} is less dangerous than $PM_{2.5}$ because it cannot penetrate as deeply into the lungs (Colorado Air Pollution Control Division, 2021), and is therefore afforded less attention. $PM_{2.5}$ is emitted from industrial activities, motor vehicles, fuel combustion, and are secondarily produced by combinations of SO_2, nitrous oxides, ammonia, and volatile organic compounds (US Environmental Protection Agency, 2019). Larger particles ($PM_{2.5\text{-}10}$) are primarily geological or biological material (US Environmental Protection Agency, 2019). The NAAQS for PM_{10} require that concentrations not exceed 150 $\mu g/m^3$ averaged over 24 hours (Colorado Air Pollution Control Division, 2021). The NAAQS for $PM_{2.5}$ require that average annual concentrations, averaged over three years, not exceed 12 $\mu g/m^3$ and that the 98th percentile of 24-hour average concentrations averaged over 3 years not exceed 35 $\mu g/m^3$ (Colorado Air Pollution Control Division, 2021).

Elevated SO_2 levels may cause breathing difficulties, especially for children with asthma and adults exercising outdoors (Colorado Air Pollution Control Division, 2021). Long-term exposure to SO_2 and PM can aggravate existing cardiovascular and respiratory conditions (Colorado Air Pollution Control Division, 2021). The primary anthropogenic source of SO_2 is coal-fired power plants, in addition to other industrial processes (US Environmental Protection Agency, 2022b).The NAAQS for SO_2 require the 99th percentile of 1-hour daily maximum concentrations, averaged over three years, not to exceed 75 ppb, and the 3-hour average not to exceed 0.5 ppm more than once per year (Colorado Air Pollution Control Division, 2021).

Ozone is usually formed from reactions induced by sunlight between volatile organic compounds and nitrous oxides (NO_x) (Colorado Air Pollution Control Division, 2021). The primary sources of these pollutants include industrial facilities, electricity production, motor vehicles, and chemical solvents (Colorado Air Pollution Control Division, 2021). Since increased sunlight leads to higher O_3 concentrations, O_3 is generally considered a summertime pollutant (Colorado Air Pollution Control Division, 2021). However, new evidence suggests that snow can also lead to higher O_3 levels because the reflectivity of the snow, similarly to extra sunlight, increases the formation of O_3 (Colorado Air Pollution Control Division, 2021). This makes O_3 a concern in the winter as well. Ozone exposure is linked to significant effects on human respiratory systems, including impaired lung function, aggravation of asthma and other diseases, and premature lung aging (Colorado Air Pollution Control Division, 2021). The NAAQS for O_3 require the annual fourth-highest maximum daily average 8-hour (MDA8) concentration, averaged over three years, to remain below 0.07 ppm (Colorado Air Pollution Control Division, 2021).

Lead in the United States is primarily emitted by metal processing and aircraft using leaded fuel (US Environmental Protection Agency, 2022h). It can affect various processes in the human body, but currently, it most commonly affects the neurological systems of children (US Environmental Protection Agency, 2022h). Nitrogen dioxide is primarily emitted by vehicles and power plants (US Environmental Protection Agency, 2022i). It can aggravate existing respiratory diseases and cause additional respiratory issues (US Environmental Protection Agency, 2022i). However, neither lead nor nitrogen dioxide are examined in this study due to the absence of monitors for either pollutant in the study area.

In the Pikes Peak region of Colorado, O_3 is the only criteria pollutant for which the area is at risk of nonattainment (Colorado Air Pollution Control Division, 2021). In 2020 and 2021, the three-year average of the fourth-highest MDA8 concentrations reached 0.072 ppm and 0.073 respectively, although the Pikes Peak region has not been declared to be in nonattainment of the NAAQS (Colorado Air Pollution Control Division, 2022).

The six NAAQS pollutants are not the only types of power plant emissions causing concern among environmental groups; one of the most prominent reasons behind the push to switch away from coal is the emission of greenhouse gases from fossil fuel burning (Budner, 2021). Although renewable energy such as that produced by wind or hydroelectric facilities is considered “cleaner” than fossil fuel energy, switching from coal to natural gas still has its benefits and is an attractive option for policymakers and utility companies (Budner, 2021; US Government Accountability Office, 2008). Carbon dioxide (CO_2) is not a NAAQS pollutant, but it is a prominent greenhouse gas and has long been the target of reduction policies due to its significant contribution to climate change (US Government Accountability Office, 2008). Burning natural gas as a fuel generates approximately half as much CO_2 as burning coal (US Government Accountability Office, 2008). Furthermore, the usage of coal as fuel requires more electricity for fuel storage, handling, and air pollution abatement than the usage of gas; the production of such electricity produces secondary CO_2 emissions (US Government Accountability Office, 2008).

In 2021, coal was the second most popular source for electricity generation in the United States at 22% of generated electricity, behind natural gas, which accounts for 38%, and just ahead of renewable energy, which produces 20%. Coal was by far the most common source of electricity in 2008, but its use has been in decline since then, largely replaced by natural gas (US Energy Information Administration, 2022). Despite this trend, Colorado Springs, the second largest city in Colorado, generated 32% of its electricity from coal in 2020 (Colorado Springs Utilities, 2022a). The coal was burned in two coal-fired power plants near the city: Martin Drake, located in downtown Colorado Springs adjacent to the intersection of Highway 24 and Interstate 25, and Ray Nixon, located approximately 13 miles southeast of the city, beside Interstate 25. Martin Drake was one of very few coal-fired power plants remaining in the downtown areas of large American cities and thus attracted significant concern from environmental groups and community members due to the pollution it emitted (Booth, 2021). Martin Drake and Ray Nixon have grown alongside Colorado Springs itself, adding new electricity generation units over time (Table 1).

Unit	Year online	Year offline	Maximum hourly load (MW)	NO_x control equipment installation date	Particulate matter control equipment installation date
Martin Drake 1	1925	1997	Unknown	N/A	Unknown
Martin Drake 2	Unknown	1997	Unknown	N/A	Unknown
Martin Drake 3	Unknown	1997	Unknown	N/A	Unknown
Martin Drake 4	Unknown	1997	Unknown	N/A	Unknown
Martin Drake 5	1962	2016	52	1998	1998
Martin Drake 6	1968	2022	86	1998	1978
Martin Drake 7	1974	2022	145	1999	1993
Ray Nixon 1	1980	N/A	227	1989	Unknown
Ray Nixon 2	1999	N/A	38	1999	N/A
Ray Nixon 3	1999	N/A	38	1999	N/A

Table 1. Information about the units in the Martin Drake and Ray Nixon power plants (Grewe, 2022; US Environmental Protection Agency, 2022c; Schimmoller, 2005). Until 2020, all units listed were coal-fired except for Ray Nixon 2 and 3 (US Environmental Protection Agency, 2022c). See Figure 1 for more fuel and timeline details.

The electricity generation units are numbered in order of their addition to the plant. Each unit has a different power generation capacity and its own array of pollution-reducing equipment. Table 1 contains information about the operation of the largest power-generating units near Colorado Springs and a summary of the installation of NO_x and PM control equipment on each one.

There have been many changes to power generation at the two plants over the past decade (Figure 1). Martin Drake shut down for nearly two months in 2014 due to damage from a fire (KRDO News, 2014). Then, pollution concerns contributed to the installation of SO_2 scrubbers on various units (Figure 1). On June 26, 2020, the Utilities Board of Colorado Springs Utilities approved a new Electric Integrated Resource Plan that included, among many other changes, the early closure of the Martin Drake Power Plant (Colorado Springs Utilities, 2020). The plant began to run only intermittently, whenever electricity demand was highest (Colorado

Springs Utilities, 2022b). In late 2020, Martin Drake's Unit 7 switched from burning primarily coal to primarily natural gas, followed later by Unit 6 in summer 2021 (US Environmental Protection Agency, 2022c). Finally, on September 1, 2022, both units stopped burning fuel entirely, marking the end of the operation of the permanent units at Martin Drake (US Environmental Protection Agency, 2022c). Currently, the site of the now-closed Drake plant houses six temporary modular units that can be used to burn natural gas during peak demand times, while the Ray Nixon plant continues to burn coal in Unit 1 (Grewe, 2022). The rest of the power supplied by Colorado Springs Utilities comes primarily from natural gas in the Nixon, Birdsall, and Front Range power plants, aeroderivative (portable natural gas) units located on the site of Martin Drake, hydropower, and solar arrays (Colorado Springs Utilities, 2020).

In the area surrounding Colorado Springs, four air quality monitoring stations regularly record levels of CO, PM, O_3, and SO_2 to ensure compliance with the NAAQS (Figure 2). The remainder of this paper analyzes the relationship between power generation and air pollutants in Colorado Springs. Section 2 supplies additional information about the data sources and analysis tools. Section 3 presents the data analysis in detail for each of the four monitored NAAQS pollutants as well as carbon dioxide. The data have been divided into 10 periods, delimited on each end by an event at either Martin Drake or Ray Nixon. The periods are listed in detail, numbered, and color-coded in Figure 1. Section 4 summarizes the findings, describing the statistical relationships between Colorado Springs air quality and changes to Colorado Springs power plants.

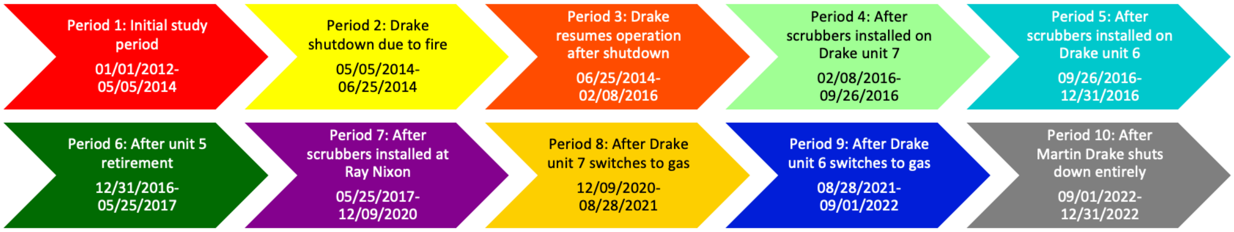


Figure 1. Timeline of events separated into periods, color-coded for distinction. The entire study period covers exactly ten years, from January 1, 2012, to December 31, 2022. In this figure and in the study timeline, the word "scrubbers" refers specifically to SO_2 scrubbers. Timeline sources: US Environmental Protection Agency, 2022c; Chalfin, 2014; KRDO News, 2014.

2. Methods

2.1. Site Locations

This study focuses on hourly measurements of Environmental Protection Agency (EPA) criteria air pollutants in Colorado Springs and the surrounding area during the period from January 1, 2012 to March 2023 (Figure 1). The primary data source is publicly available data sets collected by the Colorado Department of Public Health and Environment (US Environmental Protection Agency, n.d.). The data come from four different sites (Figure 2, Table 2). The first is the Air Force Academy (AFA), approximately 15 km north of the Martin Drake Power Plant. The AFA site is located on the southeast side of the AFA campus, at the tip of Airfield Drive, approximately 0.9 km from I-25. The second site, Highway 24 (H24), is approximately 10 m north of Highway 24, directly west from the intersection of Highway 24 and I-25, 0.9 km from the plant. The third site, at Colorado College (CC), is approximately 2.6 km north of the power plant, just beside Monument Creek, which runs alongside I-25. The fourth site, in Manitou Springs (MAN), is located just east of Crystal Valley Cemetery, approximately 6.9 km northwest of the plant.

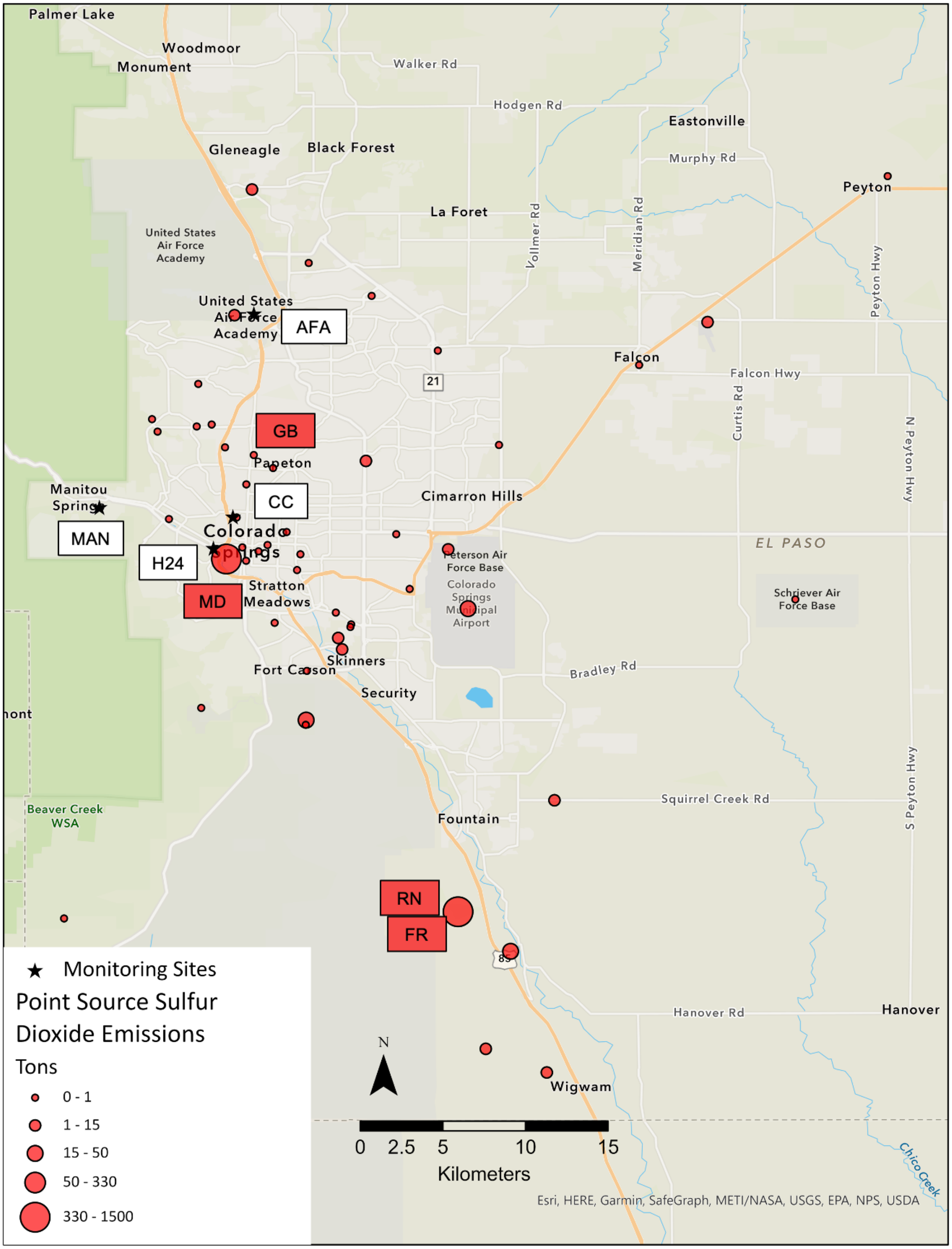


Figure 2. Locations of monitoring sites and major SO_2 point sources according to the EPA 2017 NEI (US Environmental Protection Agency, 2021). Monitoring stations are labeled in white, and Colorado Springs Utilities plants are labeled in red: Front Range is abbreviated as FR, Ray Nixon as RN, Martin Drake as MD, and George Birdsall as GB.

Site name	Site Latitude	Site Longitude	Site Elevation (m)
Air Force Academy (AFA)	38.9583	-104.8172	1971
Highway 24 (H24)	38.8309	-104.8392	1824
Colorado College (CC)	38.8480	-104.8286	1832
Manitou Springs (MAN)	38.8531	-104.9012	1955

Table 2. Locations and elevations of the four monitoring sites.

2.2. Instrumentation

The H24 site supplied all of the meteorological data used in this study, including wind direction, wind speed, relative humidity, and temperature, in addition to SO_2 and CO concentrations. Hourly-averaged wind speed and direction data were collected via an RM Young Model 05305 beginning in August 2014. SO_2 data were measured at a 1-minute frequency and averaged hourly, beginning in January 2013, via a Teledyne API 100E. CO data were collected every minute via a Thermo Scientific 48i and averaged hourly throughout the entire study period. The CC site supplied concentrations of PM (both $PM_{2.5}$ and PM_{10}). At the beginning of the study period, $PM_{2.5}$ and PM_{10} data were collected every 3 days (R & P Model 2025) and 6 days (R - P Co Partisol Model 2000), respectively, followed by hourly data beginning in June 2016 from a GRIMM EDM Model 180. Although hourly values for PM_{10} became available with the installation of the GRIMM, the CDPHE continues to use the values collected every 6 days by the R - P Co Partisol Model 2000, and this study follows suit. The AFA and MAN sites supplied data on O_3 concentrations. Ozone data were collected every 6 seconds and averaged hourly (Flynn et al., 2021) throughout the entire date range from both the AFA and MAN sites using a Teledyne API model 400 O_3 analyzer (except for a five-month interruption from December 2018 to May 2019 at the AFA site). Calibration, and quality assurance and quality control (QA/QC), procedures follow the CDPHE Quality Assurance Project Plan (Colorado Air Pollution Control Division, 2015).

Certified hourly data from all four sites (and other CDPHE measurement stations) are available through the U.S. EPA Air Quality System (AQS) database (https://aqs.epa.gov/aqsweb/documents/data_api.html). Aggregated and visual data are available from the EPA Air Data site (https://www.epa.gov/outdoor-air-quality-data).

2.3. Data Analysis

For certain analyses, data were binned by season to aid in the interpretation of temporal patterns. For the purposes of this study, December through February are considered winter months, March through May are considered spring, June through August summer, and September through November fall. Results with $p < 0.05$ were considered to be statistically significant.

The timeline used to separate the different time periods for data analysis (Figure 1) was compiled primarily using information from the EPA Monitoring Plans for Part 75 Sources (US Environmental Protection Agency, 2022c). Newspaper articles published online provided the start (Chalfin, 2014) and end dates (KRDO News, 2014) for the shutdown of Martin Drake after the fire in May 2014. The AirNow-Tech Navigator was used to evaluate overhead smoke on specific days (US EPA Office of Air Quality Planning and Standards, 2022). CO_2 data are from the EPA's Clean Air Markets Program Data (CAMPD) website (US Environmental Protection Agency, n.d.).

Matplotlib 3.6.2, R Studio 2022.07.1, Microsoft Excel 16.69, and IBM SPSS 28.0.0.0 were employed for data analysis and graphing purposes. The R OpenAir package provides methods for creating wind roses and polar wind plots (Carslaw, 2012). Matplotlib and Pandas 1.4.3 were used to read and process data, as well as to create scatter plots, line graphs, box plots for the different data periods, and line graphs. SPSS was used to generate histograms and descriptive statistics. Microsoft Excel's linear regression tool (from the Analysis ToolPak) was used to analyze trends over an uninterrupted period of time. Figure 2 was constructed using ArcGIS and Microsoft PowerPoint 16.71.

The Hybrid Single-Particle Lagrangian Transport (HYSPLIT) dispersion model (Draxler & Hess, 1998) was used with HRRR 3-km meteorological data to determine likely sources of distant air pollution by modeling the air mass backward trajectory from the monitoring stations over 24 hours. An ensemble of 27 trajectories was generated for every model run to identify all the possible sources of pollution. These trajectories were then compared to locations of large power plants identified on a map compiled from EPA data by Synapse, Inc. (Synapse Energy Economics, Inc., 2022) to locate plants that could realistically have contributed air pollution to the sampled air streams.

The Games-Howell test in IBM SPSS was used to determine whether the mean levels of criteria pollutants in the different periods (Figure 1) differed significantly. Many of the data sets were highly autocorrelated, so each one was thinned out before testing to increase the independence of the observations. Within the data sets for the four criteria pollutants, each period had a certain lag at which autocorrelation either mostly or entirely disappeared, with the one exception being period 9 in the SO2 data. Data points were selected with this amount of lag in between each point. The PM10 data set retained 70% of its points after thinning due to its low sampling frequency, but all other data sets retained less than 10%, with the greatest thinning reducing MS O_3 to just over 1% of the original set. Despite this substantial thinning, each period, on average, received only a 2% change between the means for thinned and unthinned data across all data sets. The median change between thinned and unthinned means was 1%, and the highest relative change was from 0.9 ppb to 1.1 ppb (22%) for SO_2 during period 2. Because the overall means stayed relatively similar, the thinned data in this study are considered sufficiently representative of the unthinned data for the purposes of the Games-Howell test. Once the data had been thinned, they still had highly unequal variances and means, so Welch, Brown-Forsythe, and Games-Howell tests were used to judge the presence or absence of statistically significant differences between periods. To estimate the size of the changes per period for SO2, the effect size for each period was calculated using the previous period as a control period (Wilson, n.d.).

3. Results and Discussion

3.1. Sulfur dioxide

Period	N	Mean (ppb)	σ (ppb)	95th Percentile (ppb)	Effect size compared to previous period (ppb)
Initial	10885	3.41	5.52	13.3	N/A
Fire shutdown	975	0.95	1.97	3.7	-0.46 ± 0.07
Back online after fire	13206	2.97	5.10	12.1	0.41 ± 0.07
Unit 7 scrubbers	4982	2.74	5.07	12.6	-0.04 ± 0.03
Unit 6 scrubbers	2202	2.04	2.58	6.2	-0.16 ± 0.05
Unit 5 retired	3281	1.35	1.14	3.5	-0.37 ± 0.05
Nixon scrubbers	28715	0.84	1.14	2.6	-0.45 ± 0.04
Unit 7 gas	5898	0.63	0.90	2.3	-0.19 ± 0.03
Unit 6 gas	7945	0.90	0.67	2.1	0.34 ± 0.03
Permanent shutdown	2437	0.69	0.61	1.8	-0.32 ± 0.05

Table 3. Statistics for SO_2 at the H24 site, binned by period. The effect size is calculated using the calculator at https://www.campbellcollaboration.org/research-resources/effect-size-calculator.html (Wilson, n.d.).

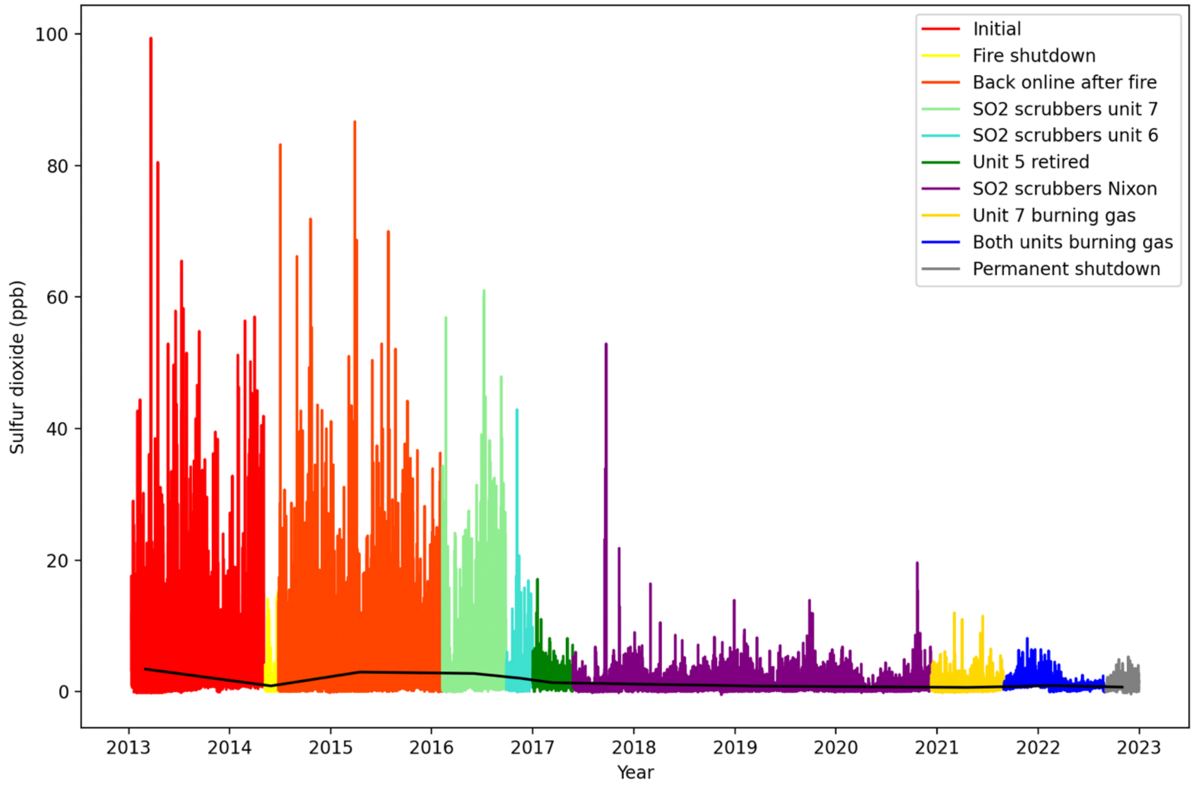


Figure 3. Hourly averaged SO_2 levels from 01/11/2013 to 12/31/2022 at the H24 monitoring station with time periods highlighted by color and average per period plotted as a black line.

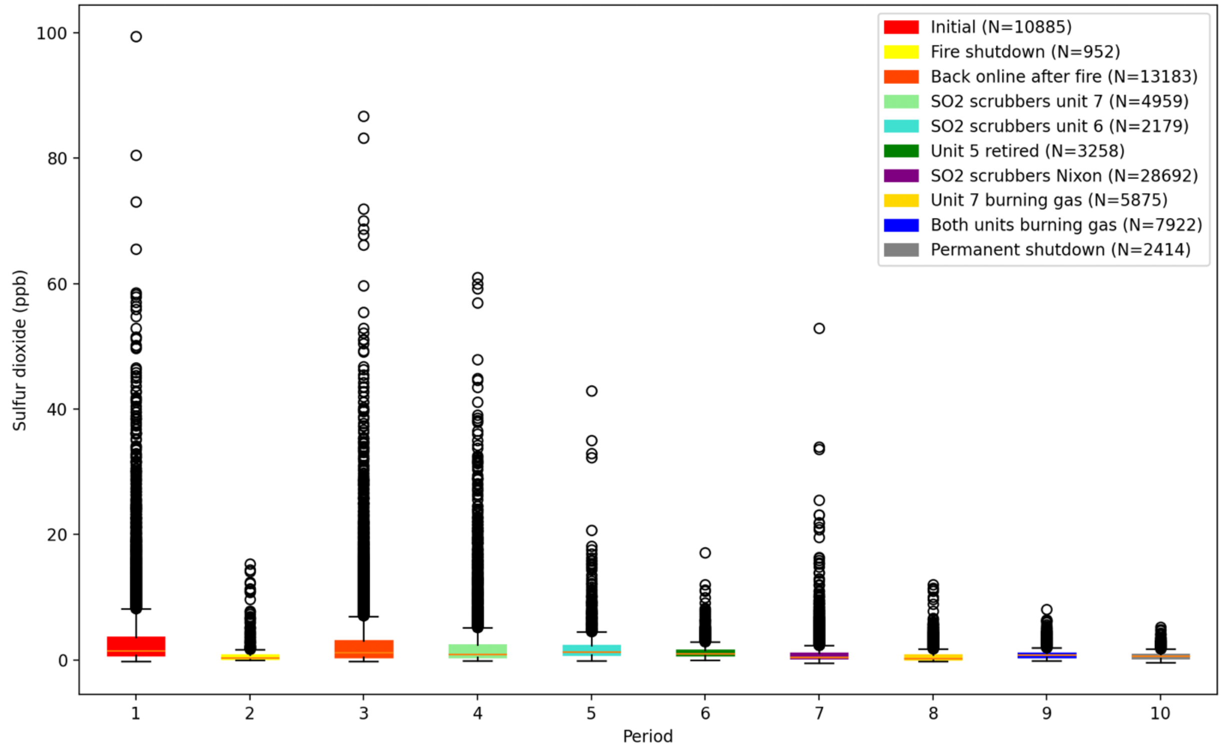


Figure 4. Box plots of SO_2 concentrations at H24 for each period, including fliers (points outside the interquartile range).

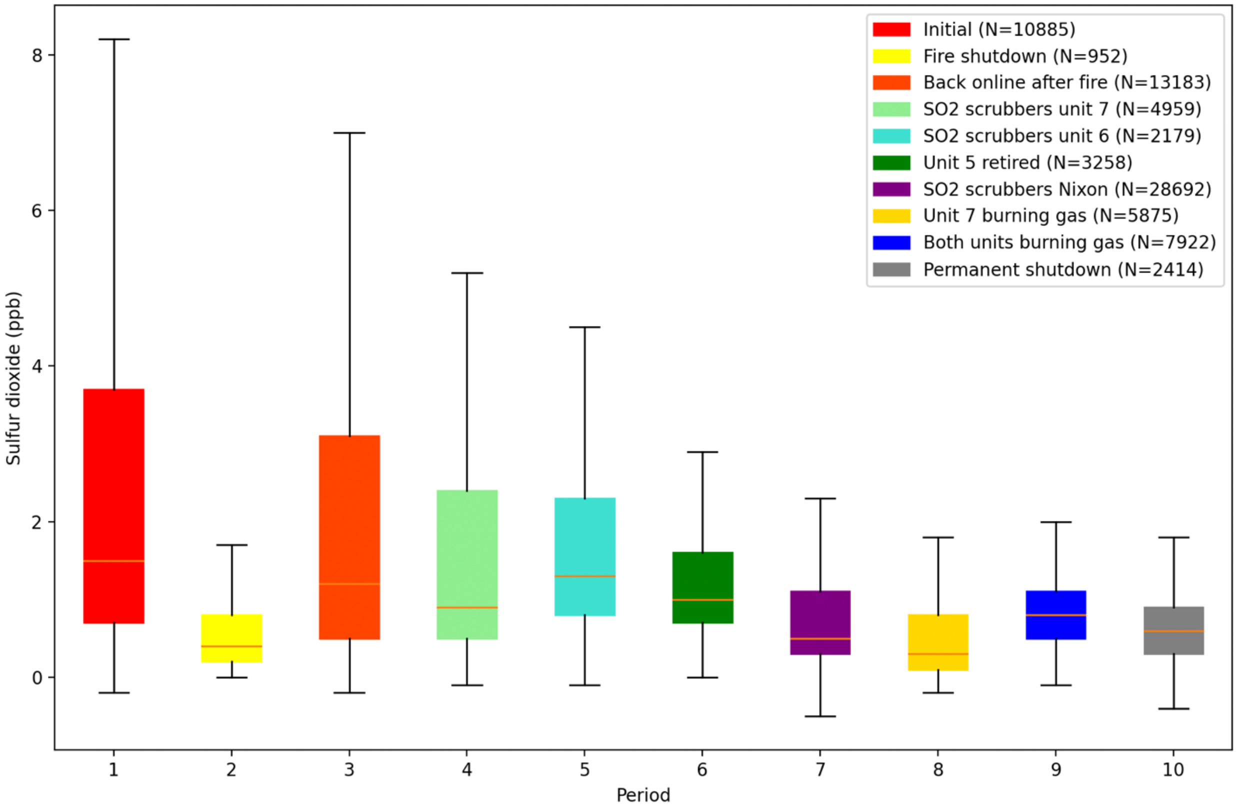


Figure 5. Box plots of SO_2 concentrations for each period, excluding fliers.

The study period begins with Period 1, consisting of 2.5 years of operations at Martin Drake before the 2014 fire, with no notable changes to pollution control or operation style (US Environmental Protection Agency, 2022c). The average concentration of SO_2 during this period was 3.41 ± 5.52 ppb (mean ± std. dev.) and the 95th percentile value was 13.3 ppb, both of which are the highest values out of all ten study periods (Table 3). During the shutdown period after the fire, which is labeled Period 2, electricity demand was redistributed to the Front Range, Ray Nixon, and Birdsall power plants. The SO_2 levels during this time dropped significantly due to the absence of coal burning at Martin Drake (Table 3, Figure 3). The difference between the means of SO_2 concentrations before and during the shutdown is statistically significant ($p < 0.001$). After plant operation resumed, SO_2 went back to similar levels as before, until the first SO_2 scrubbers were installed about two years later. Once again, the difference in means between the fire shutdown period and the post-fire-shutdown period is statistically significant ($p < 0.001$). It is clear that the fire shutdown at Martin Drake had an important impact on the SO_2 concentrations at the H24 site.

After the scrubber installation on units 7 and 6 and before the retirement of unit 5 at Martin Drake, SO_2 emissions decreased to an average of 2.04 ± 2.59 ppb, with a substantial drop in the 95th percentile to 6.2 ppb (Table 3). Although there is a clear negative change in the mean levels of SO_2 before and after scrubber installation, the statistical significance of this change is not immediately apparent. The mean levels of SO_2 before and after the unit 7 scrubber installation are not significantly different ($p = 1$), nor are the mean levels of SO_2 before and after the unit 6 scrubber installation ($p = 0.06$). The lack of statistical significance implies that the scrubbers' effect was not immediate. However, there is a statistically significant difference between the period before both scrubbers were installed and the period after both scrubbers were installed ($p < 0.001$), implying that their cumulative impact is still important. The cumulative effect size of both scrubber installations is approximately -0.2 ppb, which is 43% as large as the effect size of the post-fire shutdown (Table 3).

On the other hand, although the cumulative effect is statistically significant, it does not match the reported efficiency of the scrubbers, which is 96% for SO_2 (Carpenter, 2013). It is worth noting that the EPA lists the optimization date of both scrubbers as November 3, 2017 (US Environmental Protection Agency, 2022c), over a year after both were installed. This means it is difficult to disentangle the effects of the scrubbers from the effects of two other events that occurred in the meantime: the retirement of unit 5 at the end of 2016 and the Ray Nixon scrubber installation in May 2017 (Figure 1). However, the SO_2 concentrations between scrubber optimization and the beginning of the plant's transition from coal to gas averaged 0.84 ± 0.99 ppb (Table 3). Compared to the average of 2.97 ± 5.10 ppb before scrubber installation, we do see a substantial shift (Figure 5); the value is even lower than the average of 0.95 ± 1.97 ppb during the post-fire shutdown, which may be due to the addition of the SO_2 scrubbers on Ray Nixon's unit 1 (Table 3; Figure 1).

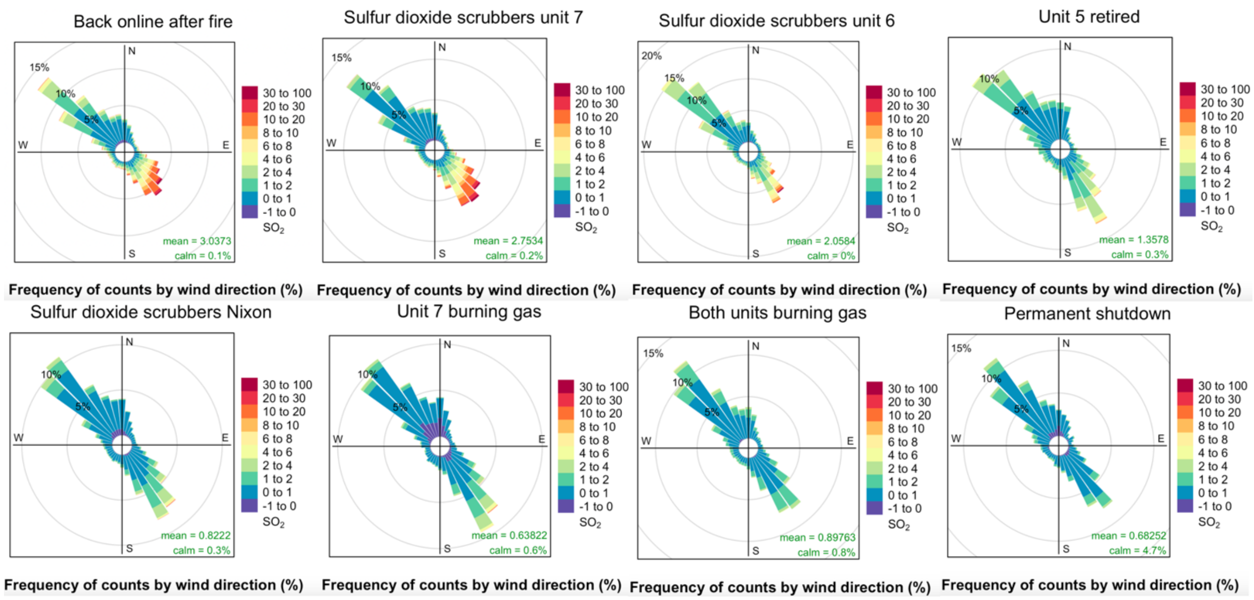
Between the unit 5 retirement and the Nixon scrubber installation, SO_2 concentrations were, on average, 1.35 ± 1.14 ppb (Table 3). This is another statistically significant change compared to the period after the Drake scrubbers were installed ($p = 0.003$). Between the Nixon scrubber installation and the beginning of Martin Drake's transition to natural gas, SO_2 averaged 0.84 ± 1.13 ppb (Table 3). This new decrease is also statistically significant and corresponds with a drop from the initial period of 2.57 ppb. However, this period still saw several notably high

SO_2 spikes (Figure 3, Figure 4). Many of these spikes may be due to strong winds bringing pollution from various coal-burning power plants in neighboring cities or states (Table 4).

Spike date, time (MST)	High-capacity coal plant near HYSPLIT path	Estimated distance from plant to HYSPLIT path
11/01/2016, 17:00	Comanche (Pueblo, CO)	0 km
11/03/2016, 13:00	Comanche (Pueblo, CO)	7 km
11/04/2016, 12:00, 13:00	Comanche (Pueblo, CO)	5 km
11/04/2016, 14:00, 15:00	Comanche (Pueblo, CO)	1 km
11/11/2016, 15:00	Gerald Gentleman (Sutherland, NE)	2 km
09/17/2017, 2:00	Comanche (Pueblo, CO), Gerald Gentleman (Sutherland, NE)	9 km, 1 km
09/17/2017, 11:00	Comanche (Pueblo, CO)	0 km
09/17/2017, 15:00	Comanche (Pueblo, CO)	9 km
09/19/2017, 12:00	N/A	N/A
09/20/2017, 11:00	Comanche (Pueblo, CO)	2 km
09/20/2017, 12:00	Comanche (Pueblo, CO)	0 km
09/22/2017, 10:00	Springerville (Springerville, AZ)	7 km
09/22/2017, 11:00, 12:00	Springerville (Springerville, AZ)	0 km
11/08/2017, 16:00	Laramie River (Wheatland, WY)	1 km
10/20/2020, 22:00	Jim Bridger (Point of Rocks, WY)	0 km

Table 4. Dates and times of SO_2 spikes (concentration at or above 99th percentile across the entire data set) at the H24 station after scrubber installation; coal plants located near one or more of the 24-hour backwards trajectories in the modeled HYSPLIT ensemble (Draxler & Hess, 1998); and approximate distance from the coal plant to the nearest trajectory in the ensemble (Synapse Energy Economics, Inc., 2022). When searching for nearby coal plants, plants with a capacity of less than 1000 MW were ignored under the assumption that a small plant would not generate sufficient emissions to cause a large spike at the station.

In general, wind direction has a strong impact on SO_2 pollution at the H24 site (Figure 6, Figure 7). Across all periods, the highest concentrations of SO_2 occurred when the wind was blowing from the southeast, which is where the Martin Drake, Ray Nixon, Front Range, and Comanche plants are all located relative to H24 (Table 5). In addition, Figure 6 shows some high values for SO_2 being blown in from the northwest, especially before all the SO_2 scrubbers were installed. Although it is not visible in any figures, these higher concentrations may be attributable to the fact that the H24 site experiences primarily southeasterly winds during the daytime and primarily northwesterly winds during the nighttime. This phenomenon is likely due to diurnal mountain wind cycles, wherein winds tend to blow from the mountains to the plains at night and the opposite direction during the day (Whiteman, 2000). It seems likely that the winds blowing SO_2 from the southeast during the day would continue to carry the same pollution in the opposite direction at night. Once the Martin Drake plant closed, the levels of SO_2 from both the southeast and the southwest remained above average, although they decreased significantly (Table 5). These values support the theory that Martin Drake was a substantial contributor to SO_2 levels in Colorado Springs and that southeasterly winds may still contribute pollution from the more distant Front Range, Ray Nixon, and Comanche plants. Additionally, the southwesterly pollution may be an indicator of SO_2 spikes blown in from the Springerville plant in Springerville, AZ, as in earlier spikes (Table 4).



Back online after fire

Sulfur dioxide scrubbers unit 7

Sulfur dioxide scrubbers unit 6

Unit 5 retired

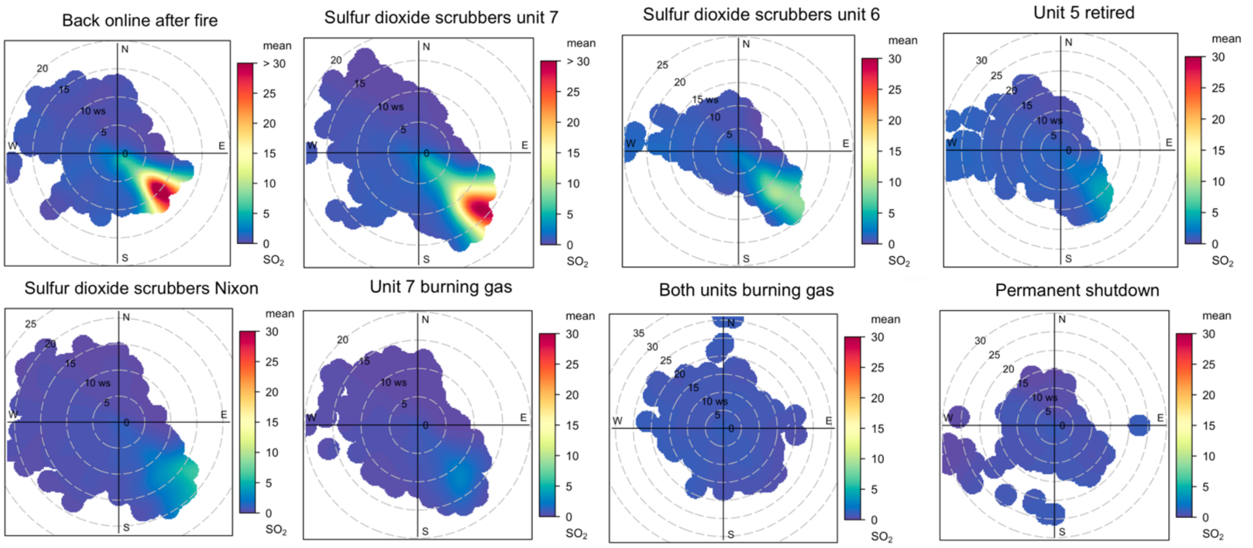
Sulfur dioxide scrubbers Nixon

Unit 7 burning gas

Both units burning gas

Permanent shutdown

Figure 6. Pollution roses showing frequency of winds from each direction around the H24 site and ranges of SO_2 concentrations from each direction for study periods 3-10 (periods 1 and 2 are not available because wind data collection began in August 2014).



Back online after fire

Sulfur dioxide scrubbers unit 7

Sulfur dioxide scrubbers unit 6

Unit 5 retired

Sulfur dioxide scrubbers Nixon

Unit 7 burning gas

Both units burning gas

Permanent shutdown

Figure 7. Polar plots showing speed of winds from each direction around the H24 site and ranges of sulfur dioxide concentrations for study periods 3-10.

Direction	All	Southeast	Southwest	Northeast	Northwest
Entire study period	1.42	2.53	1.20	0.69	0.83
Period 10	0.68	0.74	0.75	0.48	0.68

Table 5. Mean SO_2 levels, in ppb, recorded at H24 when the wind was blowing from each of four directional quadrants, for both the entire range of SO_2 data and the range that were recorded once Martin Drake had been closed (Period 10).

On December 9, 2020, Unit 7 of the Martin Drake Power Plant transitioned from burning primarily coal to burning natural gas as its only fuel source. On August 28, 2021, Unit 6 underwent the same transition, permanently ending the use of coal at the plant. Between the unit 7 transition and the unit 6 transition, SO_2 concentrations averaged 0.63 ± 0.90 ppb, whereas between the unit 6 transition and the full shutdown of the plant on September 1, 2022, concentrations were 0.90 ± 0.67 ppb. The difference in means before and after both transitions is significant ($p < 0.001$ for both), but the difference in means before the first transition and after the second transition is not significant ($p = 0.35$), implying that both shifts were more of a temporary dip than any immediate effect from the change in fuel. However, at this point, SO_2 concentrations were close enough to the amounts during the shutdown in 2014 that additional decreases would likely be caused at least partially by changes outside Martin Drake. It appears that the transition to burning natural gas did not significantly change SO_2 levels at all.

Seasonal variation in SO_2 levels may have played a large role in the dip for the period after the unit 7 transition. Sulfur dioxide levels tend to be much lower in the spring and summer than during the fall and winter (Table 6). The reasons for this seasonal fluctuation are unclear; there is no statistically significant correlation, for instance, between seasonal electricity production at Martin Drake Power Plant and seasonal SO_2 levels (Table 6). However, the period between the unit 7 transition and the unit 6 transition spanned primarily spring and summer, and when the data are binned by season, the dip looks far less dramatic in those seasons (Figure 8). The overall dip may be explainable simply by a relative lack of winter SO_2 spikes.

Season	**Winter**	**Spring**	**Summer**	**Fall**
Mean SO_2 (ppb)	1.87	1.44	1.57	1.90
Median SO_2 (ppb)	1.1	0.5	0.6	0.9
Mean Load (MWh)	90351.34	79206.99	90735.29	87164.70
Median Load (MWh)	96994.74	70683.76	83392.77	81401.00

Table 6. Mean and median values for SO_2 at the H24 monitoring station, and gross load (total electricity production) at Martin Drake Power Plant, in all four seasons. SO_2 data span 01/11/2013 – 12/31/2022 while Martin Drake data span January 2013 – August 2022 due to lack of available data.

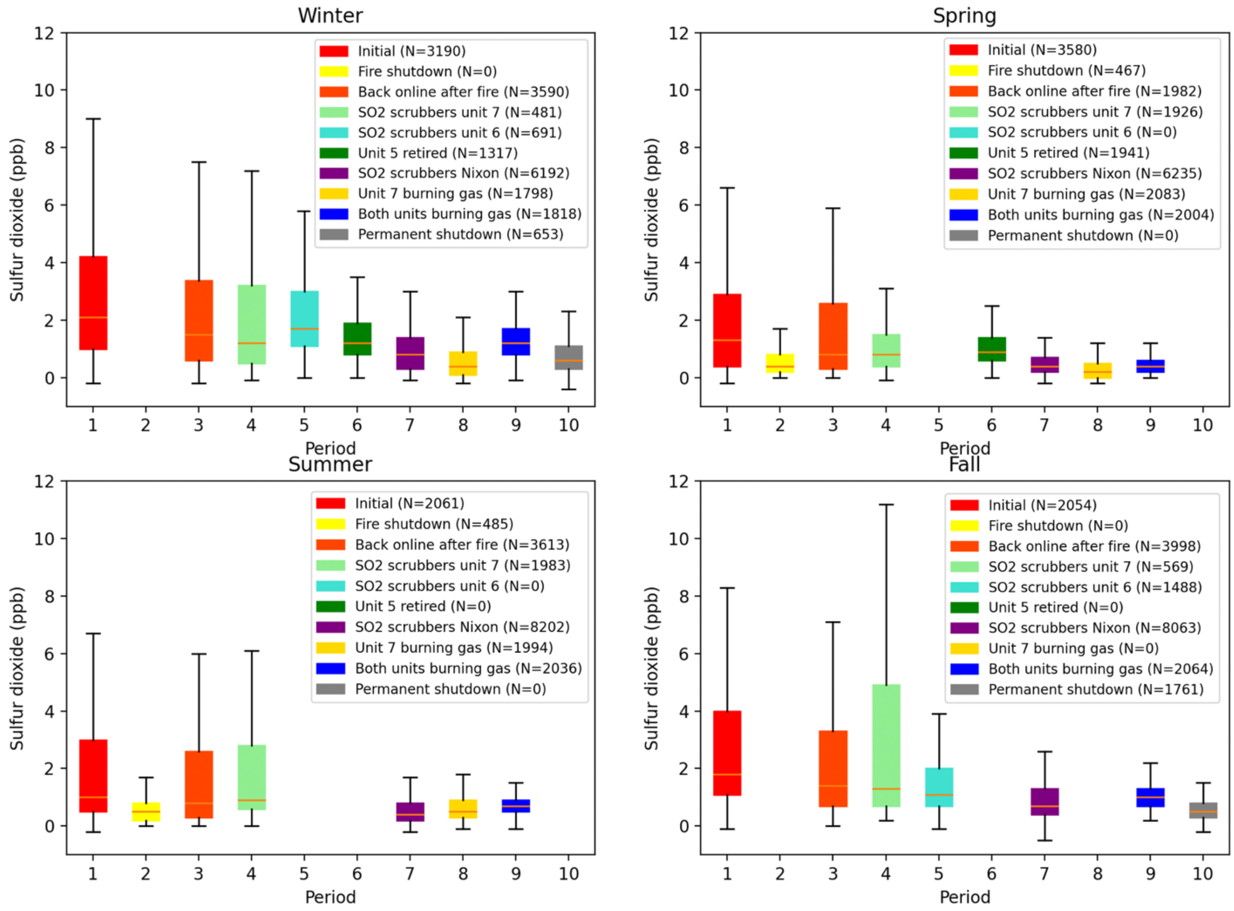


Figure 8. Boxplots of hourly SO_2 data recorded at the H24 station between 01/01/2012 and 12/31/2022, filtered by season and binned by period, with fliers (points outside the IQR) excluded. Note that some boxplots are missing because the corresponding period did not overlap with the relevant season.

The NeuStream SO_2 scrubbers were active while Drake burned coal and taken offline after the switch to natural gas (US Environmental Protection Agency, 2022c). Given that the combustion of natural gas releases less SO_2 than heavier fuels (Fard, et al., 2016), the overall lack of change after Drake's transition to natural gas may be explained by the hypothesis that burning natural gas without scrubbers releases approximately the same amount of SO_2 as burning coal with scrubbers. It is worth noting that mean SO_2 levels after both units switched to gas were quite similar to mean SO_2 levels during the 2014 shutdown (Table 6). This implies that, in terms of effect on SO_2 levels, the addition of scrubbers was approximately the same as shutting the plant down completely, and that switching to natural gas as fuel did not significantly change local air pollution even though the scrubbers were no longer active once the fuel switch occurred.

From September 1, 2022 to the end of the study period, the Martin Drake Power Plant has been dormant, with all units completely shut off (US Environmental Protection Agency, 2022c). Although not many statements can be made about year-long or future trends, current data appear to indicate a drop in SO_2 levels since the closure. The difference in means between this period and the previous period is not statistically significant ($p = 0.43$). However, the mean SO_2 levels are very low, at 0.66 ± 0.61 ppb. This mean is second only to the mean during period 8, and the standard deviation is the lowest for any period (Table 6). The fact that the mean for this final period is slightly higher than the period 8 mean may be attributable once again to seasonal variation; the shutdown period is confined entirely to the two seasons with higher mean SO_2 amounts, while period 8 is contained mostly within the two seasons with lower mean SO_2 amounts (Table 6). The effect size of -0.32 ± 0.05, while not as large as the effect sizes for other periods, is 36% of the mean of the previous period, which is a notable decrease given that SO_2 levels were already low. Compared to the lack of apparent change after the transition from coal to gas, this change suggests that shutting down the plant may have resulted in additional SO_2 decreases.

3.2. Particulate matter

3.2.1. $PM_{2.5}$

The fluctuations in $PM_{2.5}$ can be seen in Figures 9 and 10. $PM_{2.5}$ shows some seasonal variation in sites throughout Colorado (Colorado Air Pollution Control Division, 2022), so when plotting data from different periods, the data were binned by season to avoid bias due to seasonality (Figure 10). The boxplots that employ this binning suggest that there are no changes in $PM_{2.5}$ levels through different study periods that persist between seasons. The Games-Howell test also follows this pattern. Unlike the test for SO_2, the test for $PM_{2.5}$ indicates that only two of the study periods have a statistically significant mean $PM_{2.5}$ level compared to the period before them: periods 4 and 9 ($p = 0.02$ for both). However, period 4 also contains a shift within the $PM_{2.5}$ sampling rate, from every three days to every hour, and it is likely that the change in sampling method (from R & P Model 2025 to GRIMM) raised the mean (Figure 9). As for the transition to period 9, the statistically significant shift may be due to slightly higher $PM_{2.5}$ levels during period 8 (Figure 9, Figure 10). Figure 10 indicates that the period 8 $PM_{2.5}$ data contain unusually high summer values, possibly due to wildfire smoke, which is further discussed below. Thus, at least for data collected at the CC site within the period of this study, there is no clear evidence that any of the changes at Martin Drake or Ray Nixon affected local $PM_{2.5}$ concentrations. These findings suggest that the most important factors in the levels of $PM_{2.5}$ at the CC site are factors unrelated to changes at the power plants, such as changes in temperature, emissions from motor vehicles, and industrial processes.

Another notable attribute of these data is the spikes, which may be partially attributable to overhead smoke. After hourly data collection began, of the days where $PM_{2.5}$ concentrations were at the 99.9th percentile (50 $\mu g/m^3$ or above), 60% had overhead smoke (AirTech-Now, 2022). A more in-depth study would be necessary to determine whether more moderate spikes are also likely to have been caused by smoke, but such analysis is beyond the scope of this paper.

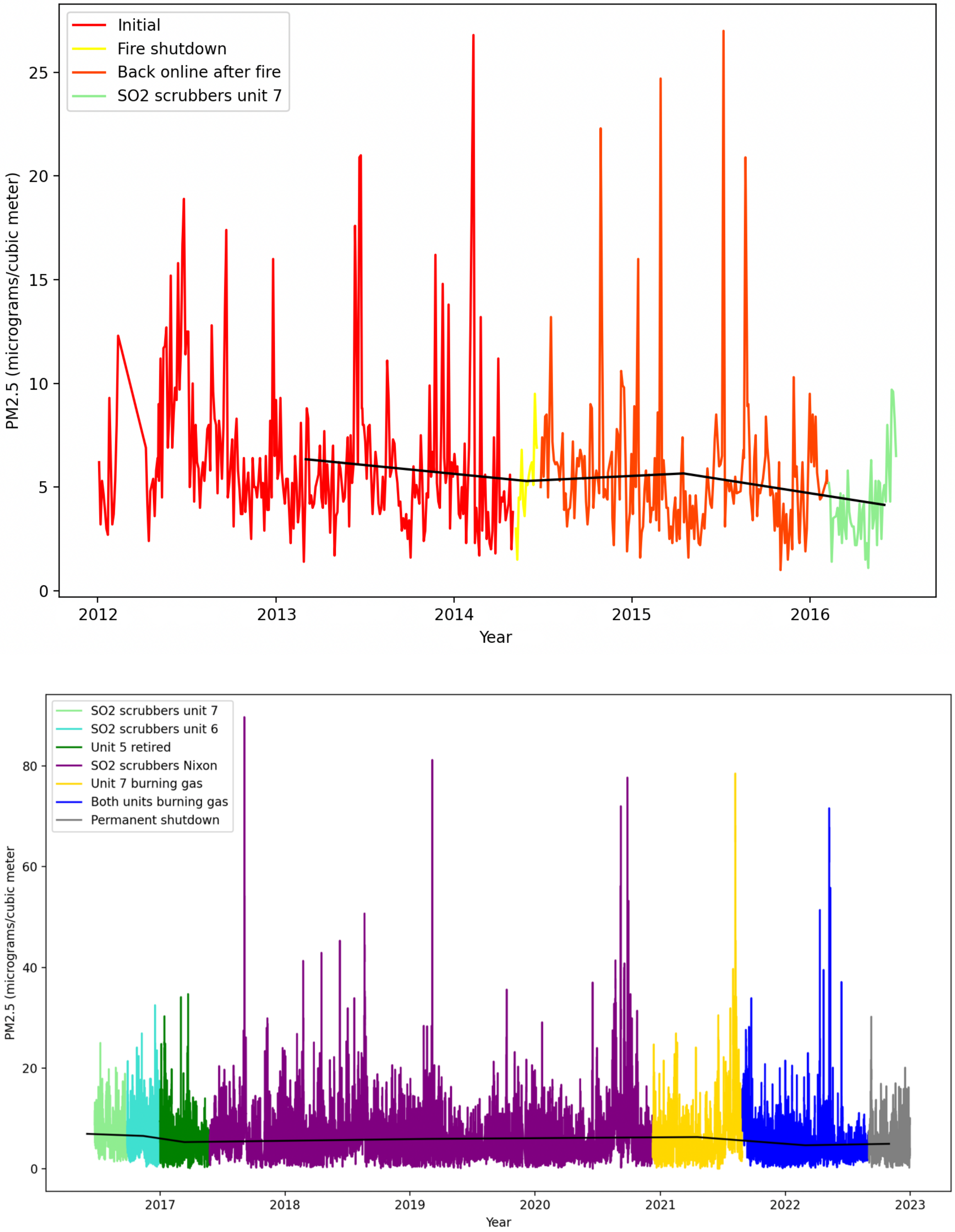


Figure 9. $PM_{2.5}$ levels with periods highlighted by color and means for each period superimposed in black. The first graph contains data collected every 3 days, while the second contains hourly data.

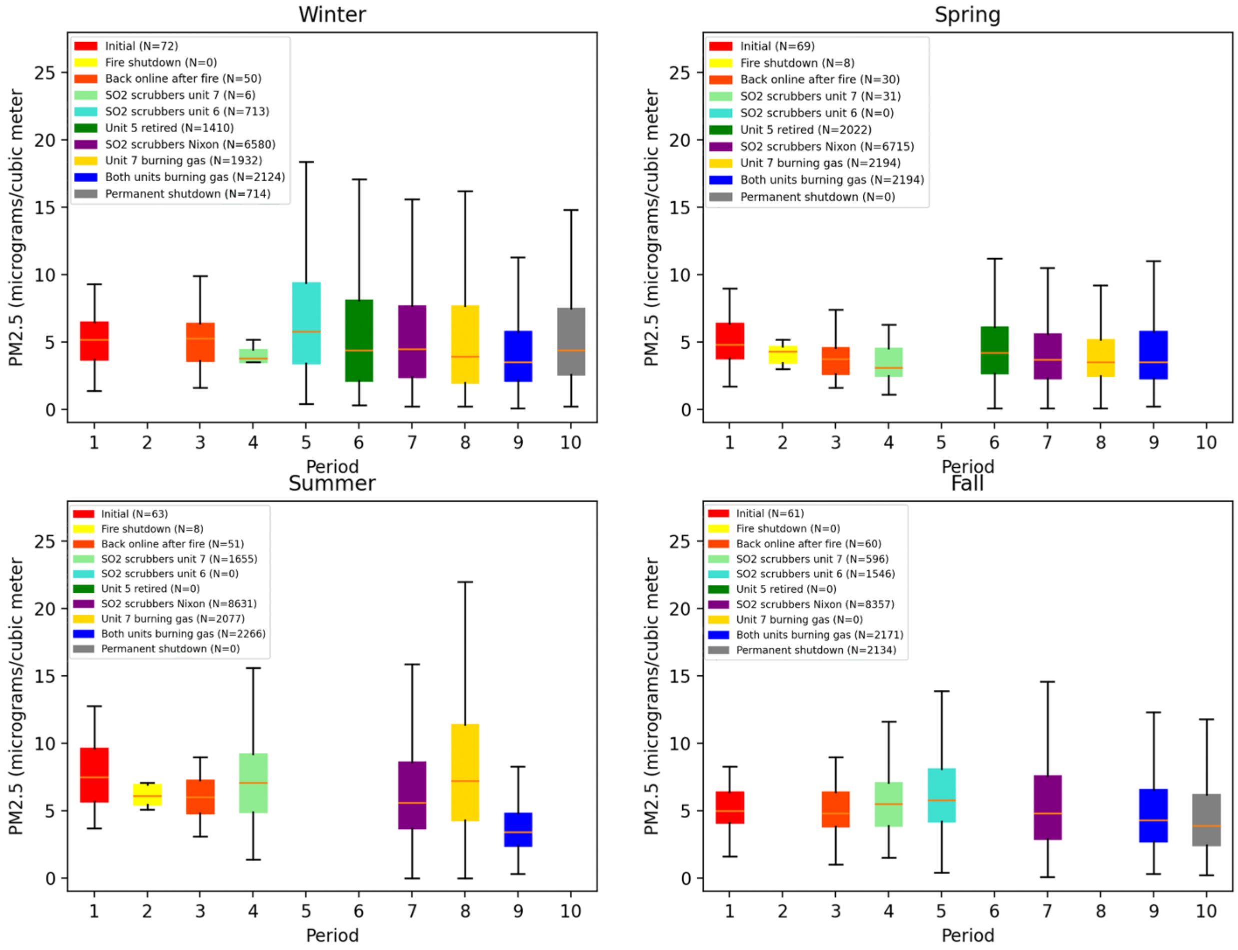


Figure 10. Boxplots of hourly $PM_{2.5}$ data filtered by season and binned by period, with fliers (points outside the IQR) excluded. Note that some boxplots are missing because the corresponding period did not overlap with the relevant season. Also note that the sampling frequency changed on June 24, 2016, partway through Period 4 (Figure 1).

3.2.2. PM_{10}

There is no statistically significant difference between PM_{10} levels in any of the ten periods for this study. Fluctuations in PM_{10} can be seen in Figures 11 and 12. Like the $PM_{2.5}$ data, the PM_{10} data feature spikes, which seem to be mostly due to overhead smoke from distant fires. Out of the 6 points in the 99th percentile of the PM_{10} data, 4 had overhead smoke present, the other two being January 10 and 11, 2013 (US EPA Office of Air Quality Planning and Standards, 2022). According to what little meteorological data exist for these dates, January 10 had relatively low average pressure (809 mb compared to an average of 816 ± 5 mb that month), somewhat low average temperature (-1.6°C compared to an average of 2.5 ± 5.8 °C that month), and relatively high $PM_{2.5}$ (9.3 $\mu g/m^3$ compared to an average of 5.5 ± 1.6 $\mu g/m^3$ that month).

Winds in Colorado Springs reached 25 knots on January 11 (National Weather Service, 2013) due to a storm (Daniels, 2013), so perhaps the high PM on those days resulted from airborne dust and other debris.

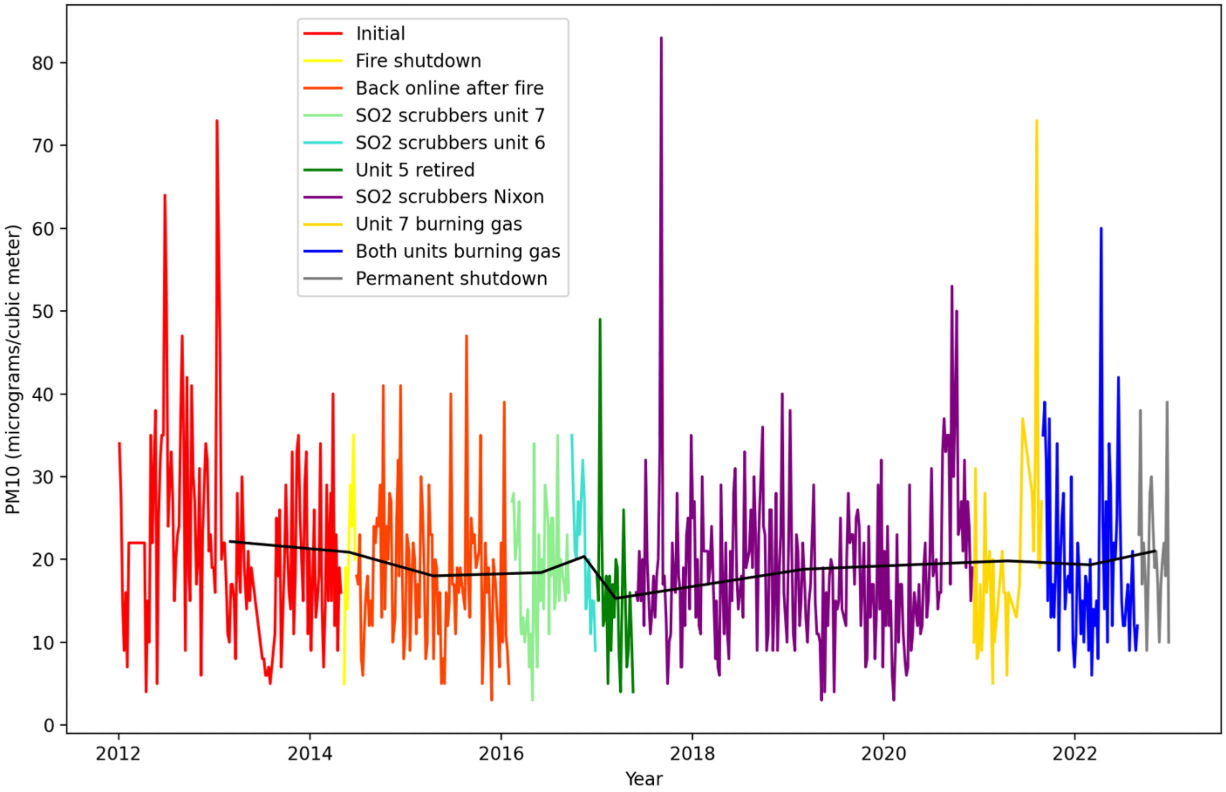


Figure 11. PM_{10} levels with periods highlighted by color and means for each period superimposed in black. Data collection was every six days for the duration of the study period.

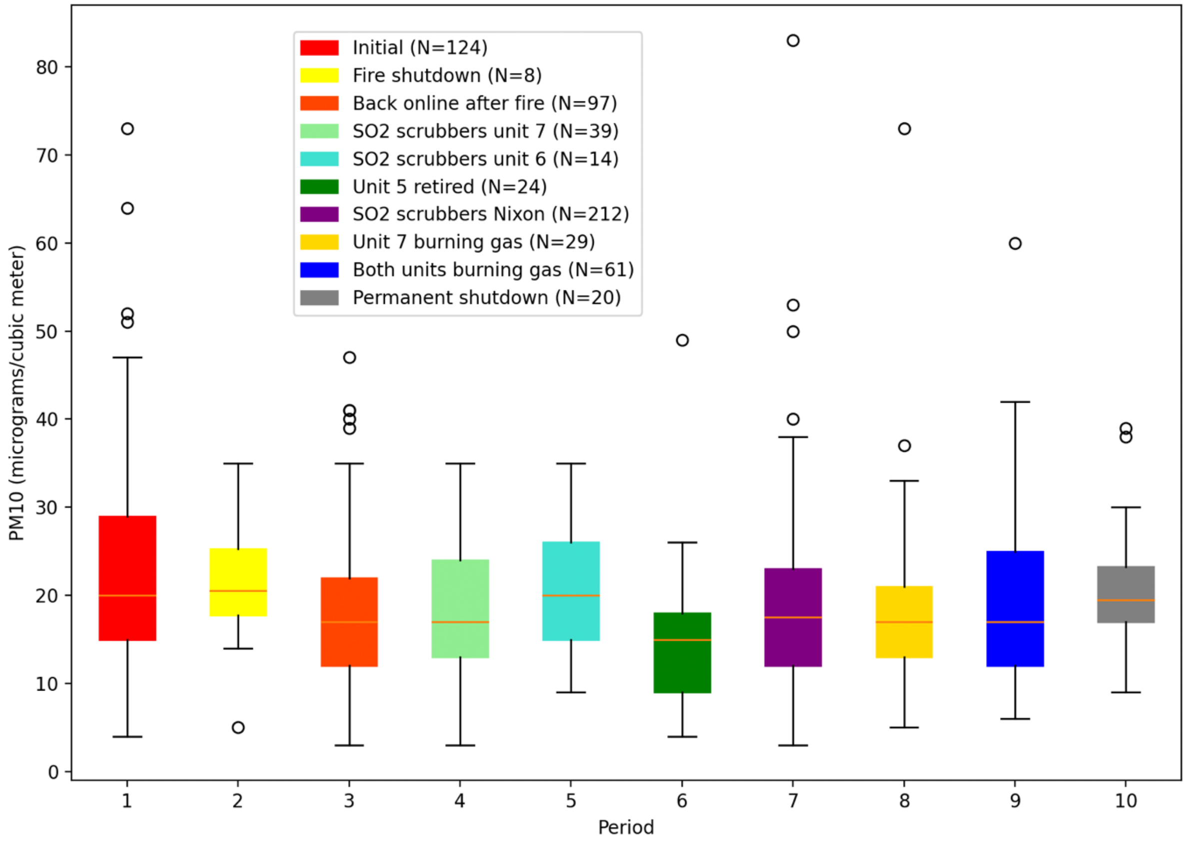


Figure 12. Boxplots of hourly PM_{10} data filtered by season and binned by period.

In general, neither amounts of $PM_{2.5}$ nor amounts of PM_{10} are near the NAAQS. The concentrations for $PM_{2.5}$ have been hovering around 50% of the NAAQS for both the 24-hour and annual mean standards for the last fourteen years (Colorado Air Pollution Control Division, 2022). PM_{10} levels have been at or below 50% of the 24-hour NAAQS for the past fourteen years (Colorado Air Pollution Control Division, 2022). Although the periods and causes of high PM in the Colorado Springs region warrant additional study to determine whether they might be associated with wildfire smoke or other sources (dust, fuel combustion at other locations, secondary sources, etc.), there is no evidence within the scope of this study to suggest that PM levels were affected by changes at the Martin Drake or Ray Nixon power plants during the study period. It is possible that the CC monitoring station is not optimally located to detect these changes, and that monitoring PM at H24 might result in clearer trends. However, the coal-fired units at both plants had had a baghouse installed for particulate control long before the start of the study period (US Environmental Protection Agency, 2022c; Jensen, 2002), suggesting that the baghouses were effective enough to eliminate statistically significant PM emissions from the plants.

3.3. Carbon monoxide

Carbon monoxide has generally declined in recent years across the planet, country, region, and state. A review of satellite observation found that airborne CO levels in the northern hemisphere decreased by 0.57 ± 0.3 % per year on average during the period from July 2002 to June 2018, although the trend was slower and not statistically significant during the second half of this period, averaging -0.43 ± 0.8 % per year from July 2010 to June 2018 (Buchholz, et al., 2021). Researchers primarily attribute this decrease to increases in combustion efficiency for anthropogenic CO sources, as well as a decrease in tropical wildfires (Buchholz, et al., 2021).

More specific regions have also experienced CO decreases over similar periods. The United States has seen a 26% decrease in CO levels, with the second maximum 8-hour average decreasing from 1.43 ppm in 2010 to 1.06 ppm in 2021 (US Environmental Protection Agency, 2022a). The southwest, meanwhile, has experienced a 31% decrease in the same value from 1.88 ppm in 2010 to 1.28 ppm in 2021 (US Environmental Protection Agency, 2022a). In Colorado, the mean maximum one-hour CO concentration has decreased 43% from 3.5 ppm in 2010 to 2.0 ppm in 2021 (Colorado Air Pollution Control Division, 2022). The decline in El Paso County is not so easily visible in the raw data (Figure 13), but it is still present. In the hourly H24 data, the mean concentration of CO has remained relatively steady for the last ten years, with an overall decrease of approximately 0.06 ppm (14%) since 2012. When the data are separated into the power plant periods, the average for periods 1-6 fluctuate, with each period having a statistically significant change compared to the previous period ($p < 0.001$ for periods 1-5, $p = 0.048$ for period 6). However, these fluctuations appear to be primarily due to seasonal variation (Figure 13). After period 6, there are no significant changes in the average between periods. On the other hand, there has been a notable decrease in the magnitudes of CO spikes, suggesting that, even though CO levels are already well below the yearly NAAQS, El Paso County's risk of nonattainment of the standards is still steadily decreasing (Figure 14, Table 7). The decrease in the 95th percentile of CO levels at the H24 station is statistically significant, as is the decrease in the average. One potential reason for these decreases is the decrease in CO levels in the southwestern United States and in the state of Colorado. CO, having a relatively long atmospheric lifespan, behaves more as a regional pollutant than a local pollutant and thus is likely to behave in Colorado Springs according to wider regional trends. Furthermore, plumes of CO blown in from regions with particularly high CO levels would become less common if CO levels decreased in those regions as well. However, there is no statistically significant trend in either the median or 5th percentile values for CO levels (Table 7). This observation suggests that CO sources in the city itself – sources of consistent CO rather than spikes – have not substantially changed, and that the changes at Martin Drake and Ray Nixon have thus not substantially affected them.

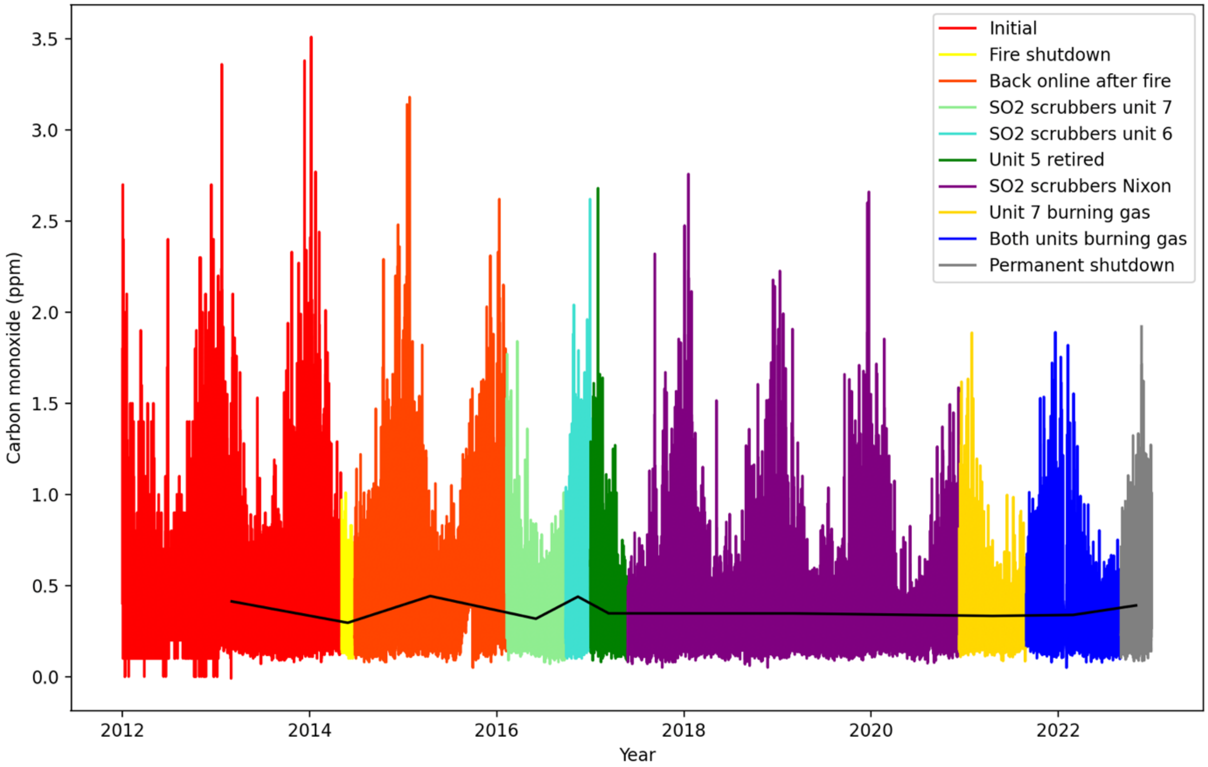


Figure 13. CO levels with periods highlighted by color and means for each period superimposed in black.

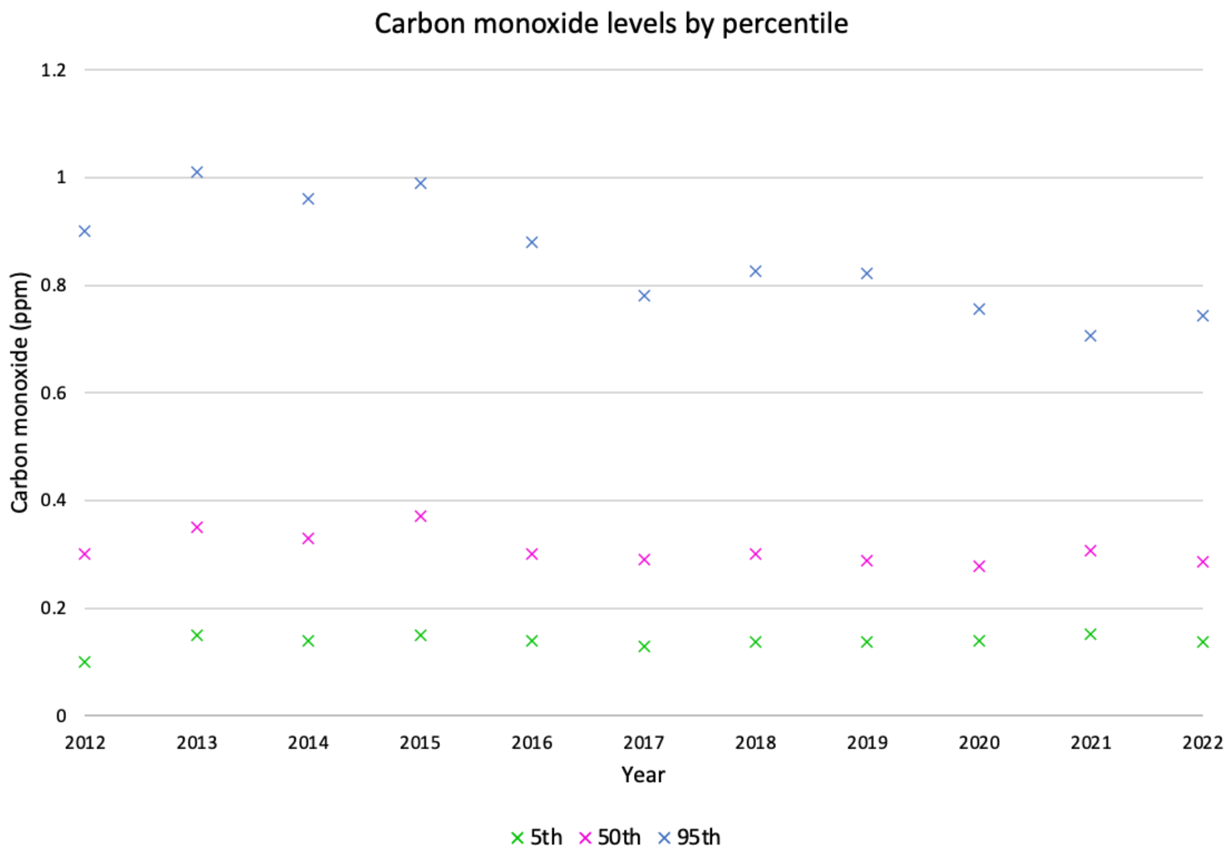


Figure 14. Scatter plot of yearly 5th percentile, median, and 95th percentile for hourly CO since 2012.

Percentile	Slope ± 95% CI	R^2	p-value
5	0.0015 ± 0.003	0.13	0.277
50	-0.005 ± 0.005	0.34	0.059
95	-0.027 ± 0.012	0.76	<0.001
Mean	-0.009 ± 0.005	0.69	0.002

Table 7. Statistics for trendlines of percentiles of yearly aggregated hourly CO measurements at H24 site, 2012-2022.

3.4. Ozone

Out of the four criteria pollutants studied here, O_3 is the only pollutant for which El Paso County is currently at risk of NAAQS nonattainment (Flynn et al., 2021). Since 2000, El Paso County has seen an increase in values for both the yearly median and 5th percentile of O_3 concentrations (Figure 15). When all data are included, the 3-year average of the 4th-highest maximum daily 8-hour average O_3 concentration has been above the standard for the past two years (Colorado Air Pollution Control Division, 2022; Colorado Air Pollution Control Division, 2021). However, as of the writing of this paper, El Paso County is not considered to be in nonattainment of the NAAQS. It is unclear whether its status will change the next time the NAAQS are reviewed. Some O_3 data from 2020 may have been considered to be part of "exceptional events" due to large wildfires both within and outside Colorado (Gunning, 2022), so similar exceptions could be made for the new data.

In 2021, Flynn et al. estimated that emissions of O_3 precursors from wildfires contributed 4-5 ppb to summertime MDA8, which significantly increases the risk of NAAQS nonattainment during high-smoke years. On the other hand, the influence of wildfires does mean that other sources of O_3 precursors in the Pikes Peak region are not necessarily to blame for the high O_3 levels. In fact, the Pikes Peak region has seen a decline in O_3 precursors from both point and mobile sources over the past decade (Flynn et al., 2021). Focusing just on summertime MDA8 O_3 measurements, both sites have a slight downward trend for the 95th percentile, and both sites have a slight upward trend for the 5th percentile. However, there are no statistically significant trends in the 5th, 50th, or 95th percentiles for summertime O_3 at either site (Table 8).

The Games-Howell test reports statistically significant changes at the start of periods 2-6, 8, and 10 at the AFA site and periods 3, 5, and 6 at the MAN site. However, the means fluctuate according to the seasons of the periods because O_3 is highly seasonal. There is not enough evidence to suggest that any of the statistically significant changes in mean between periods are due to changes at the power plants. It is more likely that yearly changes are attributable to changes in other sources of O_3 (e.g. regional background O_3) and/or its precursors.

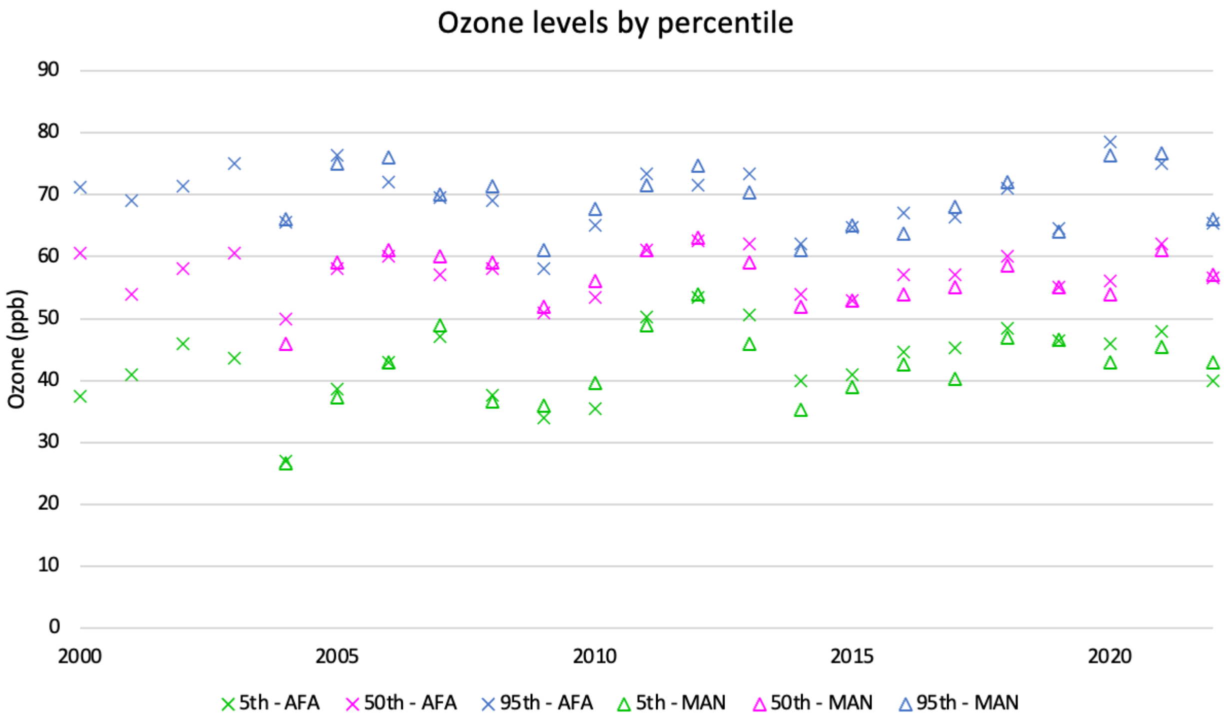


Figure 15. Scatter plot of yearly 5th percentile, median, and 95th percentile for summertime O_3 MDA-8s at the MAN and AFA sites since 2000.

Site	Percentile	Slope ± 95% CI	R^2	p-value
AFA	5	0.33 ± 0.42	0.12	0.114
	50	0.07 ± 0.25	0.02	0.562
	95	-0.05 ± 0.36	0.01	0.750
MAN	5	0.19 ± 0.50	0.04	0.441
	50	-0.18 ± 0.33	0.08	0.254
	95	-0.12 ± 0.51	0.02	0.619

Table 8. Statistics for trendlines of percentiles of yearly averaged summertime O_3 MDA8 at MAN and AFA sites, 2000-2022.

3.5. Carbon dioxide

There are no EPA carbon dioxide monitors in the Pikes Peak region. However, the Martin Drake Power Plant reports its carbon dioxide (CO_2) emissions, which are available from the EPA's Clean Air Markets Program Database (CAMPD) website (United States Environmental Protection Agency (EPA), n.d.). (It is unclear whether the emissions are calculated from other data or physically measured.) The emissions tend to fluctuate in tandem with the facility's gross load (Figure 16), but the ratio of CO_2 emissions to gross load tells a distinctive story: when normalized by monthly load, the facility's CO_2 emissions drop sharply in September 2021 (Figure 17). This date is immediately after Martin Drake stopped burning coal; specifically, Unit 6 switched to natural gas at this time, following in the footsteps of Unit 7, which had switched approximately nine months earlier (Figure 1). It is possible that, due to the higher cost of natural gas, load shifted primarily to Unit 6 after the Unit 7 transition, which would explain the sudden drop in emissions after coal is removed entirely. Regardless of the exact timing, the timing of the drop in CO_2 indicates that the switch to natural gas almost certainly caused a substantial decrease in CO_2 emissions from Martin Drake.

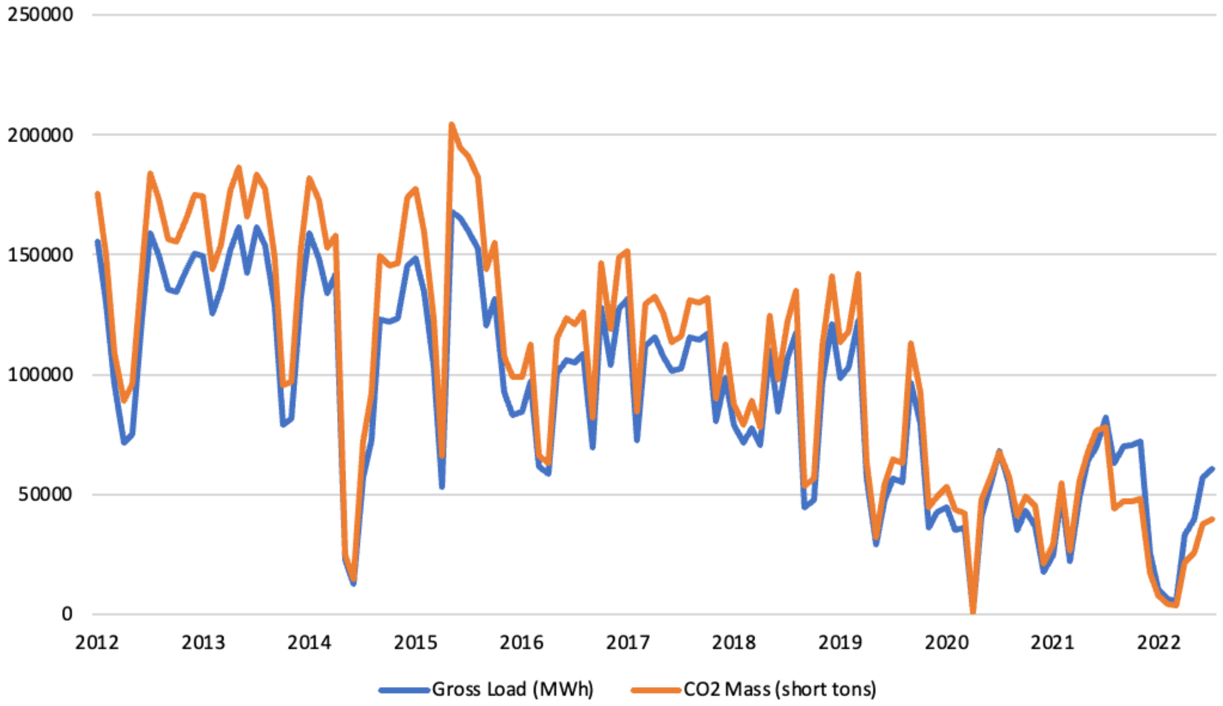


Figure 16. Gross load (total electricity production) and emitted CO_2 at Martin Drake Power Plant for every month between January 2012 and August 2022.

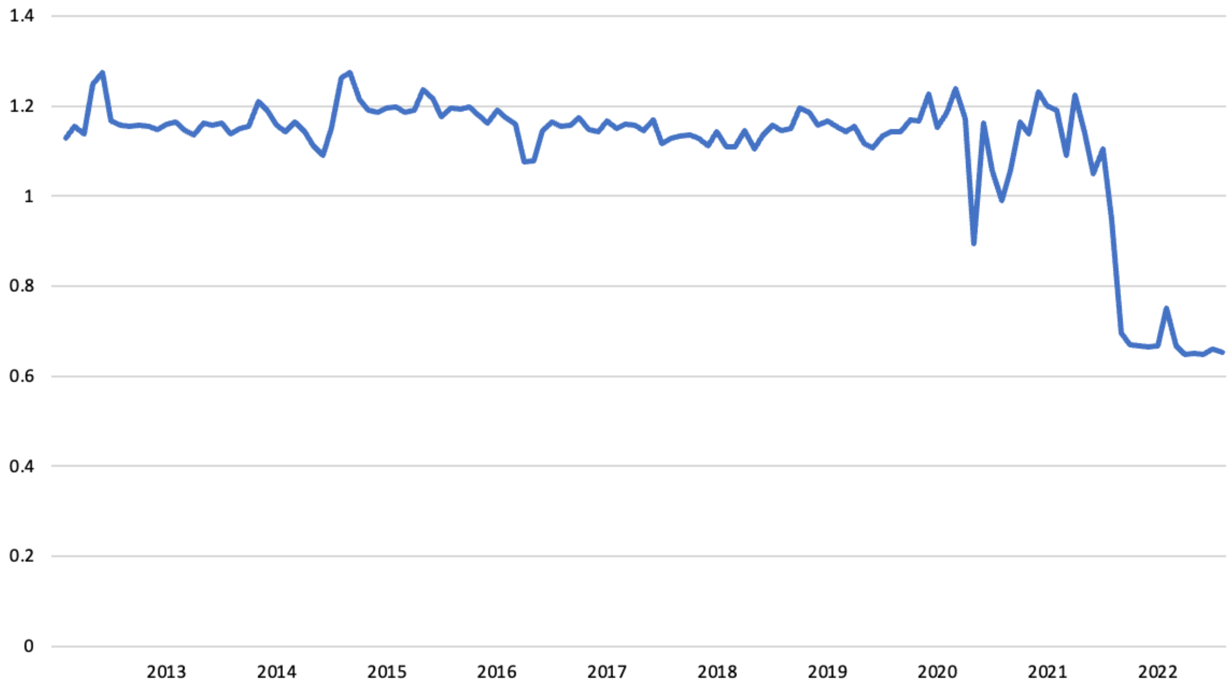


Figure 17. Ratio of emitted CO_2 to gross load at Martin Drake Power Plant in short tons per MWh for every month between January 2012 and August 2022.

4. Conclusion

The Martin Drake and Ray Nixon power plants have undoubtedly had significant impacts on the Colorado Springs region. They provided, and in the case of Ray Nixon continue to provide, electricity for much of El Paso County. Martin Drake in particular has received substantial media and community attention in recent years due to the discussion and finalization of its closure, signifying a shift in the energy priorities in Colorado Springs. However, one cannot unequivocally state that the closure of Martin Drake or even events such as the addition of the NeuStream scrubbers or the change from burning coal to burning natural gas uniformly made the air cleaner. In reality, we only see statistically significant changes to specific pollutants under specific circumstances.

Out of the five pollutants considered in this study, the one that experienced the highest number of statistically significant changes between study periods was sulfur dioxide (SO_2). Levels of sulfur dioxide changed significantly before and after the Martin Drake shutdown in 2014; after NeuStream scrubbers were installed on units 6 and 7; after Martin Drake Unit 5 was closed; after SO_2 scrubbers were installed at Ray Nixon; and after each of Martin Drake's units 6 and 7 switched to natural gas (although the latter two changes have opposite signs and are most likely due to seasonal variation). Out of these changes, there is enough evidence to conclude that all of them except the switches to natural gas genuinely affected the levels of SO_2 pollution in the air in Colorado Springs. There is also evidence to suggest that strong winds could have carried SO_2 to Colorado Springs from other coal-fired power plants in neighboring cities and states, causing spikes on certain days.

When examining the data collected on particulate matter (PM), the relative lack of statistical significance between study periods suggests that the baghouses already installed on Martin Drake and Ray Nixon prevented any substantial change in PM caused by changes at the power plants. However, circumstantial evidence suggests a link between PM spikes and wildfire smoke. Further investigation would be required to confirm this link.

The carbon monoxide (CO) data contain fluctuations due to seasonal variation, and do not seem to have any statistically significant link to changes in operations at local power plants. However, the levels of CO throughout Colorado are decreasing, and so is the 95th percentile of yearly CO in Colorado Springs, suggesting that Colorado Springs' risk of CO nonattainment is decreasing.

Ozone (O_3) levels in Colorado Springs have been nearing nonattainment levels for several years, but there are no statistically significant trends in O_3 data. Finally, although the EPA does not mandate the collection of carbon dioxide data in the area surrounding Colorado Springs, carbon dioxide data from Martin Drake Power Plant show that Martin Drake's emissions of carbon dioxide decreased significantly after the switch to natural gas (albeit not before).

Overall, these findings are to be expected. Sulfur dioxide comes primarily from coal burning, and thus experienced the strongest changes with each of the timeline events. Particulate matter is also often produced by coal and other fuel combustion, but both of the power plants under question already had PM controls and thus the selected changes did not substantially change PM levels. Ozone is a secondary pollutant formed in part by nitrogen oxides (NO_x), which are also largely emitted by power plants, but once again, both plants had NO_x controls in place. It is also worth noting that, as a secondary pollutant, O_3 takes time to form and would not necessarily show rapid changes like the other pollutants. Still, likely as a result of the control equipment, neither PM nor O_3 levels are correlated with changes at the power plants. Carbon dioxide emissions have been shown to decrease with a switch from coal to natural gas, so the emissions values from Martin Drake are to be expected, especially if the values were calculated rather than measured. Finally, CO does not come primarily from power plant emissions, and thus the lack of change in CO levels is also consistent with our understanding of its sources and atmospheric behavior.

Between the consistent decrease in sulfur dioxide levels, the slow decrease in the height of carbon monoxide spikes, the sharp decrease in carbon dioxide emissions, and the relative lack of changes to ozone and particulate matter, the changes to Colorado Springs power plants appear to be having a neutral to negative effect on Colorado Springs air pollution. However, further questions remain. How important are distant events such as wildfires and emissions from other cities to local air quality? Do scrubbers and other pollution control equipment create by-products that might negatively affect the environment in other ways? How many other forms of air pollution – other greenhouse gases and nitrogen dioxide, for example – are present but untracked or undetected in Colorado Springs? All of these questions may require further research. In the meantime, the risk of nonattainment of the O_3 NAAQS looms large over El Paso County, and deserves further scrutiny. Air quality in Colorado Springs and the surrounding area may have improved in some respects, but it is still dangerously close to unacceptable in others.

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