Ozone Pollution in New Mexico: An Economic Analysis of its Human Health Impacts and Damages[1]

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Executive Summary

Ozone (O3) is a significant contributor to air pollution problems in New Mexico. Against a backdrop of increasing automobile and vehicular traffic and substantial growth in the production of oil and gas in New Mexico, there are challenges and opportunities for addressing the public health impacts and associated economic costs of ozone across the state.

The peer-reviewed literature shows that exposure to ozone can lead to respiratory diseases, asthma exacerbation, and premature mortality. These impacts all impose health-related damages to New Mexicans, especially among populations sensitive to air pollution, including seniors, children, and those with underlying health conditions.

In this white paper, we undertake a comprehensive three-phase study of ozone pollution in New Mexico. Phase 1 undertakes a multi-sector analysis of ozone precursors (NOx and VOCs) to identify locations of emissions sources and trends over time. Phase 2 investigates ozone concentrations directly to study the spatial and temporal trends of ozone in New Mexico. Finally, Phase 3 estimates the human-health impacts and associated dollar-denominated damages of ozone pollution by applying peer-reviewed and US Environmental Protection Agency (US EPA) methods and economic cost metrics.

Three key findings emerge:

1. The state-wide health damages of ozone pollution in New Mexico are estimated at $2.26 billion (in 2015 inflation-adjusted dollars) per year, on average, over the years 2011–2017. This is largely driven by excess premature mortality, which averages 259 ozone-related deaths per year between 2011-2017.
2. From 2014 to 2017, average ozone levels in New Mexico have improved. This downward trend in concentrations has resulted in fewer ozone-related health impacts and lower associated damages. As evidence of this, the state-wide premature mortality from ozone in New Mexico decreased 19% between 2014 and 2017 from 297 to 242 ozone-related deaths.
3. Based on our review of the literature, the largest sources of New Mexico's ozone concentrations are from neighboring states (e.g., Texas, Colorado, Arizona) and Mexico. Additionally, the majority of the health impacts of ozone in New Mexico occur on days in which the concentrations (the daily maximum of 8-hour average concentration) are below the US EPA's threshold of concern (set at 70 parts per billion since 2015). Both findings suggest limited potential, under current rulemaking authority, for the state to directly and significantly affect ozone levels and impacts occurring within New Mexico's boundaries. However, policies targeted at ozone "hotspot" areas may still be impactful.

With several New Mexico counties (or regions within counties) near or out-of-compliance with the current US EPA ozone standard (i.e., Doña Ana, Eddy, Lea, Rio Arriba, Sandoval, San Juan, and Valencia counties), the regulatory focus is on mitigating emissions to prevent or achieve compliance. This work adds to this discussion a modeled state-wide estimate of the health consequences and damages of ozone pollution in New Mexico. Considerations of these impacts, including areas of ozone and health impact “hotspots,” are important factors that should influence how New Mexico approaches regulations and policies aimed at mitigating the harms from ozone pollution. We offer this white paper as admissible evidence towards ongoing air pollution policy discussions.

1. Introduction

Ozone (O3) is a significant contributor to air pollution problems in New Mexico (NM). Exposure to ozone has been shown to be associated with respiratory diseases, asthma exacerbation, and premature mortality, impacting sensitive populations in NM, including seniors, children, and those with underlying health conditions [1,2]. Sources of ground-level ozone pollution include emissions by vehicles, power plants, oil and gas production, and biogenic sources [3]. With increasing vehicular traffic and substantial growth in the production of oil and gas in NM, there are questions about how these trends effect the state's ozone problems.

The objective of this analysis is to estimate the health impacts and associated damages in dollar terms from ozone pollution in NM over 2011–2017 (the most recent years of data available at the time of the analysis) using various data sources from the US Environmental Protection Agency (US EPA) and the expert literature in this area. The analysis includes four components. First, we use figures and choropleth maps to visualize ozone precursor emissions trends in NM. Second, we calculate the ozone concentration at the county-level using 12 km grid-cells modeled data. Third, we use health impact functions and data on ozone concentrations to estimate the morbidity and premature deaths associated with ozone pollution. Fourth, we use benefits of avoided illness and value of statistical life (VSL) measures to assign economic values to health endpoints.

Following this approach, several key findings emerge:

1. On average over the years 2011–2017, there were an estimated 259 premature deaths per year in NM due to ozone pollution. In addition to premature deaths, NM ozone is associated with a statewide average of 961 respiratory-related emergency room (ER) visits per year and 59,910 cases of asthma exacerbation (combined chest tightness, cough, shortness of breath, and wheezing) per year among children aged 5–14 years. In total, the state-wide dollar damages of ozone pollution in NM are estimated at $2.26 billion per year (approximately 2.2% of state gross domestic product over this period), on average, over 2011–2017.
2. The health impacts of ozone in NM declined between 2015–2017 relative to 2011–2014. Thus, during the most recent data years, we find that fewer New Mexicans were exposed to ozone, thus lowering associated health impacts.
3. Permian Basin ozone concentrations have generally remained constant over the 2011–2017 study period. Furthermore, ozone levels in the NM Permian Basin are not a relative outlier in the state. Ozone concentrations in the Permian Basin are low compared to other parts of the state, particularly compared to the northern and western regions. However, emissions of VOCs, an ozone precursor, increased in the Permian Basin over the study period. Limited availability of NOx appears to limit ozone formation in the region despite rising VOCs levels, but additional research is needed.
4. In our review of the literature, we found evidence that the largest sources of NM ozone pollution come from other states and Mexico (so-called "transboundary ozone sources"). That is, Mexico and neighboring states such as Texas, Colorado, and Arizona are the largest contributors to ozone in NM, according to the 2020 NM Ozone Photochemical

Modeling Study [4]. If true, an implication of this finding is that regulation and management of ozone and ozone precursor emissions in NM would only be expected to have a limited impact on statewide ozone concentrations and associated human health impacts.

5. Finally, reducing the frequency of extreme ozone event days (defined as ozone levels >70 ppb; generally regarded as a threshold of concern) in NM would be anticipated to have only a marginal impact on the overall health burden of ozone pollution in NM. This is because we find that the majority of ozone-related health impacts in NM occur on days in which ozone concentrations are below the 70 ppb threshold of concern. Put differently, the health burden of ozone in NM is being primarily driven by frequent low or moderate exposure levels and not primarily by infrequent extreme ozone events. Obtaining meaningful reductions in the health burden of ozone would therefore require relatively large reductions in ozone, to levels substantially below 70 ppb.

1.1. Background on ozone and ozone pollution in New Mexico

Ozone (O3) is a highly reactive gaseous molecule composed of three oxygen atoms. The stratospheric ozone layer serves as a protective shield against the Sun's harmful ultraviolet (UV) radiation. Ground-level ozone, on the other hand, is a major air pollutant that is hazardous to plants and animals. The most common pathway for the production of ozone in the troposphere is via the chemical combination of nitrous oxides (NOx), volatile organic compounds (VOCs), and oxygen in the presence of sunlight. Ozone decomposes into highly reactive nascent oxygen which can damage cell linings and stimulate the release of proinflammatory mediators in humans and animals [5]. The basic raw ingredients for ozone generation are NOx and VOCs. NOx is produced by the combustion of gasoline, oil, coal, or wood in power plants, automobiles, wildfires, and other combustible activities. Vehicles, chemical plants, refineries, industries, gas stations, paint, and similar sources release VOCs [3].

High temperature, abundant solar radiation, low relative humidity, and low wind speed are all favorable meteorological conditions for photochemical ozone synthesis [6]. The hot and dry conditions in the southwestern United States frequently cause the planetary boundary layer to reach depths of 3 km or more [7]. As a result, trapping of ozone rich lower stratospheric air and ozone delivered from Asia is more likely to afflict most of the southwestern United States. This phenomenon has been reported to add 20 to 50 parts per billion (ppb) to the maximum daily 8-hour average ozone concentration [8].

The US Environmental Protection Agency (US EPA) has designated ozone as one of the criteria air pollutants and has set rules to restrict its concentration in outdoor air. This set of rules, known as National Ambient Air Quality Standards (NAAQS) is mandated by the Clean Air Act (CAA) of 1970 (42 U.S.C. §7401 et seq.) and CAA amendments of 1990 (104 Stat. 2468), and is based on the periodic reviews of evidence and scientific assessments to protect public health and welfare. The most recent amendment of NAAQS in 2015 established both primary (health-related) and secondary (welfare-related) criteria for ozone at 70 parts per billion (ppb) [9]. The standard is assessed according to the annual 4th highest daily maximum 8-hour concentration of ozone, averaged over three years. The primary goal is to preserve public health as ozone is a major aggravator of heart and lung ailments and may contribute to premature death [1,2]. The secondary goal of the standard is to preserve the health of vegetation (trees and crop yields) and foliage from the detrimental impacts of ozone. The US EPA estimated national net benefits for 2025 (excluding California) of $1.5 billion to $4.5 billion (2011$) for tightening the NAAQS standard for ozone from 75 ppb to 70 ppb standard [10].

The US EPA identifies an area (often a jurisdictional boundary such as a county or city) as in *attainment* or *nonattainment* with NAAQS after consulting with states and tribes and reviewing data from air quality monitors. Attainment regions have air pollution that is below the national standard, whereas nonattainment regions have air pollution in exceedance of the standard. The state of New Mexico has its own New Mexico Air Quality Control Act (NMAQCA) of 1978 that requires the New Mexico Environment Department (NMED) to develop a plan to address elevated ozone levels when air pollution is above 95 percent of the ozone NAAQS for the state (with exceptions for Bernalillo County and tribal lands). Bernalillo County and the Albuquerque metropolitan area are under the jurisdiction of Albuquerque-Bernalillo Air Quality Control Board.

NMED maintains fourteen ozone monitoring stations across eight counties in the state. Seven of these stations are in northern New Mexico (NM): San Juan County (3 stations), Sandoval County (1), Valencia County (1), Santa Fe County (1), Rio Arriba County (1); and seven are in southern NM: Lea County (1), Eddy County (1), Doña Ana County (5). Currently, only the Sunland Park region of Doña Ana County is designated as nonattainment (and has been since July 1995). The Albuquerque-Bernalillo Air Quality Control Board has jurisdiction over another three ozone monitoring stations in Bernalillo County. All counties (except Santa Fe County) with ozone monitoring stations under NMED's or ABAQD's jurisdiction, including Bernalillo County, reported elevated ozone levels, within 95% of the NAAQS over the years 2016-2018.

In addition to the apparent clustering of monitoring stations based on geography, splitting NM into three distinct regions as southern, northern, and central also facilitates in understanding the origins and photochemical pathways of ozone unique to these regions. Northern New Mexico includes the San Juan Basin, which borders Colorado. Ozone from outside the state, as well as emissions from local power plants and oil and gas production sites, are the main ozone contributors of this region [4]. High ozone concentrations in northern New Mexico are also linked to the presence of a large high-pressure system over the region, which causes slow winds and high temperatures [4].

Bernalillo County, including Albuquerque and the surrounding area, make up the central region. Anthropogenic sources, which include vehicular emissions and non-point/non-road equipment, contribute approximately 14-24% of the total ozone precursor emissions in Albuquerque [4]. However, ozone dispersion from northern New Mexico, into the central region, remains the region's most significant source of ozone pollution [4].

Southern New Mexico's Doña Ana, Lea, and Eddy Counties have a major transboundary ozone problem. Medium-range ozone transport from Mexico and Texas, as well as long-range ozone transport from other US states and global sources, are the primary causes of ozone pollution in this region [4]. Although contributions from non-road mobile and the oil and gas industries are increasing, the on-road mobile sector remains the largest in-state contributor, according to the 2020 NM Ozone Photochemical Modeling Study [4].

Technological advancements since the turn of the century, notably in the field of hydraulic fracturing and horizontal drilling, have enabled the exploitation of hitherto uneconomical shale reserves, resulting in an unprecedented growth in oil and gas output of the United States [11,12]. Over the last decade, oil and natural gas output in the Permian Basin has quadrupled and tripled, respectively [13]. Thanks to this development, NM is now the second largest producer of oil and gas in the US. Oil exploration and extraction activities such as heavy drilling, power production at drill sites, trucking, leakages and controlled emissions from well sites are heavy pollutant releasing events that degrade both local air quality and global atmospheric conditions [14,15]. Due to historically low natural gas pricing and a lack of infrastructure such as pipelines and storage, a significant percentage of produced natural gas has been historically lost to the atmosphere through venting, flaring, and leaks. Natural gas is mostly composed of methane (CH_4), with minor amounts of VOCs and other non-organic compounds. According to a recent assessment of basin-wide methane emissions, total CH_4 emissions are 5.5–9.0 times higher than the US EPA's National Emission Inventory (NEI) estimates for the region [16]. These findings have sparked a public debate on how to limit CH_4 emissions. The Energy, Minerals, and Natural Resources Department (EMNRD) of New Mexico published new rules on May 25, 2021, requiring oil and gas producers to capture 98% of their natural gas waste by the end of 2026, thereby prohibiting routine natural gas venting and flaring [17]. Moreover, the New Mexico Environment Department (NMED) has recently proposed a rule that directly regulates the production of VOCs and NO_x and improves air quality by reducing ground-level ozone generation in the state's most afflicted areas.

The bulk of the ozone concentrations in NM are attributed to Ozone transported from outside of NM, according to the 2020 NM Ozone Photochemical Modeling Study [4]. This includes medium-range transport from the neighboring regions of Texas and Mexico as well as long-range transport from the rest of the United States and global sources (Central America and Asia) [4]. Put differently, most ozone in NM is not being produced in NM. This is important context for considering potential regulatory and rulemaking options for affecting ozone concentrations in the state moving forward.

1.2. Role of methane (CH_4) in ozone concentration

Climate change, ozone recovery in the stratosphere, and growing CH_4 levels are all major factors influencing tropospheric ozone composition [18]. However, rising CH_4 levels may be the primary source of rising background ozone. Background ozone refers to the amount of ozone existing in a region that cannot be traced to local anthropogenic sources [19]. Reducing global anthropogenic methane emissions by 20% from the start of 2010 would reduce average daily maximum 8-hour surface ozone by 1 ppb by volume worldwide [20].

Photochemical oxidation of VOCs or similar organic compounds and oxygen or compounds with reactive oxygen such as carbon monoxide (CO) in the presence of NOx produces ozone in the troposphere [21]. Not all VOCs are equally reactive – i.e., they do not react to form ozone at the same rate or produce the same amount of ozone [22]. Although CH4 is not a VOC, it behaves similarly to a slow-reacting VOC under suitable conditions and adds a negligible amount to local ozone levels. However, due to the greater volume and longer lifetime of CH4 in the atmosphere compared to VOCs, they are carried throughout the planet, where their contribution accumulates, culminating in a significant contribution to the global background ozone levels [21,23–25]. As air quality requirements are tightened, as they are in European countries (55–65 ppb), the percentage contribution of background ozone to non-attainment of ozone criteria will continue to rise [21]. One noteworthy feature regarding CH4 mitigation is that it reduces ozone concentrations by roughly the same amount in both urban and rural regions [20,21].
CH4 is a greenhouse gas that contributes to anthropogenic climate change second only to carbon dioxide [26]. As a result, lowering CH4 emissions decreases tropospheric ozone levels while simultaneously decreasing global warming [21,27]. CH4 abatement has been seen as a low-cost approach to combat climate change [28,29], especially in the short term. However, because ozone pollution is typically seen as a local and regional concern, and the local advantages of local CH4 reductions are modest, CH4 abatement has not been considered for air quality management [27].

While CH4 emissions are a substantial contributor to global ozone concentrations, the slow development of ozone from CH4 means that the impact on NM ozone concentrations from emissions of CH4 in NM is minimal. According to the 2020 NM Photochemical Modeling Study [4], there is a correlation between higher VOC and NOx production and increased ozone levels, although the study does not always correlate increasing CH4 emissions to increased local ozone levels.

2. Emissions of Ozone Precursors (NOx and VOC) in New Mexico

In this section, we investigate ozone precursor (NOx and VOC) emissions sources and trends in New Mexico using data from the US EPA.

The National Emissions Inventory (NEI) is a national database updated every three years that contains estimates of annual emissions of criteria pollutants, criteria precursors, and hazardous air pollutants from point, nonpoint, and mobile sources. The EPA compiles this database using emissions reported by state, municipal, and tribal air agencies, which is then corroborated with other data sources [30]. The emissions inventory is a source-wise list of the pollutants that were released into the atmosphere. The emission inventory is required under 40 CFR Part 51 Subpart A - (Air Emissions Reporting Requirements) of the Code of Federal Regulations, which mandates all state agencies responsible for air pollution regulation to gather emissions data from certain facilities [30].

Based on the data collection processes and the sector to which they belong, emission sources can be classified in two ways: data categories and source categories. There are five main data categories of emission sources: point sources, non-point sources, on-road sources, nonroad sources and event sources. Point sources include estimates from larger stationary sources such as industrial facilities, power plants, airports and some smaller non-industrial, commercial, or portable emitters such as asphalt and rock crushing operations and, sometimes voluntarily, sources such as dry cleaners, gas stations and livestock farms. The thresholds set out in the Air Emissions Reporting Rule are used to determine a point source. All sources that are too small to be reported as point sources are reported as nonpoint sources. Residential heating, commercial combustion, asphalt paving and commercial and consumer solvent use are some examples of non-point sources. On-road sources include emissions from fossil fuel-burning vehicles that are either driving or idling on roadways. Non-road sources include off-road mobile sources that use fossil fuels such as aircraft, trains, construction machinery, lawn and garden equipment, aviation ground support equipment and commercial marine vessels. Event sources include fires reported in a day-specific format such as wildfires and managed burns but exclude agricultural fires which are reported as nonpoint sources. Emission sources can also be classified into different source categories based on the sectors in which they operate. These source categories are biogenic, agriculture, dust, fires, fuel, industrial processes, mobile, solvent, waste disposal and miscellaneous.

The NEI data that we use in our statewide analysis is obtained from the US EPA. Because our focus is on ozone formation and transport, we confine our analysis to the most potent ozone precursors, VOC and NOx. Data are made available once every three years. We obtain data from 2002-2017 (six NEI years of data; released every three years), of statewide data to examine the broader emission trends (in this section), and confine our analysis of county-specific emissions and ozone concentrations to 2011-2017 (in Section III). Petroleum and related industries (oil & gas), wildfires (fires), automobiles and vehicles (mobile), and fossil fuel combustion (fuel combustion) are the major sources of both NOx and VOC emissions that we investigate.

Importantly, biogenic (or naturally occurring) sources of VOC emissions are excluded from our statewide analysis in Figure 1 to focus on anthropogenic sources of emissions. The county-level maps in Figure 4 include biogenic sources and demonstrate that most NM VOC emissions are biogenic.

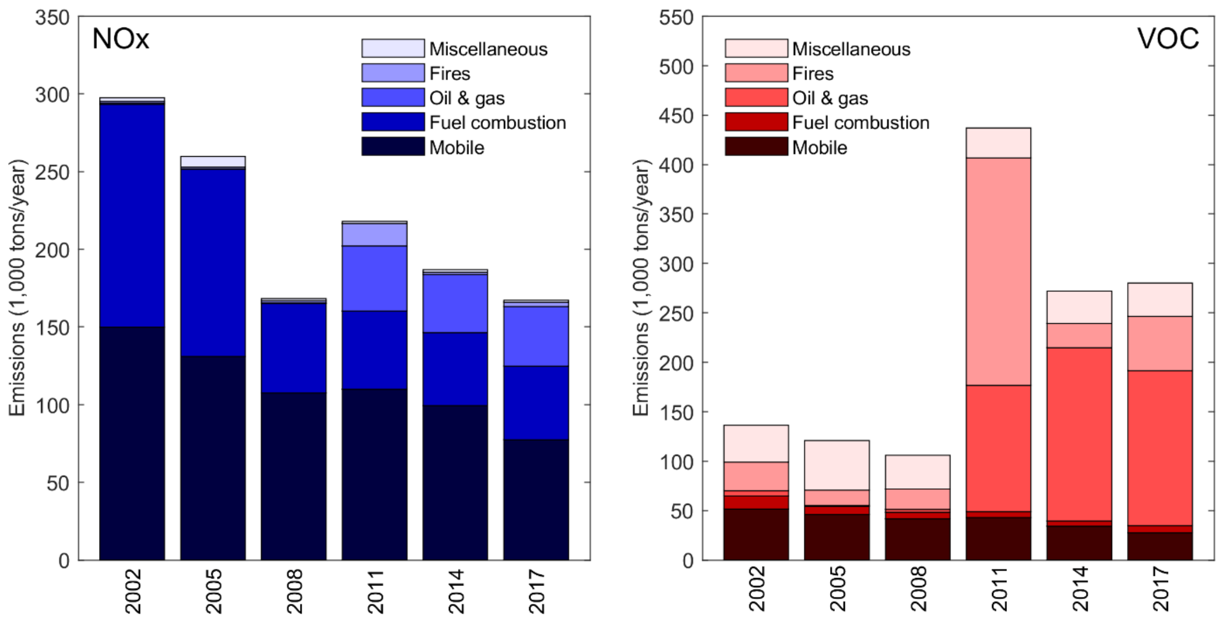

Figure 1: Ozone precursor (NOx and VOC) emissions and emission sector categories from 2002 to 2017 in NM. Naturally-occurring biogenic sources of VOC are not included in this figure. Source: NEI [30].

Using triennial NEI data for NM emissions, Figure 1 depicts the trend of ozone precursor emissions in NM from 2002 to 2017. While NOx emissions trended downward during this time, decreasing by 44% between 2002 and 2017, VOC emissions spiked in 2011, and remained elevated in 2014 and 2017.

Figure 1 also illustrates trends of sector-by-sector contributions to VOC and NOx, providing a more detailed account of the changes over time. Mobile sources (e.g., automobiles, other vehicles, etc.) have been the most prominent producer of NOx over the years. We can also see that there was an abnormal contribution of fires to VOC emissions in 2011. Similarly, as the state's total crude oil output increased by 2.4-fold between 2011 and 2017 [31], so has the contribution of petroleum and associated industries to NOx and VOC emissions. This is notably true for VOC emissions from 2011-onward. Fuel combustion for industrial purposes (e.g., fossil fuel power plants) is also a sizeable source of NOx emissions in NM, though it has been declining over time as a share of total emissions.

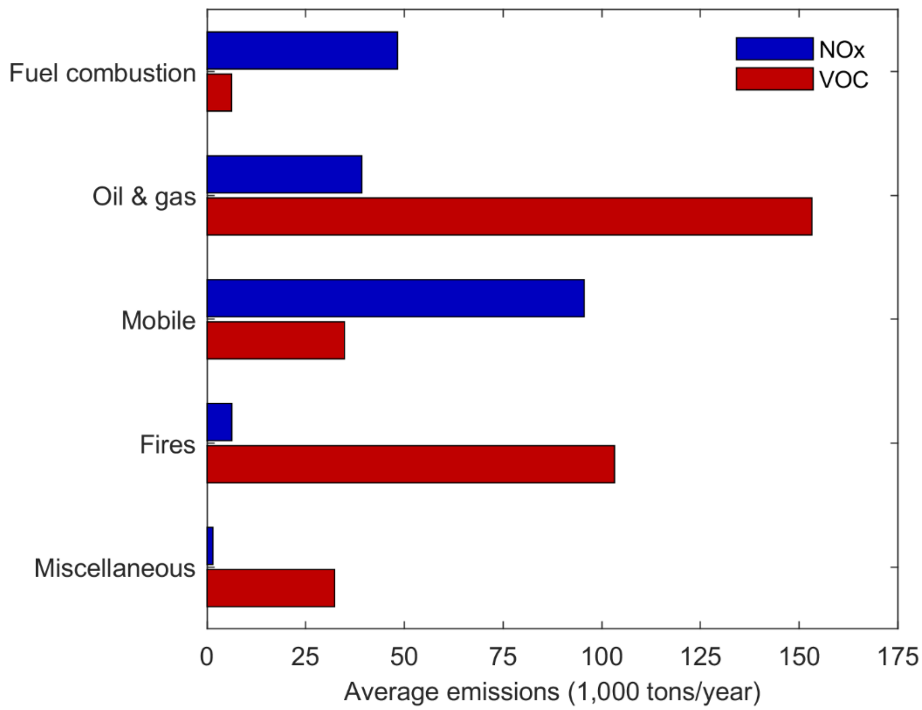

Figure 2: Sources of NM ozone precursor emissions averaged over the years 2011, 2014, and 2017. Naturally-occurring biogenic sources of VOC are not included in this figure. Source: NEI [30].

Figure 2 shows the breakdown of VOC and NOx emissions by sources, averaged over 2011, 2014, and 2017 for NM. We observe that anthropogenic VOC emissions over this period are mostly related to the oil and gas industry and fires (combined wildfires and prescribed burning), whereas NOx emissions are primarily caused by mobile sources, fuel combustion sources, and the oil and gas sector. When compared to other sources, this figure demonstrates the petroleum industry's disproportionate contribution to anthropogenic ozone precursors, particularly VOC emissions. However, given that ozone formation requires both NOx and VOC precursors, limitations of either would therefore limit how much ozone is created in a given context.

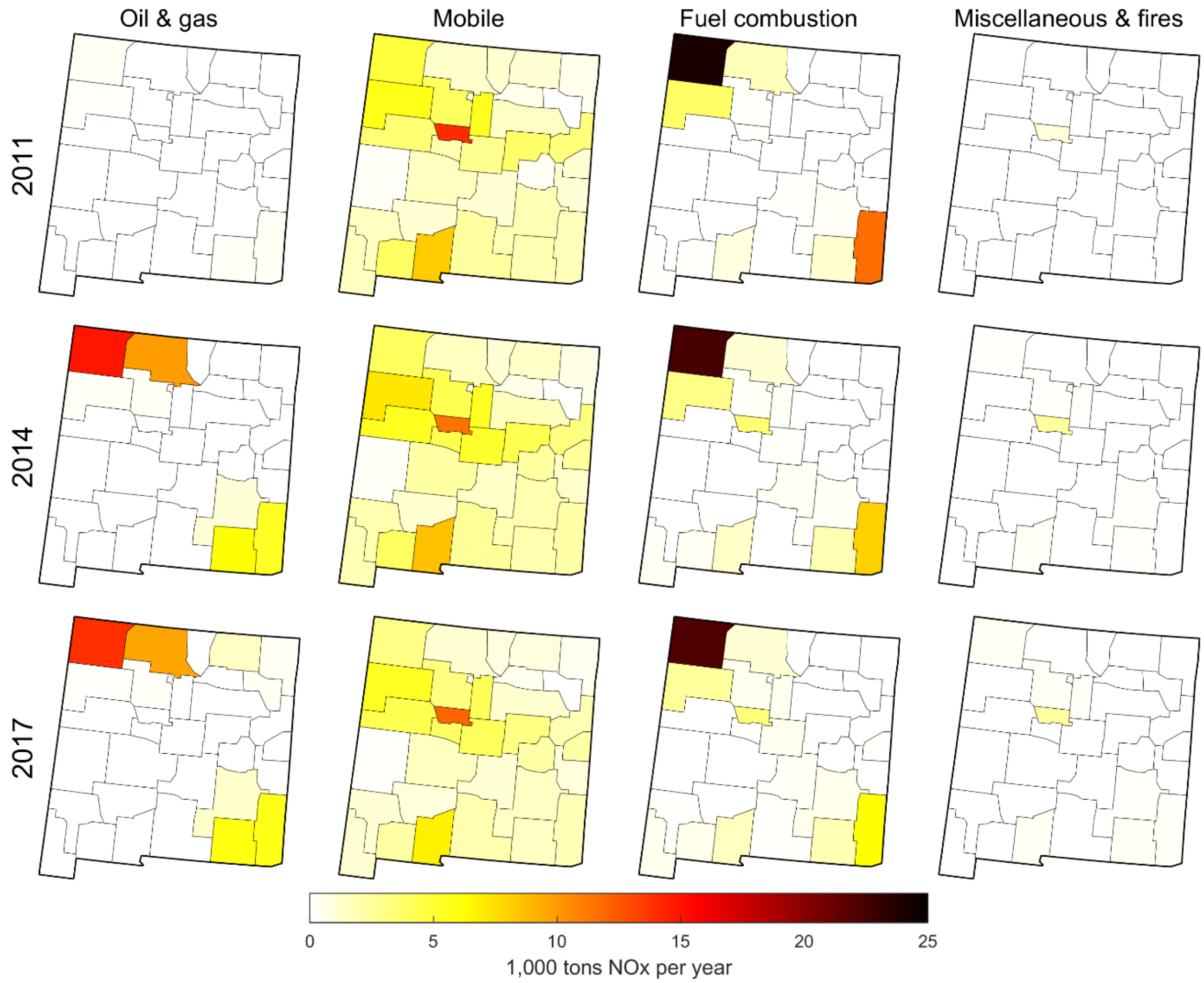

Figure 3: County-level NOx emissions by sector in 2011, 2014, and 2017 (1,000 tons per year). Source: NEI [30].

Figure 3 shows the spatial (county-level) and temporal (years 2011, 2014, and 2017) distribution of NOx emissions in NM across several economic sectors. Emissions of NOx are generally highest from mobile sources of emissions, which include on-road and off-road vehicles and automobiles, construction equipment, aircraft ground support equipment, train locomotives, and other mobile vehicles that use gasoline, diesel, or other fuels. Bernalillo County is an outlier for mobile NOx emissions because concentrations of motor vehicles and equipment are likely highest there among all counties in the state. Fuel combustion caused by electricity generation (from coal and natural gas) also makes up a significant share of NM's NOx emissions, primarily in the northwest and southeast corners of the state. The share of NOx emissions from the oil and gas sector grew over time, from 0.9% of total NM NOx emissions in 2011 to 19.2% in 2017.

This is likely being driven by the increased exploration and production of oil and gas in the state [31].

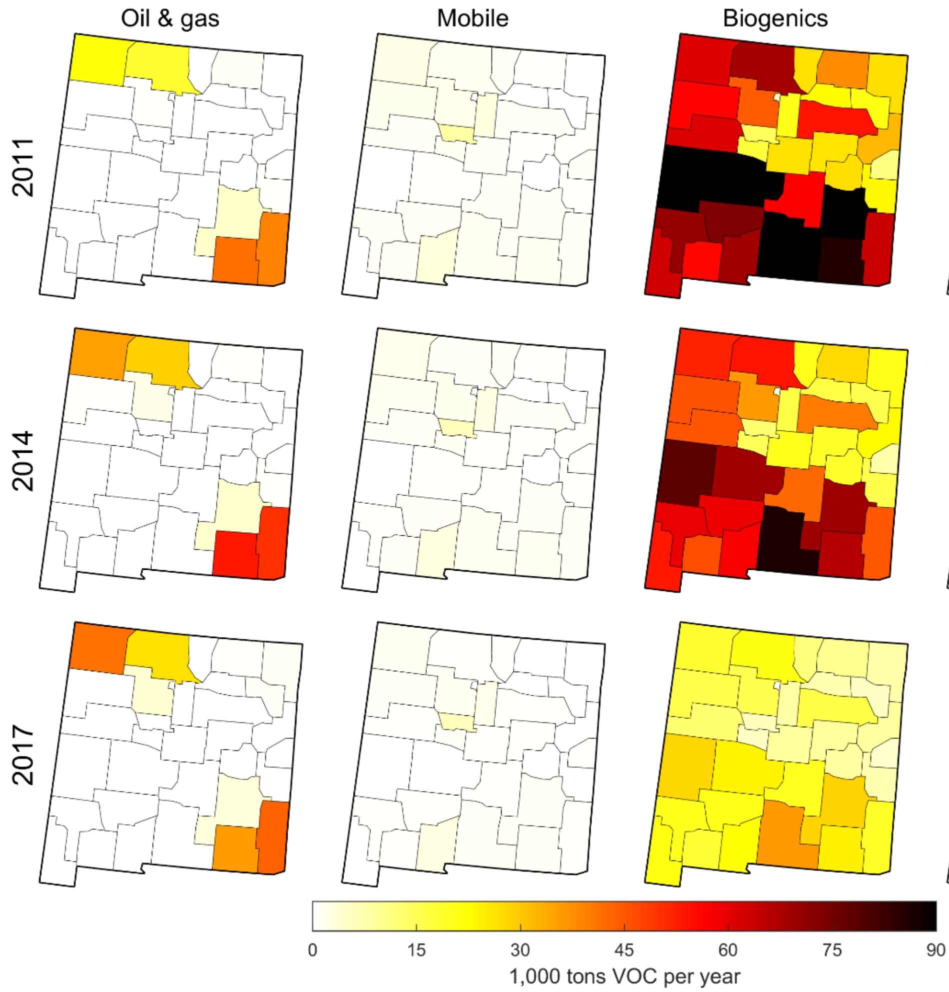

Figure 4: County-level VOC emissions by sector in 2011, 2014, and 2017 (1,000 tons per year). Source: NEI [30].

Figure 4 shows the spatial (county-level) and temporal (2011, 2014, and 2017) distribution of VOC emissions in NM across several economic sectors. Biogenic sources are by far the single largest source of NM VOC emissions, and these are background sources, such as vegetation and soils, and are naturally occurring in the environment. Emissions of VOC from the oil and gas sector grew over time. Oil and gas VOC emissions are clustered in the northwest and southeast parts of the state where active operations are ongoing. All other sectors produce substantially fewer VOC emissions.

3. Ozone Trends in New Mexico

In this section, we investigate state-wide ozone concentration trends in New Mexico using data from the US EPA over 2011-2017.

Ozone data were collected from the US EPA's Remote Sensing Information Gateway.[2] The data consist of daily 8-hour maximum concentration estimates by grid cell across the US, created using the Community Multiscale Air Quality (CMAQ) model [32]. CMAQ is three-dimensional Eulerian photochemical air transport model that uses spatial and temporal emissions to predict air quality levels of ozone and fine particulate matter at 12 km grid cells [32,33]. We collected the data from this model for 2011-2017 (the most recent year available) and for all grid cells in New Mexico. These data are modeled ozone concentrations, and do not correspond precisely with observed monitoring station data. The modeled ozone estimates are obtained using a state-of-the-science air transportation model (CMAQ), which is used for many purposes to understand air pollution concentrations. While the monitoring station data captures observed ozone concentrations, there are a limited number of stations in NM (not all NM counties contain an ozone monitoring station, for example), and the observed concentrations may be representative of a relatively small area surrounding each station. The modeled concentrations obtained from the US EPA allow for a more complete representation of ozone concentrations and trends in NM.

Figures 5 and 6 show average daily 8-hour maximum ozone concentration trends in NM by season—"summer" (defined as April through September here) and "winter" (defined as January through March and October through December here)—over the years 2011–2017. Ozone is substantially more prominent in the summer due primarily to higher temperatures and greater precursor emissions. Summer ozone concentrations are on average 13 ppb higher than winter (53 ppb in summer and 40 ppb in winter). The year 2014 stands out for both high summer (60 ppb on average) and high winter (47 ppb on average) ozone levels, though upon further investigation high ozone concentrations in 2014 appear to have been a phenomenon that occurred more broadly across the Western US and were not unique to NM. Notably, ozone levels appear to be substantially lower in NM between 2015–2017.

[2] Data available at: https://www.epa.gov/hesc/rsig-related-downloadable-data-files#output

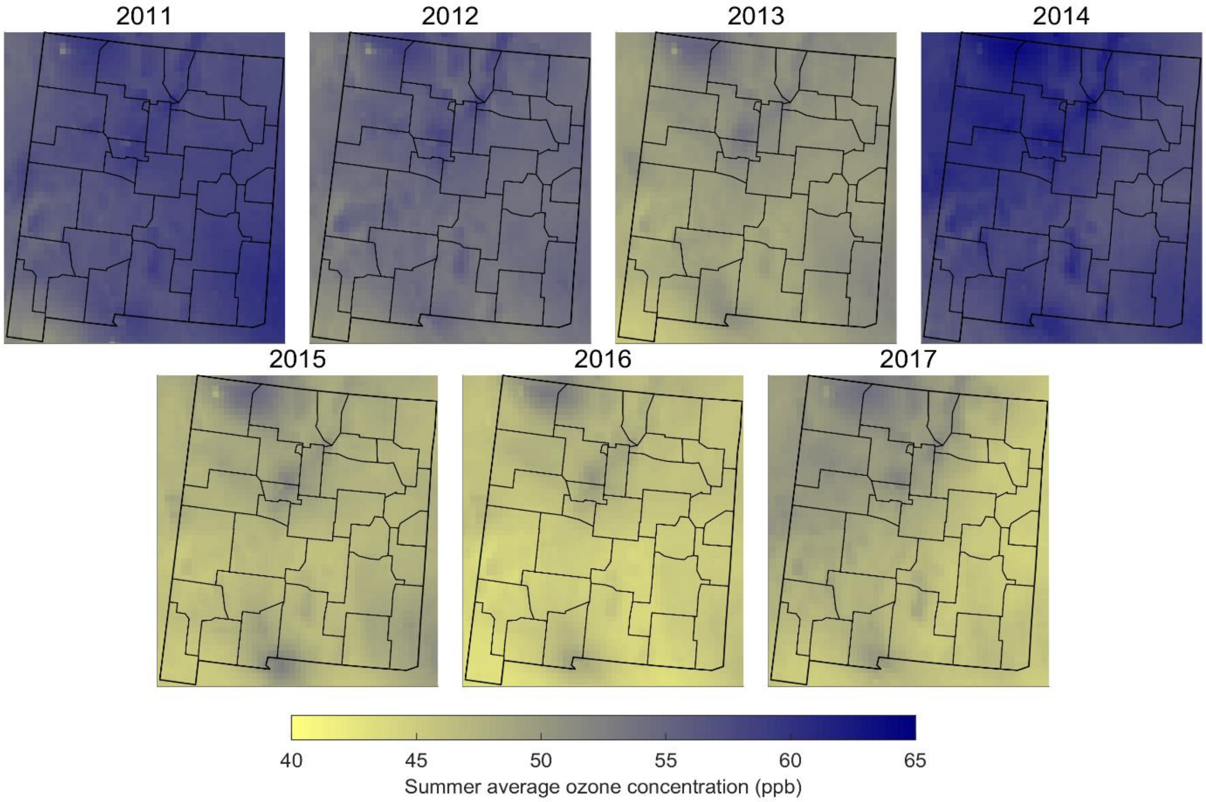

Figure 5: Summer average ozone concentration (ppb) by year, 2011–2017. Data are daily 8-hour maximum ozone concentration by each 12 km grid cell, averaged over the months April–September. Source: US EPA [32].

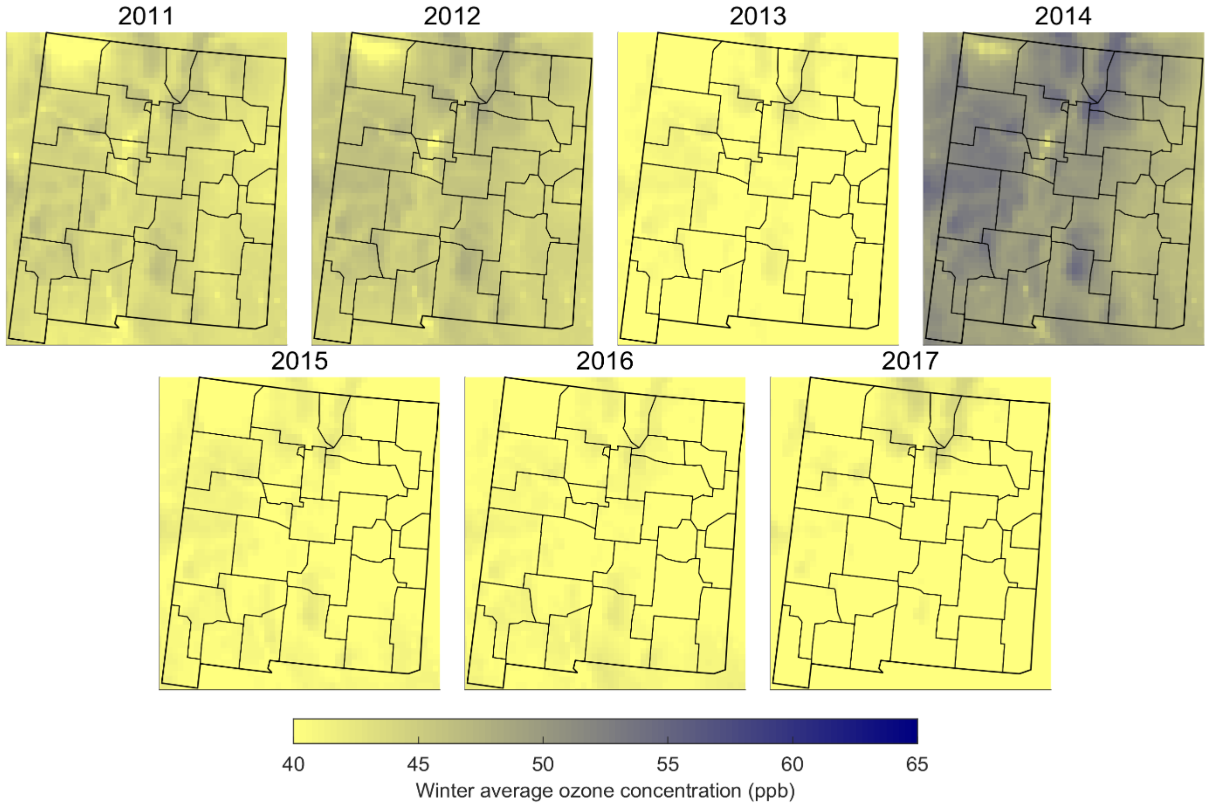

Figure 6: Winter average ozone concentration (ppb) by year, 2011–2017. Data are daily 8-hour maximum ozone concentration by each 12km grid cell, averaged over the months January–March and October–December. Source: US EPA [32].

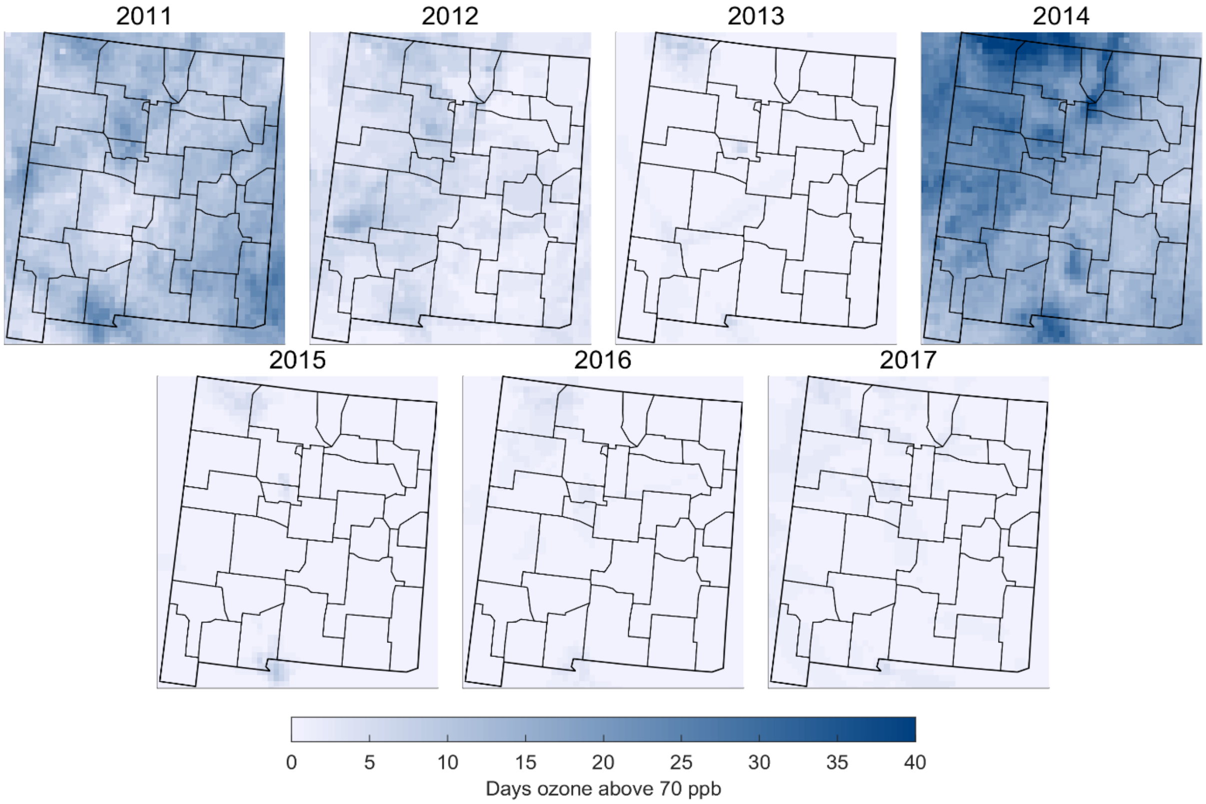

Figure 7: Total number of days each year that ozone concentrations (8-hour daily maximum) exceed 70 ppb (a threshold of concern) by 12 km grid cell. Source: US EPA [32] and author calculations.

In Figure 7, we show the total number of days each year where ozone concentrations exceeded 70 ppb at the 12 km grid cell-level in NM. 70 ppb is generally a threshold of concern for human health considerations and serves as the basis for the current ozone NAAQS (National Ambient Air Quality Standards) set by the US EPA. The years 2011 and 2014 standout for 30+ days of above 70 ppb ozone levels across many areas of the state. In 2014, pockets of consistently high ozone concentrations are observed in the northwest and northern sections of the state (near the New Mexico-Colorado border), in the western half of the state, and along the New Mexico-Texas-Mexico border in the extreme south-central portion of the state. Between 2015 and 2017, few areas of NM experienced days above 70 ppb ozone levels. Sections of Bernalillo and San Juan counties are outliers in most years due to pockets of high ozone concentrations. Vehicle emissions and electricity generation are likely key contributing factors in these two counties.

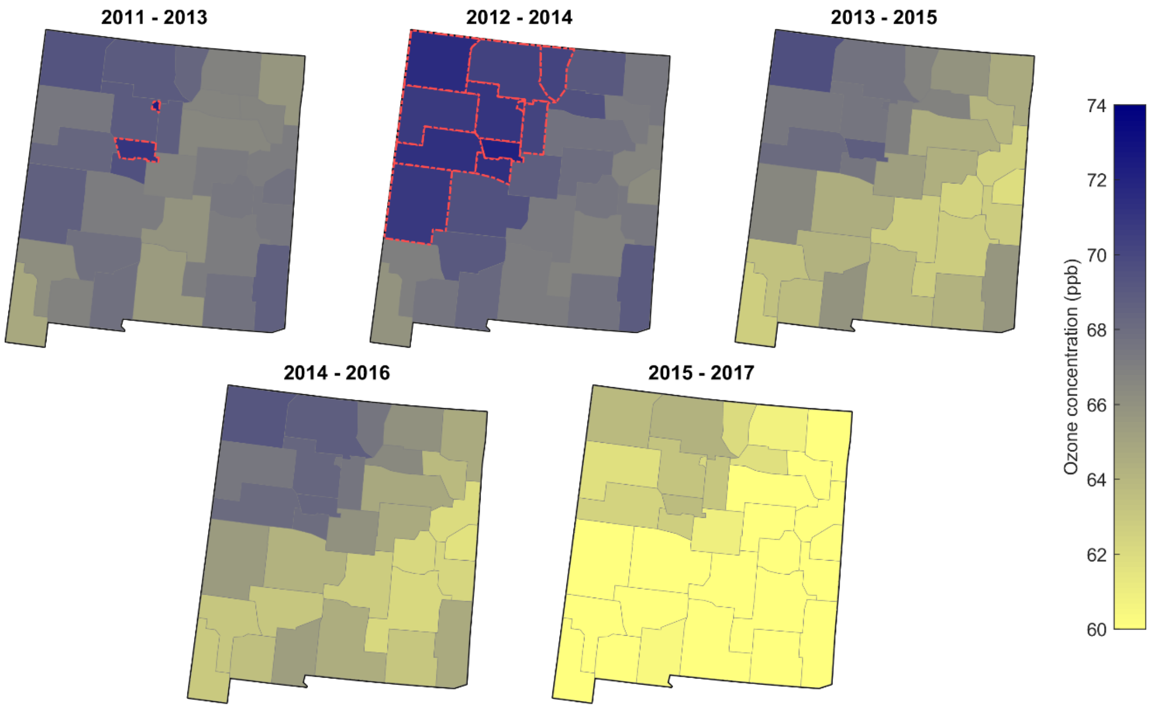

Figure 8: Modeled ozone concentration (ppb) at the county-level for purposes of the NAAQS attainment, 2011–2017. Calculated as the fourth-highest daily maximum 8-hour ozone concentration, averaged across three consecutive years. Counties with a red-dotted outline are out of compliance, according to our estimate, with the US EPA NAAQS standard (70 ppb) over the three-year average shown. Note: these are not official NAAQS calculations, rather these are based on estimated concentrations at 12 km grid cells averaged to the county level. Source: US EPA [32] and authors calculations.

Figure 8 shows the county-level fourth-highest concentration day of ozone (ppb) across New Mexico for five different three-year averaged time periods. The ozone concentrations shown are calculated according to the current (since 2015) US EPA National Ambient Air Quality Standard (NAAQS) of 70 ppb, calculated as the fourth-highest daily maximum 8-hour ozone concentration, averaged across three consecutive years. We perform the calculations at the county level, as shown in Figure 8, by averaging the ozone concentration of every grid cell inside each county. Counties outlined in red have ozone concentrations that exceed the EPA NAAQS standard over the three-year period listed.

There is a clear downward trend in NM ozone concentrations after the 2012–2014 peak. Ozone pollution is highest, by the EPA standard calculation, in the northwest portion of the state. The southeast part of the state, where oil and gas activity is ongoing, is generally not a relative outlier. In fact, during the 2014–2016 and 2015–2017 periods, ozone concentrations in the southeast are relatively low compared to other areas of the state. This may be due to NOx limitations in this area. Several counties appear to be out of compliance with the EPA standard during the 2011–2013 period, with even more out of compliance over 2012–2014. Bernalillo County, in particular, is one area of compliance concern.

4. Health Impacts of Ozone in New Mexico

In this section, we estimate the human-health impacts of ozone exposure in New Mexico using the ozone concentration data previously discussed in Section III, in combination with health impact functions used by the US EPA, as discussed below.

Populations at higher risk of ozone exposure include those with asthma, children, older adults and those who spend much of their time outside, particularly outdoor laborers [34]. Due to their underdeveloped respiratory tracts and substantially higher outdoor engagements, children are among the most vulnerable [34]. Children also have higher incidences of asthma compared to adults.

4.1. Health impact functions

Health impact functions are the relationships between changes in pollutant concentration and particular health endpoints. They are derived from epidemiological studies that relate pollutant concentrations with health outcomes [35]. This relationship can be shown in the following simplified form, where the incidence change in a given health endpoint, $\Delta Health\ Endpoint$, is some function, $f(.)$, of air quality changes, the exposed population, and the baseline health incidence of the endpoint:

$\Delta Health\ Endpoint$ = *f(Air Quality Change, Exposed Population, Health Baseline Incidence)*

The health impact functions that we employ are from the peer-reviewed literature, vetted by the US EPA, and often used in US EPA's own regulatory analyses. These functions are derived from the published epidemiological literature, the strength and veracity of which are evaluated by the US EPA to ensure that they fulfill both minimum and preferred criteria. The minimum requirements are that the study should be externally reviewed by Integrated Scientific Assessment; be conducted in the United States or Canada with sufficient information on air quality, affected populations, and underlying characteristics; be epidemiological in nature, and report risks/hazards as a function of a unit change in pollutant concentration [35]. The preferred criteria are that it should use recent data; encompass a relatively long time period and use a mix of techniques to quantify emissions and exposures [35].

We reviewed many US EPA-recommended studies and assigned a health impact function to each health endpoint based on the study's contextual and spatiotemporal relevance to our work. In this study, we estimated the total attributable mortality and morbidity to overall ozone levels in NM each year. The total attributable mortality or morbidity means that our results are reflective of the total health burden of ozone in NM for the endpoints we examine.

The specific health endpoints considered in this study are: (i) all-cause premature mortality for all ages; (ii) asthma related health effects for children (5–14 years), and; (iii) emergency room (ER) visits for all ages.

Premature mortality (all-cause; all ages)

We use the health impact function derived from Zanobetti and Schwartz (2008) [36] to assess the effect of short-term ozone concentration on premature mortality due to all causes for all age groups. The Zanobetti and Schwartz study combines mortality data from 48 cities across the United States with 8-hour ozone concentrations and meteorological data in a generalized liner model with a quasi-Poisson link function. The metric used is daily 8-hour maximum ozone concentrations over a summed lag structure of zero to three days and the model controls for season, day, and temperature fixed effects.

Asthma-related health effects (children; 5-14 years)

To assess the effect of ozone pollution on asthma exacerbation, we use the health impact function developed by Lewis et al. (2013) [37]. Lewis et al. studied how acute ozone exposure affected the frequency of asthma symptoms in a group of asthmatic children aged 5–12. The study estimated and categorized asthma incidences based on self-reported prevalence of four specific asthma symptoms (cough, wheeze, chest tightness, and shortness of breath). Cough is the most commonly reported symptom and is a natural reflex of the body to remove irritants from respiratory tract [37,38]. Wheezing is another asthma symptom associated with a high-pitched whistling sound made while breathing and is caused due to inflammation and narrowing of the airway [39]. Chest tightness includes any type of pain or discomfort that occurs between the upper belly area and lower neck [40]. Shortness of breath is an intense tightening of the airways associated with the feeling of air hunger, difficulty breathing, breathlessness or a feeling of suffocation [41]. The acute ozone exposure in this study is measured using multiple specifications ranging from a 0 to 5 days moving average of 1-hour and 8-hour maximum value of ozone concentration. We apply this health impact function to children aged 5–14 years, which is the narrowest range of population data we could obtain for NM.

ER visits (respiratory; all ages)

We apply the health impact functions from Barry et al. (2018) [42] to estimate the effects of acute ozone exposure on emergency room (ER) visits for respiratory diseases and for all age groups. The 3-day moving average (of lag days 0-2) of the daily 8-hour maximum ozone concentration is used to determine the acute exposure to ozone. The study includes ER visits for the following respiratory outcomes: asthma, upper respiratory tract infection (URI), chronic inflammatory lung disease (COPD), and a combined respiratory disease (RD) group consisting of visits for asthma, URI, COPD, pneumonia, and bronchiolitis.

Population attributable fraction (PAF)

For each health endpoint, we calculate the population attributable fraction (PAF) which estimates the share of the total health outcomes for some given endpoint that is attributable to a cause or factor. In this case, we are estimating the share of the NM population-wide premature mortality, asthma symptoms, and ER visits that are attributable to exposure to ozone. The equation for PAF for health endpoint j, in grid cell i, and age group a is

$$PAF_{i,a}^{j} = \frac{\left(RR_{i,a}^{j} - 1\right)}{RR_{i,a}^{j}},$$

where $RR_{i,a}^{j}$ is the relative risk of endpoint *j* from exposure to ozone compared with the no-risk baseline exposure (i.e., zero ozone concentration). We multiply the PAF by the relevant NM population age group ($Pop_{i,a}$) and the baseline rate of the endpoint (λ_a^j) to get the total health burden, *M:*

$$M_{i,a}^{j} = Pop_{i,a} \times \lambda_a^j \times PAF_{i,a}^{j}.$$

For each endpoint, the relative-risk equations come from the peer-reviewed literature discussed above.

For premature mortality (health endpoint *j* = *I*), from Zanobetti and Schwartz (2008), the relative-risk equation is a logistic form:

$$RR_{i,a}^{I} = (1 - \lambda_a^I)\exp\{\beta_a^I \cdot C_i\} + \lambda_a^I,$$

where λ_a^I is the baseline all-cause age-group specific mortality rate, C_i is the daily 8-hour maximum ozone concentration in grid cell *i*, and β_a^I is the estimated age-group specific coefficient from Zanobetti and Schwartz (2008). There is an estimated coefficient for each of eight age groups: (i) 0-20 years, (ii) 21-30, (iii) 31-40, (iv) 41-50, (v) 51-60, (vi) 61-70, (vii) 71-80, (viii) 81-99. All results below were combined for all ages, but age-group specific results are available.

For ER visits (health endpoint *j* = *II*), from Barry et al. (2008), the relative-risk equation is a log-linear form:

$$RR_i^{II} = \exp\{\beta^{II} \cdot C_i\},$$

which is applied to all ages, and thus has no subscript *a*.

For asthmatic events (health endpoint *j* = *III*–*VI* : *III* = cough, *IV* = wheeze, *V* = chest tightness, *VI* = shortness of breath), from Lewis et al. (2013), the relative-risk equation is a logistic form:

$$RR_{i,a}^{j} = \left(1 - \lambda_a^j\right)\exp\left\{\beta_a^j \cdot C_i\right\} + \lambda_a^j,$$

where λ_a^j is the prevalence of asthma symptom *j* for the 5–14 age group.
All estimates of health burden were originally made at the grid cell level and for each day across our seven-year time period. We aggregated the grid cell estimates to the county-level and summarized all outcomes monthly and annually.

4.2. Population and baseline incidence and prevalence data

Data on age-group-specific population by 12 km grid cell was downloaded from the US EPA BenMAP-CE program for the year 2015 [35]. We applied this population dataset to each of our seven years of analysis (2011–2017). The population was separated into five-year age-group increments, and we combined the groups to fit the specified age groups from each study as necessary.

Baseline mortality incidence data was collected from the US Centers for Disease Control and Prevention (CDC) WONDER Online Database, of mortality rates for each year (2011–2017) by five-year age groups for NM [43]. We used the state-level mortality rates by age groups and by year and applied them to each grid cell.

Baseline ER visit data was also collected from the US EPA BenMAP-CE program. The data are ER visit rates by age and grid cell across the US. We average across the grid cells to get national rates by age group. We then apply these rates to each grid cell in NM by weighting by the age distribution in the grid cell to obtain a grid-cell-specific all-ages ER visit rate. Asthma symptom prevalence also comes from BenMAP-CE.

4.3. Ozone Health Impact Results

4.3.1. Mortality and morbidity impacts of ozone in NM

Table 1 lists the annual values of health endpoints for total attributable mortality and morbidity from ozone in NM over 2011–2017. Mortality estimates include the deaths that happen on the same day or within a few days following ozone exposure for all-causes. On average, we estimate that ozone was associated with 259 premature deaths (excess acute mortality) per year over 2011–2017, equivalent to a rate of 11.6 per 100,000 people per year, on average. In total, there were an estimated 1,811 premature deaths in NM due to ozone pollution between 2011–2017. Morbidity estimates related to ozone are shown using two endpoints: respiratory ER visits and asthma symptoms (across various types). Statewide, there were an average of 961 respiratory-related ER visits per year in NM and 59,910 cases of asthma exacerbation (combined chest tightness, cough, shortness of breath, and wheezing) per year, on average, among children aged 5–14. Apart from a rise in 2014, the mortality and morbidity impacts of ozone have generally been on the decline.

Table 1: Total attributable mortality and morbidity (and rate per 100,000 population) from ozone for New Mexico (2011–2017)

Endpoint	2011	2012	2013	2014	2015	2016	2017
Mortality—all cause, all ages (rate per 100,000)	273 (12.2)	271 (12.1)	246 (11.0)	297 (13.3)	241 (10.8)	241 (10.8)	242 (10.8)
Respiratory ER visits—all ages (rate per 100,000)	1,018 (45.6)	1,012 (45.4)	919 (41.2)	1,101 (49.3)	904 (40.5)	887 (39.8)	887 (39.8)
Asthma—chest tightness, ages 5-14 (rate per 100,000)	15,841 (5,050)	15,749 (5,021)	14,679 (4,679)	16,871 (5,378)	14,467 (4,612)	14,239 (4,539)	14,218 (4,532)
Asthma—cough, ages 5-14 (rate per 100,000)	21,395 (6,820)	21,251 (6,774)	19,592 (6,246)	23,036 (7,344)	19,269 (6,143)	18,922 (6,032)	18,893 (6,023)
Asthma—shortness of breath, ages 5-14 (rate per 100,000)	9,242 (2,946)	9,179 (2,926)	8,452 (2,694)	9,964 (3,176)	8,311 (2,649)	8,159 (2,601)	8,147 (2,597)
Asthma—wheeze, ages 5-14 (rate per 100,000)	16,424 (5,236)	16,319 (5,202)	15,096 (4,812)	17,624 (5,618)	14,856 (4,736)	14,600 (4,654)	14,578 (4,647)

When compared to other endpoints in Table 1, we can see that asthma symptoms have a greater incidence of occurrence. Coughing is the most prevalent asthma symptom, followed by wheezing and chest tightness. Shortness of breath is the least prevalent asthma symptom. Mortality impacts are rare and infrequent compared to morbidity impacts because exposure to ozone is more likely to lead to illness and disease, rather than premature death. All the morbidity and mortality endpoints follow a similar pattern, closely mirroring the ozone levels, with 2014 being the worst impact year across all endpoints.

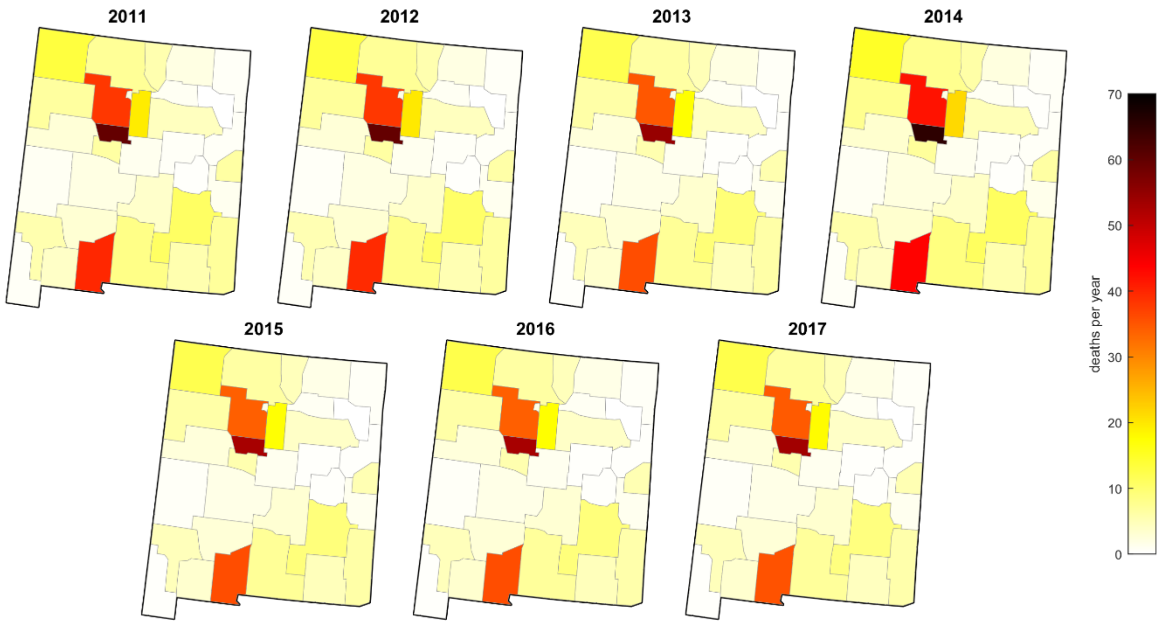

Figure 9: Ozone-related acute mortality per county (all ages; number of attributable deaths per year).

Figure 9 shows the attributable all-cause mortality (all ages) due to ozone concentrations spatially, by county, for each year between 2011 and 2017. These are considered excess short-term deaths due to ozone exposure by the population. Most ozone-related deaths are clustered in Bernalillo, Sandoval, and Doña Ana counties. This is due primarily to the fact that these are the population centers in NM, and because ozone concentrations are relatively high in these areas.

In Figure 10, the average premature mortality over the 2011–2017 period is shown. Figure 10 shows that there are several ozone-related mortality clusters around New Mexico, where both ozone levels and population are concentrated.

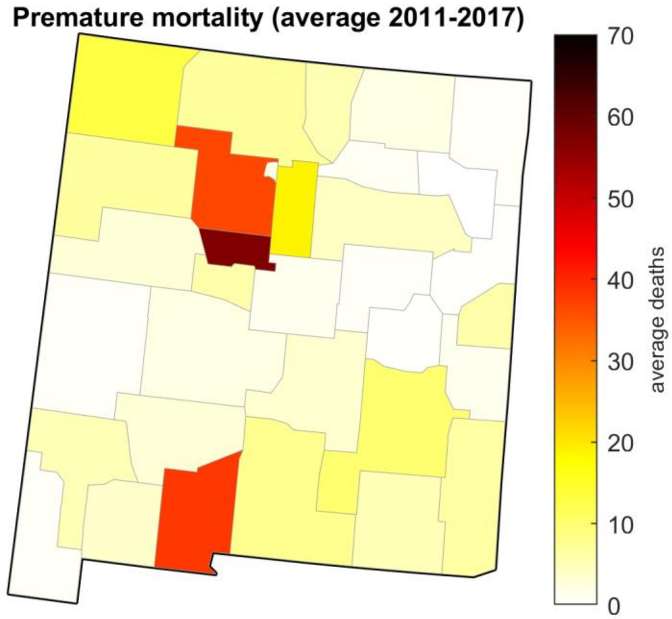

Figure 10: Ozone-related acute mortality averaged over 2011–2017 (all ages; average annual number of attributable deaths).

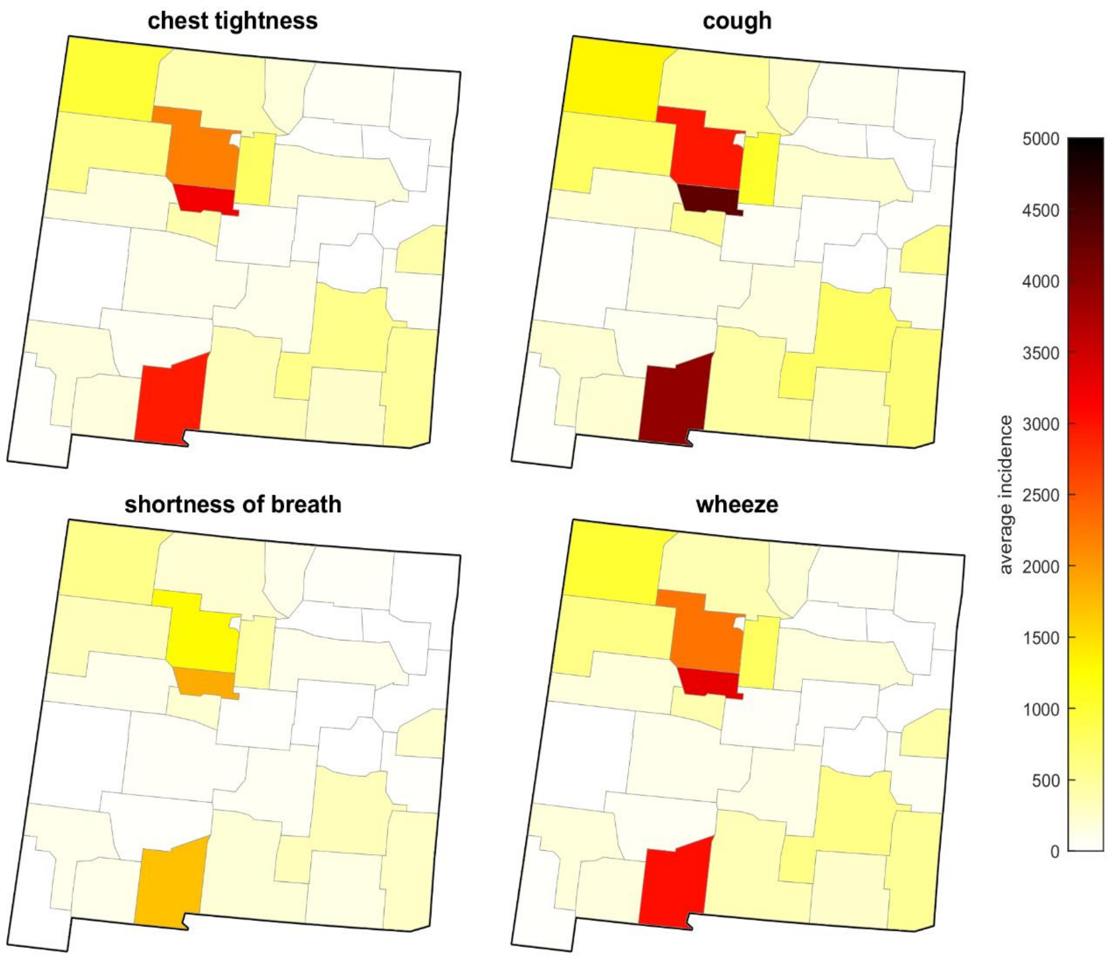

Figure 11: Ozone-related incidence of asthma by symptom averaged over 2011–2017 (for ages 5–14).

Figure 11 shows the 2011–2017 average county-level incidence of asthma symptoms across New Mexico. Cough is the most common symptom, with thousands of cases per year across the state attributable to ozone exposure. Experiencing chest tightness and wheezing are also both commonly experienced impacts of ozone. As before, hotspots exist in Bernalillo, Sandoval, and Doña Ana counties given their relatively large populations and high levels of ozone concentration.

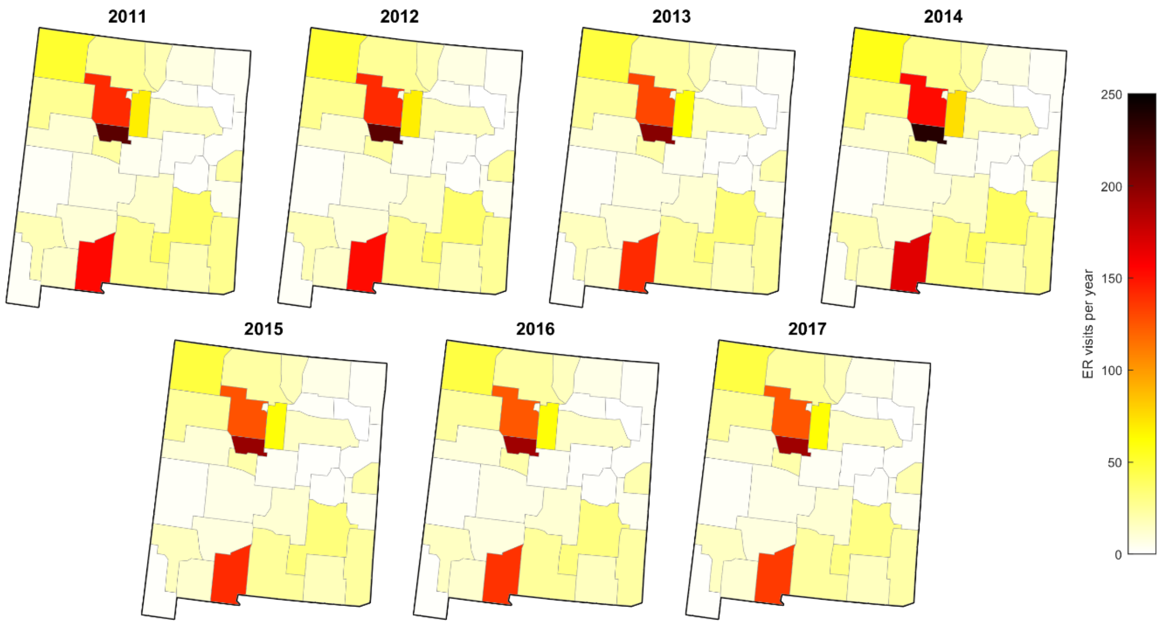

Figure 12: Ozone-related respiratory emergency room (ER) visits over 2011–2017 (all ages).

Figure 12 shows the spatial and temporal impacts of ozone on annual county-level respiratory emergency room (ER) visits across New Mexico between 2011–2017. These represent estimates of the total number of respiratory-related county-level cases of individual visits to a hospital ER due to ozone exposure each year. ER visits are highest in 2014, with up to several hundred cases in Bernalillo, Sandoval, and Doña Ana counties. Other NM counties generally experience a few dozen ER cases per year. There is a noticeable downward trend in cases from 2015-onward, reflecting reduced ozone concentration across the state over this period.

In Figure 13, the 2011–2017 average number of ER visits are shown. On average, Bernalillo County experiences approximately 200 respiratory ER visits per year over 2011–2017 due to ozone.

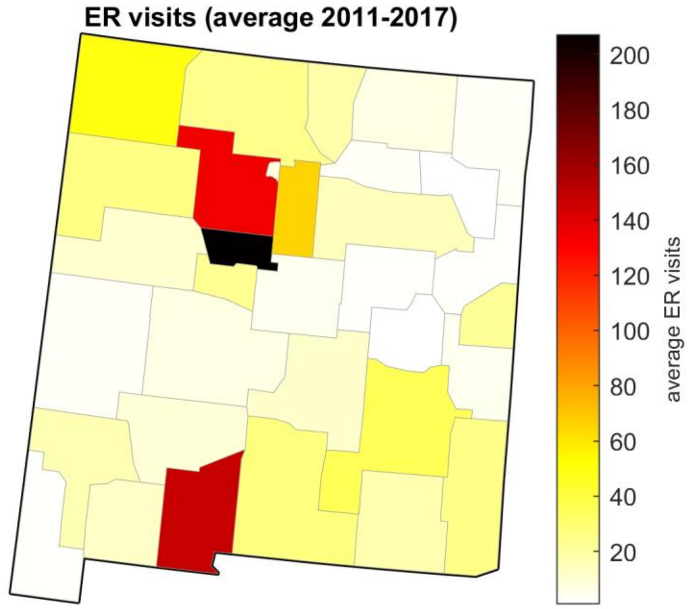

Figure 13: Ozone-related respiratory ER visits averaged over 2011 –2017 (all ages).

4.3.2. Premature mortality from ozone above and below 70 ppb threshold of concern

To provide some policy and regulatory context to the results presented thus far, we ask the following hypothetical question: “What are the total avoided deaths (in terms of ozone-related acute mortality) if days where ozone levels were >70 ppb in a given NM county were reduced to 70 ppb?” This is a measure of the approximate “benefit” of satisfying a similar 70 ppb standard as that used by the US EPA under the NAAQS (where 70 ppb is considered to be a “threshold of concern” with regards to human health). In other words, how many lives can be saved per year in NM if there were no days of >70 ppb ozone levels?

As shown in Figure 14, few lives would be saved from such a policy. This is because there are relatively few days of >70 ppb ozone levels in the state. In 2014, where the potential life savings are largest, approximately two deaths could have been avoided, out of a total ozone-related mortality of 297 across the entire state in that year, if all >70 ppb days were moved to 70 ppb. This is roughly a 1% improvement in the ozone-related mortality rate. However, in several of the years studied (i.e., 2013 & 2015–2017), the mortality improvements are negligible and close to zero. This suggests that enforcing a blanket 70 ppb standard on NM counties, in keeping with the spirit of the US EPA NAAQS standard, would have small to negligible effects on the acute mortality impacts of ozone in New Mexico.

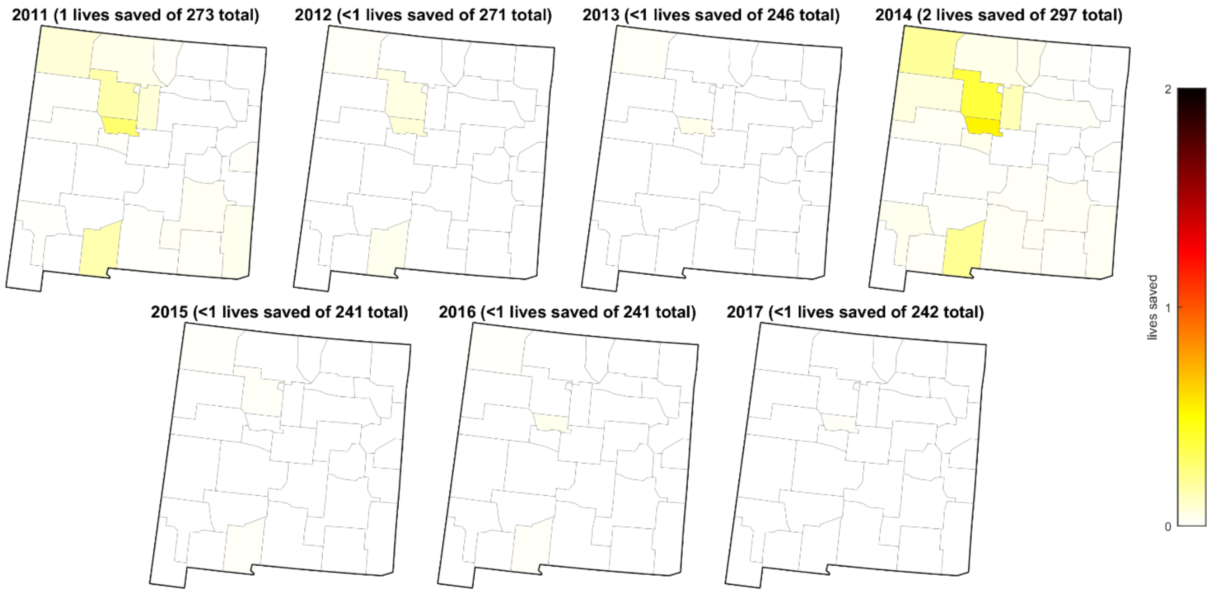

Figure 14: Potential reduced acute mortality (lives saved) if extreme ozone event days (>70 ppb threshold of concern) were ex post made to be at the threshold of concern (=70 ppb).

Figure 15 complements Figure 14 by showing the share of acute deaths (over 2011–2017) due to ozone in NM across various concentration ranges. Panel A (left) shows the share of deaths (in blue) due to ozone by concentration ranges and the share of days (in grey) that ozone levels fall within the listed ranges between 2011–2017. Panel B (right) shows the cumulative number of deaths associated with the same concentration ranges listed in Panel A.

From Panel A, we observe that ozone concentrations in NM are most frequently in the 40–60 ppb range. Ozone concentrations above 60 ppb are rare (less than 10% of all days in NM over 2011–2017) and concentrations above 70 ppb are exceedingly rare (1.3% of all days). Two-thirds of ozone-related deaths in NM occur on days where the concentration is between 40–60 ppb. This is because ozone concentrations in this range are the most frequently observed in NM (69% of days). As ozone concentrations increase beyond 60 ppb in Panel A, the share of associated deaths is correspondingly and disproportionally high (because higher ozone levels are more harmful), but the share of days over which these high levels of ozone occur are rare.

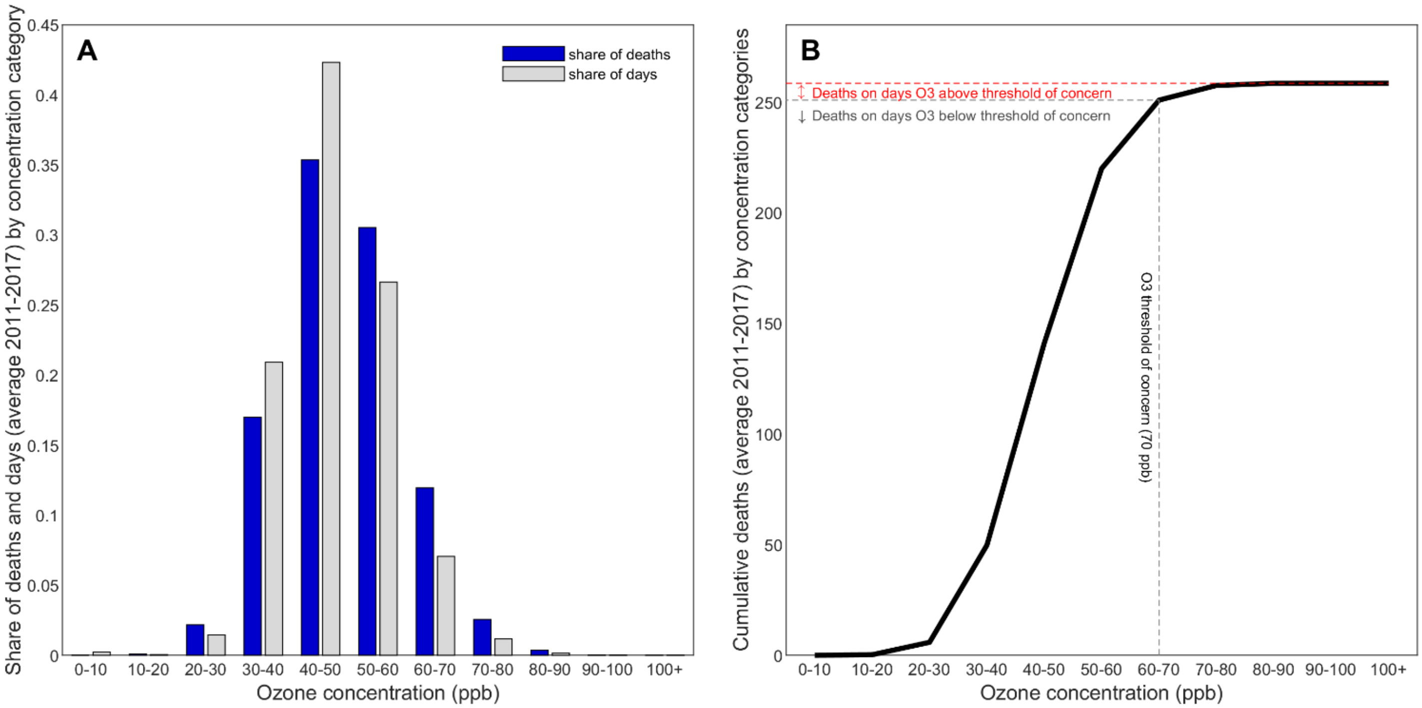

Figure 15: Ozone-related acute mortality deaths by days in concentration ranges averaged across 2011–2017.

Panel B illustrates that the vast majority of ozone-related mortality in NM occurs at concentrations below 70 ppb (the basis for the US EPA NAAQS standard and a threshold of concern). This is because ozone concentrations above 70 ppb are rare in NM, as Panel A shows. Only 3% of deaths are associated with days in which O3 concentrations exceed 70 ppb. Thus, policies targeted only at high or extreme ozone levels (e.g., >70 ppb) will have small to negligible impacts on ozone-related acute mortality in the state. Of course, we recognize that higher ozone exposure causes disproportionally higher mortality, but, in the aggregate, >70 ppb ozone days are rare enough in NM that disproportionate policy action targeted at high ozone levels will have only small overall impacts on ozone-related mortality in the state. Rather, from a public health perspective, policies targeted at reducing overall ozone levels (i.e., not extreme event days) would be more impactful, for the case of NM. Importantly, Figures 14 and 15 illustrate that ozone exposure is harmful even in locations and at concentrations that are in compliance with the NAAQS.

5. Health Economic Costs of Ozone Pollution

In this section, we estimate the health economic costs of ozone pollution in New Mexico over 2011-2017 using data from the US EPA combined with author calculations.

The costs and benefits of ozone pollution and the efficacy of mitigative measures are challenging to compare and comprehend without quantifying the improvements and impediments stemming from such measures in monetary terms. The US EPA publishes periodical reports estimating the benefits and costs of the Clean Air Act [33,44]. These reports have extensive, peer-reviewed information on the Clean Air Act's social benefits and costs, including improvements in human health, welfare, and natural assets as well as the regulation's economic impact [33]. In this study, we calculate the annual estimate of the dollar damages associated with the health impacts of ambient ozone concentrations.

While calculating the health damages of ambient ozone concentration, we focused exclusively on the impacts to human health. This choice is because the US EPA estimates that the substantive portion of the overall damages of air pollution exposure are due to human health costs [33]. In the results that follow, we show estimates of the damages of ozone pollution representing the health burden of ozone in NM.

There are two different health damage metrics for estimating the monetary value of the adverse health events related to ozone pollution exposure. These are willingness-to-pay (WTP) to avoid exposure and the cost-of-illness (COI) from ozone exposure. WTP is a monetary value that a person is ready to pay to avoid being exposed to ozone pollution. Therefore, economists prefer WTP because it is the proper economic measure of the value of averting a negative outcome [33,35]. A person's WTP to prevent an asthma episode, for example, would be the value of an avoided asthma attack. These values can be elicited from surveys or inferred from observed behavior. When WTP estimates are unavailable, as when valuing the cost of hospital admissions, an alternative estimate is used: the cost of treating or mitigating the effect of ozone pollution exposure, in this case the hospital bill. This is known as the cost-of-illness (COI) metric. For our purpose, we use the US EPA recommended COI estimate of the value per statistical incidence for each adverse health endpoint. These estimates are pooled from the peer-reviewed literature and are updated frequently. The US EPA recommended COI value per statistical incidence of respiratory emergency room visit is estimated to be $875 (in 2015 inflation-adjusted USD; 2015$) and for any kind of asthma symptom for the age range 0–17 years, it is estimated to be $219 (in 2015$) [35]. By multiplying the value per statistical incidence by the total number of annual incidences, we obtain the total health damages of ozone pollution per health outcome.

For the valuation of premature acute mortality, we multiply the annual excess premature mortality obtained from the health impact function by the value of a statistical life (VSL). VSL, or dollars per mortality avoided, is inferred by adding up individuals' WTP to avoid small increases in mortality risk over enough individuals [35]. For our purpose, we use the standard VSL adopted by US EPA which is equal to $8.7 million (2015$).

Table 2 presents estimates of the state-wide annual health economic costs of ozone pollution in NM across various health endpoints, between 2011–2017. Costs are shown in millions of inflation-adjusted 2015 USD (2015$).

Table 2: Health damages of ozone pollution in NM (in millions 2015$).

Endpoint	2011	2012	2013	2014	2015	2016	2017
Mortality damages (all-cause, all ages)	2,400	2,400	2,100	2,600	2,100	2,100	2,100
Respiratory ER visit damages (all ages)	0.89	0.89	0.80	0.96	0.79	0.78	0.78
Asthma damages (chest tightness, ages 5-14)	3.47	3.45	3.21	3.69	3.17	3.12	3.11
Asthma damages (cough, ages 5-14)	4.69	4.65	4.29	5.04	4.21	4.14	4.14
Asthma damages (shortness of breath, ages 5-14)	2.02	2.01	1.85	2.18	1.82	1.79	1.78
Asthma damages (wheeze, ages 5-14)	3.60	3.57	3.30	3.86	3.25	3.20	3.19

All-cause acute mortality impacts of ozone impose a $2.26 billion burden on NM, on average, per year. When NM experiences abnormally high ozone levels, such as witnessed in 2014, the mortality health costs increase to $2.6 billion. These are the dominant economic impacts of ozone pollution in NM. Morbidity costs, while significant, are orders-of-magnitude lower than those observed for mortality. This is because the US EPA VSL, which captures the value of small reductions in mortality risk, is substantially larger than the US EPA recommended COI metrics for ER visits and asthma events [45]. Intuitively, this is because not all illness leads to death. We estimate that ozone-induced respiratory ER visits are associated with health damages averaging $841,000 per year, state-wide. From Table 1, this is on the basis of 961 average annual ER-respiratory visits in NM. For asthma impacts among children aged 5–14, average annual damages range from a low of $1.92 million (for shortness of breath) to a high of $4.45 million (for cough). Combining all asthma symptoms together, childhood asthma impacts of ozone pollution impose average annual damages of $13.1 million per year in NM. Notice, however, that the health damages vary, sometimes substantially, from year-to-year, due to changing ozone conditions experienced across the state.

6. Conclusions and Policy Implications

We began our investigation against the backdrop of increasing concern about rising ozone levels across NM [4]. There is no single contributor to high ozone levels; rather, there are a variety of in-state and out-of-state sources. While sources inside the state can be categorized as transportation emissions, oil and gas development, industrial pollutants, and wildfire emissions, the ozone attributable to out-of-the state sources are lumped together as background ozone. Elevated ozone levels have a detrimental impact on the health and welfare of the NM residents. Several decades of peer-reviewed scientific research show that exposure to ozone can cause respiratory diseases and even premature death. Recognizing these potential harms, the 1970 Clean Air Act identified ozone as a criteria air pollutant, establishing air quality standards and a set of regulations to restrict ambient levels. Thus, knowing the harmful effect of ozone, measuring its concentration and distribution, as well as the associated damages, can assist policymakers in comprehending the magnitude of the problem and developing effective policy tools to manage it.

We developed a comprehensive map of ozone concentrations in New Mexico from 2011 to 2017 at a spatial resolution of 12km using CMAQ data obtained from the US EPA. We then estimated the total incidence of different health endpoints as well as total premature deaths attributable to ozone pollution using health impact functions derived from the epidemiological literature approved by the EPA. Following that, we calculated the total dollar denominated damages of each health endpoint, including mortality.

Between 2011 and 2017, we found:

- Ozone pollution caused an estimated 259 premature deaths per year in New Mexico and an annual average of 961 respiratory-related emergency room (ER) visits and 59,910 asthma exacerbations (chest tightness, cough, shortness of breath, and wheezing combined) in children aged 5–14 years.
- The average annual damages of health-related effects caused by ozone pollution in New Mexico was estimated at $2.26 billion (2015$) during the study period.
- 97% of the ozone-related deaths occurred on days in which ozone levels were below 70 ppb (the NAAQS threshold of concern), with two-thirds of deaths occurring from concentrations between 40–60 ppb.

The evidence indicates that the predominant contributors to ozone pollution in NM are the transboundary sources. In other words, the bulk of ozone in NM can be traced back to the emissions from adjacent states of Texas, Colorado, and Arizona, as well as Mexico’s Chihuahua region. Given the considerable contribution of transboundary sources to the overall ozone concentration, even if all anthropogenic sources of ozone precursors were to be removed from NM, the background ozone level is expected to remain relatively high. The hypothetical removal of all in-state anthropogenic ozone precursors might reduce the total number of high ozone days (>70 ppb) but these high ozone days are already infrequent and the associated health risks are minimal compared to the health impacts associated with ozone below 70 ppb. Therefore, if we are unable to control transboundary emissions entering the state, both the background ozone concentration and the overall dollar damages of ozone will continue to be a concern in NM.

The importance of reducing ozone concentrations below 70 ppb is paramount from a regulatory standpoint, as it maintains compliance with the federal NAAQS. However, we emphasize the relatively small benefits, from lessening or eliminating these infrequent, high-concentration days. Conversely, we highlight the severe health burden imposed on NM from the more moderate ozone concentrations most commonly observed in the state. A focus on reducing these moderate concentration days, especially in the most highly populated areas of NM, will have the largest improvement in health outcomes.

7. References

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