UC Merced

UC Merced Electronic Theses and Dissertations

Title

The Health Economics of Ambient Air Pollution in the San Joaquin Valley

Permalink

https://escholarship.org/uc/item/7nc5z6n4

Author

Zarate-Gonzalez, Gilda

Publication Date

2023

Copyright Information

This work is made available under the terms of a Creative Commons Attribution License, available at https://creativecommons.org/licenses/by/4.0/

Peer reviewed|Thesis/dissertation

eScholarship.org Powered by the California Digital Library
University of California

UNIVERSITY OF CALIFORNIA, MERCED

The Health Economics of Ambient Air Pollution in the San Joaquin Valley

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy

in

Public Health
and Health Economics

by

Gilda Zarate-Gonzalez

Committee in charge:

Paul M. Brown PhD, Chair and Professor of Public Health and Health Economics
Ricardo Cisneros, PhD, MPH, Professor of Public Health
Kurt Schnier, PhD, Vice Chancellor and Chief Financial Officer, Professor of Economics

2023

Copyright (or ©)

Gilda Zarate-Gonzalez,

2023

All rights reserved

The Dissertation of Gilda Zarate-Gonzalez is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

Ricardo Cisneros, PhD, MPH

Kurt Schnier, PhD

Paul M. Brown, PhD, Chair

University of California, Merced

2023

Dedication

To Patricio Tochtli, Enrique Yolotli, Paloma Galilea Ixchel, and Tito.

Para mi Papá y mi Nana que me cuidan desde el Cielo, y para quienes ni siquiera la educación primaria les fue posible, pero tenían planes diferentes para su hija.

Para mi Mamá a la que siempre me esforcé en hacer orgullosa con lo único que sé hacer.

Para mi Tía quien me motivó a seguir adelante en defensa de mi propósito.

To my Father-in-Law, Tomas Gonzalez, to this day I cannot believe what kind of superhero you were until I attempted this feat just like you did with six children and all by yourself. It is humbling to know you did your best you could and had time to help so many accomplish their education and immigration dreams.

Table of Contents

Page

LIST OF FIGURES vii

LIST OF TABLES viii

ACKNOWLEDGEMENTS x

VITA xi

ABSTRACT xiii

Chapter

1. INTRODUCTION 1

Economic View of Air Pollution 2

Air Pollution Pathway to Ill Health 4

Pollution Control Policy Standing 6

The San Joaquin Valley Region and Asthma . . . 7

Aims and Research Questions 9

Study Justification 10

2. REVIEW OF LITERATURE 12

Air Pollution Mitigation Strategies 12

Cost-Effectiveness Evidence of Air Pollution Interventions and Policies 17

Gaps in the Literature: Equity and Region . . . 23

3. STUDY 1 26

Rationale 26

Methods 27

Results 29

Conclusions and Limitations 40

4. STUDY 2 43

Rationale 43

Methods 46

Results 50

Conclusions and Limitations 55
5. STUDY 3 58
Rationale 58
Methods 63
Results 64
Conclusions and Limitations 79

6. DISCUSSION AND CONCLUSION 82
Contribution to the Literature 82
Limitations 84
Implications for Further Research 85
REFERENCES 86

List of Figures

Figure Page

1. Air Pollution as an Externality 3
2. CHIS Asthma Diagnosis by Region in 2021 . . . 9
3. Analytical Framework for Pollution Defensive Behaviors. . 16
4. Temporal Distribution of Pollutants Concentrations . . 31
5. Cost Typology for Asthma ED Visits and Hospitalizations . 48
6. General Health Status by Health States 70
7. Health Utility Curves by Health States 72

List of Tables

Table		Page
1.	Cost Effectiveness, Cost Utility, Cost Benefit Analyses Literature Review	167
2.	Characteristics of ED visits and Hospitalizations for Asthma	30
3.	Distribution of air pollutants from sampling stations	31
4.	Patient characteristics for exposure to highest pollutant concentration percentiles	32
5.	Single ozone pollutant exposure model	33
6.	Multi-pollutant ozone exposure model	34
7.	Single NO_2 pollutant exposure model	35
8.	Multi-pollutant NO_2 exposure model	37
9.	Single $PM_{2.5}$ pollutant exposure model	38
10.	Multi-pollutant $PM_{2.5}$ pollutant exposure model	39
11.	Cost of Illness Analyses Literature Review	188
12.	Health endpoints	46
13.	Economic values	49
14.	Attributable risk proportion	50
15.	Region population attributable fraction	51
16.	Region population exposed by county and criteria pollutant	51
17.	ED events attributed to pollutant background levels	52
18.	Hospitalizations attributed to pollutant background levels	53
19.	Health effects of per marginal reduction of pollution concentration	54
20.	Mitigation and exposure control measures and applications	59
21.	Demographic characteristics of survey participants	64
22.	Air quality information assessment by health status	67

23. Utility values by health status 70
24. Hybrid and electric car concerns rotated factor loadings . . 73
25. Effectiveness of organizations to improve air quality rotated factor loadings 73
26. Cost of policies and factors to consider rotated factor loadings 74
27. Mitigation and control policy statements rotated factor loadings 75
28. Persistence of poor air effects rotated factor loadings . . 76
29. Predictors of latent factors 77

Acknowledgements

This journey did not begin six years ago and as I went through it was not possible to wander without countless people who have protected, supported, and loved me in this lifetime. Some of you are now in Heaven and losing you during these years was earth shattering and remembering that you believed in me became an imperative to carry on.

I have profound gratitude to the members of my doctoral committee who have helped made possible, through trials and tribulations, this pilgrimage to become a researcher. Economists Dr. Paul Brown and Dr. Kurt Schnier, whose guidance ensured that I could do this work, and Dr. Ricardo Cisneros your friendship and encouragement gave me the answers to stay on the path. To my lab colleagues who are now lifelong friends.

My heartfelt thanks to my mentor in public health, and in life, Steve Debuskey. You taught me everything I know about public health without forgetting to defend my integrity, enjoy what I do while practicing with care and generosity. You will always be a role model, the perfect boss, and a father figure.

I also want to thank my public health siblings Erika Ireland and Terrance Tovar, and my guiding elders Lupe Tovar, Debbie Martinez, and Abraham Castaneda, once we were warriors. My spirit brothers Rufino Dominguez and Leoncio Vasquez, who believed and practiced in the leadership of Native women while calling me your hermanita. Beginning my career with you was the plan of the Universe for a clearsighted start.

Thank you to my sisters Gabriela and Gloria, and my brothers Gabriel, Croix, Ernesto, Alejandro, and Gilberto Jr., for all your encouragement and love. Also, to my precious nieces Mixtli and Amari, Gianna, Melanie and Angela, and beautiful nephews Luciano, Finn, Vaughn, Graysen, Izel, Jayden, and Gilbertito. You are my pride and all our future.

The person who never gave up on me when I felt mistrusted and misunderstood, my therapist. You helped me recognize my very heavy loads and made them lighter, thanks to you I gently unloaded some of them. Understanding and seeing me is a spiritual gift that at first meant survival and then helped me to thrive.

Most of all, I want to acknowledge my beloved Amigas and Comadres Nayamin, Edith, Erica and JJ, Yanela, Lily, Reinita, Lupita, and Rocio, the family I chose, who love me for who I truly am, held me, and kept me grounded when I questioned my life choices.

Last but never least, in fact the contrary, to my children and my husband. You make me so proud, and I hope you are content of the choice your mother made beginning anew to build an authentic and honest life. You may not have a lot of stuff but that of what matters you have plenty, and that is the kind of wealth that gives a life its purpose.

To all of you, and those whom I am forgetting, I am indebted and will live my life letting you know how much you mean to me. Whether is in person or in prayer, in lak'ech alak'in, All my relations.

Vita

Gilda Zarate-Gonzalez

1999	B.A. in Economics, Universidad de Guadalajara, Mexico.
2010	Master of Public Health Policy and Management, California State University, Fresno.
2021	Master of Science in Public Health Research, University of California, Merced.
2023	Doctor of Philosophy in Public Health and Health Economics, University of California, Merced.

Field of Study

Health Economics in Public Health, Advisor: Paul Brown, PhD

Publications

Zarate-Gonzalez, G., Brown, P., Cameron, L.D., Song, A.V. (2023*).* Will tobacco price increases lead more people who smoke to vape? The results from a discrete choice experiment amongst U.S. adults. *BMC Public Health* 23, 2296. https://doi.org/10.1186/s12889-023-17094-5

Zarate-Gonzalez, G. (2021). Understanding Smoking Preferences: Results from a Discrete Choice Experiment Amongst U.S. Adults. *UC Merced: School of Social Sciences, Humanities, and Arts*. Retrieved from https://escholarship.org/uc/item/5kr8m58x

Zarate-Gonzalez, G., Toor, I., Fabian, R. (2020) *Increased Risks and Crises in Trust: The Intersection for Smokers, Vapers and Cannabis Users in California During the COVID-19 Pandemic [Policy Brief]*. Merced, CA. https://ncpc.ucmerced.edu/resources/covid-19-tobacco-vaping.

Zarate-Gonzalez, G., Spezzano, T., Wright, T. (2020) *COVID-19 Non-Pharmacological Interventions Mitigation Summary [Research Brief]*. Merced, CA. https://trc.ucmerced.edu/sites/trc.ucmerced.edu/files/page/documents/uc_merced_covid19_mitigation_summary_april_23_2020.pdf. doi:10.1101/2020.03.03.20029843v3

Kwan, K., Do-Reynoso, V., **Zarate-Gonzalez, G**., & Goldman-Mellor, S. (2018). *Development and implementation of a community health survey for public health accreditation: Case study from a rural county in California*. Evaluation and program planning, 67, 47-52.

Zarate-Gonzalez, G. (2010) *Overweight and obesity factors for adults in the San Joaquin Valley, California: Data from the Behavioral Risk Factor Surveillance System (BRFSS), 2000-2005* (Master Thesis). California State University, Fresno. Fresno, CA.

Zarate-Gonzalez G., & Perez M. A. (2007) *Social Factors as Mediators of Public Health*. Salud Uninorte Journal. 23 (2): 193-203.

Presentations and Invited Lectures

Session Panelist (Presenter) Panel: New Evidence on Regulating E-Cigarettes, "Price Sensitivity and Cross Elasticities of Smokers and Vapers: Results from a Discrete Choice Experiment Amongst U.S. Adults". *American Society of Health Economists Annual Conference*, June 2021.

Poster (Presenter) "Will tobacco price increases lead more smokers to vape? Results from a discrete choice experiment amongst U.S. adults". *International Congress of Behavioural Medicine, Glasgow, UK*, June 2021.

Guest Lecturer, Future Trends in Health Promotion and Education: Discrete Choice Experiments. *UC Merced.* November 2019.

Guest Lecturer, Smoking Preferences of U.S. Adults: A Discrete Choice. UC Merced. May 2019.

Poster (not presenting), Community Health Assessment for Public Health Accreditation: Survey Development and Implementation in a Diverse, Low-Income County. *American Public Health Association Conference.* October 2016.

Workshop Facilitation, "Hispanic Roundtable" *California Speaks for Health Care Reform Conference*. December 2007.

Keynote Address, "Indigenous Youth in California*" See S'aavi Indigenous Youth Conference*. July 2004.

Abstract of Dissertation

The San Joaquin Valley (SJV) of California has been consistently identified as having one of the highest levels of air pollution in the US. Despite federal and state standards, the SJV has been in non-attainment status for daily $PM_{2.5}$ concentrations, extreme non-attainment for 8-hour O_3 levels, and in attainment for NO_2. Periods of pollution exposure are associated with increased health burden related to respiratory inflammation and undermined lung function, which aggravates respiratory diseases such as asthma and leads to symptoms such as coughing, wheezing, or difficulty breathing. Asthma costs US$ 82 billion annually in healthcare costs, missed work, and school in the U.S.

Combining public health and economics methods, a comprehensive study of the epidemiological burden, monetized cost, cost-utility analysis, and policy options was conducted to one of the region's most conspicuous and pervasive public health issue, air pollution. An epidemiological time-stratified case-crossover design was used to estimate the relationship between exposure to NO_2, O_3, $PM_{2.5}$ and adverse health outcomes in asthma and upper respiratory infections (URIs). This study compared pollutant exposure effects for each case during limited time intervals and adjusting for seasonality. Employing a societal perspective, a prevalence approach burden of disease design was combined with environmental epidemiological methods to analyze the economic impact of O_3, NO_2, and $PM_{2.5}$-related adverse health outcomes amongst SJV residents who attended the emergency room (ED) or were hospitalized in 2016. A cross-sectional online survey asked about self-protective behaviors, attitudes toward air pollution recommendations, air quality information knowledge, and mitigation behaviors, as well as whether their views are favorable or unfavorable. The EuroQOL-5D-3L instrument was utilized to assess differentials in health-related quality of life (HRQoL) distribution and favorability of policies.

The study found that elevated concentrations of three criteria outdoor air pollutants are associated with increased asthma and URI-related ED visits and hospitalizations in SJV for all ages. NO2 exposure increased the odds of having an ED visit by 2.4% in lag 1 (95% CI: 1.017, 1.031). Lags 2, 3, 4, 5, 7, 9, and 14 were statistically significant. O3 modestly increased the odds of ED visits by 0.3% (95% CI:1.000, 1.006) after immediate exposure in the warm season. In the cold season, PM2.5 estimates were significant for all lags except for lags 4 and 12. The two-week lag increased the odds by 28% (95% CI:1.218, 1.345) for ED visits, and 16.5% (95% CI:1.009, 1.345) increased odds of being hospitalized after cumulative exposure to PM2.5. Asthma exacerbations monetized value ranged from US$ 3,353 to US$ 5,003 per ED visit, and for hospital admissions US$ 2,584 per inpatient day for adults 65 years and older to US$ 3,023 per child. The estimated value to society in healthcare costs, productivity losses, school absences, and opportunity costs from air pollution adverse health outcomes totaled US$ 498,014,124 in ED visits and US$ 223,552,720 in hospital admissions for the SJV population in 2016. The marginal reduction per one unit measure in the background concentrations of pollutants would avert 21,786 ED adverse events and

19,328 hospitalizations from the health burden on the SJV population. A total of 310 adult residents of the SJV participated in the survey. The mean age for the participants was 42.90 (+/- 16.84), and 34% reported having been diagnosed with asthma by a healthcare practitioner. People with asthma reported the lowest HRQoL with a health utility of U=0.747, with the lowest health utility reported by people with 4 or more chronic conditions that are sensitive to air pollution. Latent factors reported by SJV residents were concern for charge, expense, and car attributes for their interest in adopting electric vehicles. A differential interest in the involvement of local and not-local organizations in regulating air quality for the region. Also concern with what are the costs of air pollution and who pays for that cost of transforming practices. Nevertheless, SJV residents support air pollution control and preservation of public space. In terms of individual factors, residents report persistence of adverse symptoms due to poor air quality, and having to adopt personal actions to protect themselves, their children, and elders from air pollution. Socio-economic variables (age, sex, income) are significant predictors of those factors, and political views such as left-wing ideologies predicted favorability for policies that charge polluters to clean the air, control air pollution emissions, preserves public space, and interventions that reduce air pollution health symptoms and eases the burden on health. This study found that right wing ideology was a negative predictor for EV charge, EV car attributes and having local organizations intervening in air pollution emission control.

This study provides new evidence about the effects of three criteria air pollutants and adverse health outcomes in the SJV region. Although, pollutant data from some rural population centers of the region were unavailable and that resulted in the exclusion of their residents' ED visits and hospitalizations, these findings demonstrate that air pollution is a negative externality that imposes substantial social, environmental, and healthcare costs on the SJV. The air quality regulatory and public health governing bodies should consider revisions to regional pollutant thresholds and local public health strategies to prevent adverse health outcomes during short and prolonged periods of air pollution exposure, by doing this, the region would avert significant adverse health outcomes realizing economic savings of reducing air pollution in the region. In terms of adoption of air pollution control initiatives, these results could help public health, regulators and decision-makers, and communities understand the reasons for differential responses to mitigation efforts and help develop recommendations for improving air quality that are more likely to be supported by SJV residents.

Chapter I.

Introduction

The substantial growth of human population, its resources use and demand, as well as advancements in technology have had significant adverse effects in the earth's atmosphere (Godish, 2014). Also known as "anthropogenic air pollutants", pollution produced and emitted onto the atmosphere by human activity is viewed as a serious public health and environmental problem (Kampa & Castanas, 2008).

The industrial revolution, which began its incipient stage in the late 18th century and culminated in the 19th century (Ashton, 1997), is credited for giving rise to contemporary atmospheric contamination (Hanlon, 2016). In 1948, residents of Donora, Pennsylvania were enveloped by a haze produced by the local steel and zinc smelters (US EPA, 2018), 14,000 experienced severe respiratory and cardiovascular problems, and 40 people perished (Brimblecombe, 1995). Four years later, in the United Kingdom (UK) 1952, smog containing sulfur dioxide, carbon dioxide and smoke particles, combined with a pervasive weather system that acted as a lid over the area, resulted in the deaths of 4,000-12,000 London residents from respiratory and cardiovascular causes, and 150,000 hospitalizations (Dawson, 2018).

Dr. G.B. Longstaff, a legislator of the London County Council, stated that *"the combination of fog and smoke had disastrous effects on human life ... [and] when the people of London knew what the cost in life and money was, they would be willing to do everything possible to stop the smoke nuisance"* (Bernstein, 1975). The human catastrophe in the UK led to the eventual creation of the first overarching federal legislation worldwide, the Clean Air Act (U.K. Parliament, 1956). This legislation was designed to impose strict controls on a declining industry and incentivize relocation to rural areas. Both industry and residents were also required to curb the use of coal for power and heating generation favoring alternative types of fuels, such as 'cleaner' coal, gas, and electricity (Brimblecombe, 2006).

Globally 3.5 million premature deaths in 2017 from lower respiratory infections, ischemic heart disease, chronic obstructive pulmonary disease, lung cancer, and stroke were attributable to ambient air pollution (Anenberg, Miller, Henze, & Minjares, 2019). The International Council for Cleaner Transportation (2019) has indicated that the concentrations of just two criteria pollutants in the atmosphere ($PM_{2.5}$ and ozone) resulted in 7.8 million years of life lost and approximately US$1 trillion in health damages for the year 2015 worldwide.

Substantial epidemiological evidence exists of the adverse health effects of air pollutants (American Thoracic Society, 1996). Since the time of the well documented smog-related disasters, the Ministry of Health in London found that the mortality correlation coefficients for smoke and sulfur dioxide were as high as 0.41 compared to 0.61 for overall deaths in the winter of 1958-1959 in Greater London (Martin, 1964).

Air pollution exposure is associated with elevated cardiorespiratory mortality rates (Ebenstein et al., 2015). Longitudinal studies have found positive associations between long term air pollutant exposures and myocardial infarction, lung cancer, kidney cancer and circulatory system diseases (Ali et al., 2018; Gandini et al., 2018). A recent study found that an increase deterioration in air quality is associated with increases in polyclinic attendance for upper respiratory tract infections, acute conjunctivitis, lung disease, asthma, bronchitis, emphysema, and pneumonia (Sheldon & Sankaran, 2017).

Worldwide, the concentrations of two criteria air pollutants, $PM_{2.5}$ and ozone, resulted in 7.8 million years of life lost (YLL) and approximately US$1 trillion in health damages (Anenberg et al., 2019; A. Gao et al., 2021). By 2050, global health-related costs from ozone exposure will be estimated to reach $580 billion (Selin et al., 2009). For Etchie et al. (2017), in just one region of India, economic losses due to PM2.5 pollution were valued at US$ 2.2 billion in 2013. NO_2 has been deemed the "most harmful" of all nitrogen oxide compounds that humans are exposed to daily (UN, 2021), and the National Health Service (NHS) of England has estimated that by 2025, NO_2 will cost US$ 3.29 billion in healthcare and social costs for childhood asthma, coronary heart disease, stroke, and lung cancer (Public Health England, 2018).

Economic View of Air Pollution

Health economics has been concerned with investigating the equilibrium "*between population and resources*" since its incipient application in broad public health and medicine (Mushkin, 1958). Mushkin tentatively defined health economics as a discipline in which the core issues are the allocation and balanced use of resources for the caring of ill persons and health promotion. The latter involving factors outside of the health market, such as housing, income, food, and recreation.

The environment and social context have not been extraneous matters to economists. For example, Alfred Marshall (1920) in the Principles of economics eloquently exhorts readers to examine the *"conditions on which depend health and strength, physical, mental and moral"*. , and it was clear that early attempts to quantify the costs of sickness, and determination of personal capital and social costs were not performed by economists, but rather health administrators in the health professions.

Virtually every human activity can potentially create pollution (Ali et al., 2018). Air pollution, from point sources (i.e. cars, trucks, agriculture, incinerators) and nonpoint sources (i.e. wildfires and forest fires) (Peterson et al., 2020), are contaminant byproducts, or tradeoffs, resulting from economic production and human activity and which enter the environment. From the health economics perspective, air pollution are externalities that impose negative social and environmental costs on society (Hensher, 2020).

Externalities can be both negative and positive. Air pollution is widely known as a negative externality (Klarl, 2016). Where consumers and producers pursue the

maximization of their own contentment by engaging in activities that could emit noxious contaminants at liberty; these will affect other consumers or producers who will not be compensated for this burden (Carande-Kulis, Getzen, & Thacker, 2007). This dynamic exchange of externalities are valued in utility by health economists and is based on Bentham and Hill's Utilitarianism Theory (Burns, 2005). Mathematically, the expected utility theory is used as the principle to analyze decisions that individuals make for market and nonmarket goods (P. M. Brown, Cameron, Wilkinson, & Taylor, 2020).

Based on this theory, air pollution is acknowledged as a market failure (Holcombe & Sobel, 2000; Neumayer, Plümper, & Barthel, 2014). The options to act on these imperfect conditions are: i) to be relieved by the market privately; and/or ii) the government must intervene to abate. Given this framework regulatory frameworks have been chief instruments for air pollution control, but both the health sector and individuals have endured the corollary of unmitigated bad air.

Carriazo (2016) illustrated a supply and demand analysis of a factory which producing goods generate smokestacks affecting the efficiency of the market outcome (see figure 1). In which Q_m and P_m reflects the market equilibrium when emissions are unregulated, and the producers received the total revenue of pollution and the victims of pollution assume all the costs. In this point the social costs (S') are larger than the private costs to the factory owners.

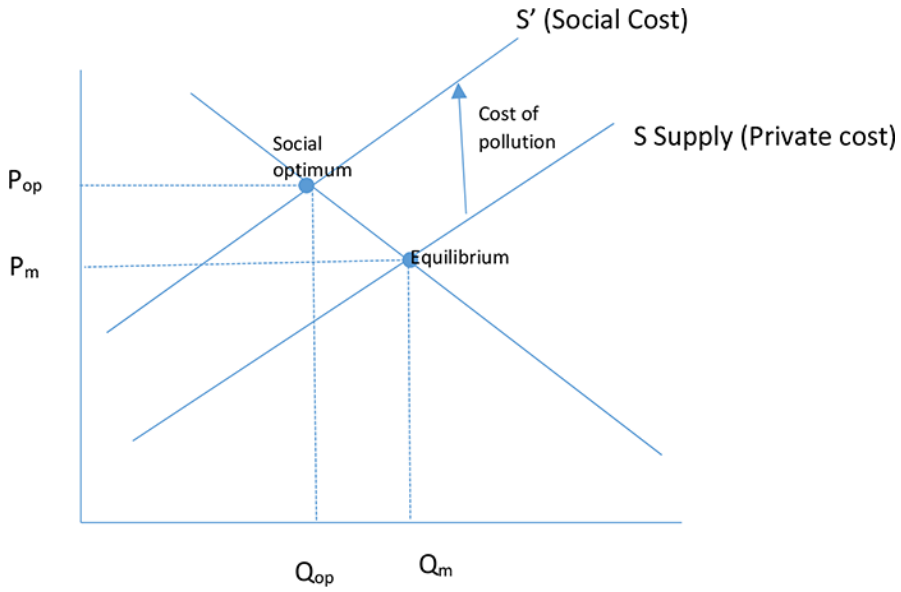


Figure 1. Air Pollution Externality

From the societal perspective if all the polluters are compelled to pay the entirety of social costs, the supply curve will shift upwards where the combination of Q_{op} and P_{op} is the social optimum and the externalities have been internalized.

Although there is a menu of economic instruments for air pollution control and those have been written about elsewhere (Klaassen & Forsund, 1994), there is a general consensus that air pollution is not created only by corporations and firms but individuals partake in the generation of this externality. Thus another role of economists is to participate in the formulation of policies and programs that induce behavior change. Brown, Cameron, Wilkinson, & Taylor, (2020) identify four economic approaches to change behavior based on normative economic theory: *"1) Provide information, 2) incentivize the desired behavior, 3) tax or subsidize the undesired behavior, or 4) impose regulations".* Furthermore, they advise about the field of behavioral economics which includes nudges.

Whether is at the macroeconomic (structural) or microeconomic (individual and household) level, the health economics offers a lens in which preferences of decision-makers, health outcomes, and health costs (Yazdi & Khanalizadeh, 2017) can be assessed to adopt cost-effective mitigation and control measures of air pollution and avoid ill health.

Air Pollution Pathway to Ill Health

Air pollution is a mix of gases and particles that can reach outdoor and indoor concentrations that are dangerous and harmful to human health (Godish, 2014). There is compelling scientific literature supporting that air pollutants have adverse health impacts in humans. The studies reviewed demonstrate the detrimental short- and long-term health effects of three underlined components of primary and secondary anthropogenic air pollution: nitrogen dioxide, particulate matter, and ground-level ozone.

Furthermore, scientific literature has demonstrated the detrimental effects on human health of primary and secondary anthropogenic ambient air pollution: nitrogen dioxide (NO_2), particulate matter ($PM_{2.5}$), and ground-level ozone (O_3) (Billionnet, Sherrill, & Annesi-Maesano, 2012; Kampa & Castanas, 2008; Kelly & Fussell, 2015). Children, adolescents, the elderly, and patients with cardiopulmonary diseases are particularly at risk of the deleterious effects of exposure to concentrations of criteria pollutants (American Lung Association, 2019; Landrigan et al., 2002).

Periods of pollution exposure are associated with increased health burden related to respiratory inflammation and undermined lung function, which aggravates respiratory diseases such as asthma and leads to symptoms such as coughing, wheezing, or difficulty breathing (Latza et al., 2009). Furthermore, the U.S. Environmental Protection Agency (EPA) has recognized that human exposure to air pollutants, such as particular matter and ground-level ozone, are likely causes of asthma and respiratory infections (EPA, 2019a).

Nitrogen Dioxide (NO_2) is one of a group of highly reactive gases known as oxides of nitrogen or nitrogen oxides (NO_x) (US EPA, 2018b). NO_2 reacts with other chemicals in the air to form ozone and particulate matter (Godish, 2014). Short periods of exposure can aggravate respiratory diseases such as asthma leading to symptoms such as

coughing, wheezing or difficulty breathing (Latza, Gerdes, & Baur, 2009). Children and the elderly are particularly at risk of the deleterious effects of exposure to high concentrations to nitrogen dioxide (Landrigan, Schechter, Lipton, Fahs, & Schwartz, 2002). Sources of nitrogen dioxide are related to the burning of fossil fuels from combustion engines, such as cars, trucks and power plants, and in California, the agricultural sector (Almaraz et al., 2018; US EPA, 2018b).

NO_2 can also react with water, oxygen and other chemicals in the atmosphere to form acid rain and its known for its yellowing hazy aspect when in high concentrations in the environment (Reding et al., 2015). In the SJV region the Air District Control has reported federal and state standards attainment status for nitrogen dioxide. The federal guidelines consists of 1-hour 100 parts-per-billion (ppb) and annual 53 ppb concentrations (SJV Air Pollution Control District, 2021).

For fine particulate matter - $PM_{2.5}$, the SJV region has been chronically classified as a nonattainment area for fine particular matter pollution since the 1997, 2006, and 2009 EPA National Ambient Air Quality Standards (NAAQS) reports (San Joaquin Valley Air Pollution District, 2019). Fine particulate matter (PM) are complex and varying mixtures suspended in the air that are composed of metals, organic compounds, material of biologic origin, ions, reactive gases, and the particle carbon core. $PM_{2.5}$ refers to its aerodynamic diameter smaller than 2.5 μm (Godish, 2014). At this size, $PM_{2.5}$ can penetrate the human lung deeply to irritate and corrode the alveolar wall, resulting in impaired lung function (Kelly & Fussell, 2015). PM2.5 is linked to asthma, respiratory inflammation, undermined lung function, and cancer promotion (Kampa & Castanas, 2008). Most susceptible to PM2.5 are the elderly, infants, adolescents, pregnant women, and patients with cardiopulmonary diseases (American Lung Association, 2019).

$PM_{2.5}$ is emitted through sources such as oil, gasoline, and diesel combustion. Wood burning, and domestic heating. Windblown dust from roadways, agriculture and construction (US EPA, 2018c). $PM_{2.5}$ has a seasonality profile, concentrations of are highest during the autumn and winter seasons (Cisneros et al., 2012). No evidence has been found of safe levels to particulate matter exposure for human health (Kelly & Fussell, 2015).

Ground-level ozone (O_3), also known as the ‘bad’ ozone (Canada, 2016; US EPA, 2018a), directly attacks lung tissue while chemically reacting with it (Y.-Y. Meng et al., 2010). Risk of premature death is increased when persons are exposed to higher levels of ozone (Romieu et al., 2012). Immediate problems with exposure are shortness of breath, asthma attacks, increased risk of respiratory infections and susceptibility to pulmonary inflammation resulting on excess emergency department visits (Gharibi et al., 2018) and hospitalizations. Individuals may be more reactive to ozone by breathing other pollutants (American Lung Association, 2018).

When sunlight is present volatile organic compounds (VOCs) and nitrogen oxides react to form ground-level ozone, sources include burning of oil, gasoline in cars and trucks, coal, chemical plants, and incinerators (EPA, 2018). With increasing climate

disruption and rising temperatures, increasing ground-level ozone days are projected (Shindell, 2002) . It is estimated that by 2050, global health-related costs from ozone exposure will reach $580 billion (Selin et al., 2009).

For the SJV area ground-level ozone is measured by two federal and state 8-hour standards at 0.070 parts-per-million (ppm). The SJV region has been a nonattainment area since 1997, but in 2019 the SJV region was reclassified to an extreme nonattainment area in the federal register (SJV Air Pollution Control District, 2016).

Pollution Control Policy Standing

In the United States (US) the Air Pollution Control Act was established in 1955 to launch air pollution research (EPA, 2017). In 1970, the Clean Air Act was the first legislation in the US authorizing the development of comprehensive federal and state regulations to limit emissions from industrial and mobile sources, as well as creating the National Ambient Air Quality Standards (NAAQS) and the National Emission Standards for Hazardous Air Pollutants (NESHAPs). In the same year, the Environmental Protection Agency (EPA) was established to consolidate environmental protection tasks: monitoring, research, setting of standards and regulations, and enforcement. Major cities, regions, and countries have moved towards regulation to impose air pollution controls to protect the health of their citizens and address anthropogenic sources (World Health Organization, 2017).

The U.S. EPA monitors and regulates over 189 hazardous contaminants including six criteria pollutants: ground-level ozone, particle pollution, carbon monoxide, sulfur dioxide, lead, and nitrogen dioxide (EPA, 2018). In spite of federal and state emission standards, the region has achieved attainment status for NO_2, and was classified a non-attainment area since 1997 for particulate matter (SJV Air Pollution Control District, 2021). In 2019, the EPA pronounced its decision to reclassify the SJV as an Extreme non-attainment area for 8-hour ozone in the federal register (EPA, 2019b).

Federal and State laws require emission control measures in areas where air pollution exceeds standards or non-attainment areas (US EPA, 2017). The San Joaquin Valley Air Pollution Control District is the public health entity entrusted to develop local plans and implement air pollution control measures. The SJV Air Pollution Control District is funded by DMV fees, stationary sources and permit fees, and federal/state grants and is governed by an appointed board made of elected officials and two public members appointed by the Governor (San Joaquin Valley Air Pollution District, 2019).

In the other hand, local county public health departments are also commissioned to protect the public's health, prevent illnesses, surveil, and respond to endemic factors that complicate the attainment of their constituency's full health. Several departments have found that their communities would like specific diseases, such asthma, and air pollution to be addressed in their action plans (FCDPH, 2013; MCDPH, 2019; TCHHSA, 2017).

The San Joaquin Valley Region and Asthma

The San Joaquin Valley region is in the heartland of California and comprised of eight counties: Kern, Tulare, Kings, Fresno, Madera, Merced, Stanislaus, and San Joaquin. The region is the home of approximately 4.3 million residents (PPIC, 2018).

There is evidence that the San Joaquin Valley (SJV) region is overburdened by both air pollution and related ill health. California's SJV is one of the most polluted regions in the U.S., exceeding state and national standards for ozone (O_3) and particulate matter ($PM_{2.5}$) (Barboza, 2013; Gharibi et al., 2018; Y.-Y. Meng et al., 2010). In 2022, the American Lung Association gave every major city in the SJV a failing grade -*F*- in their 'State of the Air' report for high ozone days, 24-hour particulate matter pollution, and annual particle pollution. Gharibi et al. (2018) found a positive association between ground-level ozone exposure and increased emergency department visits, especially in children 6-18 years old (OR: 1.219) and people of color (OR: 1.159).

The SJV is an air basin with unique topography, and meteorological conditions that combined with its arid and semi-arid geography, trap pollution emitted by sources, and gusted from contiguous regions (Schoups et al., 2005). Most recently, the region has added wildfires and forest fires to the top contributors of air pollutants in the region (Cisneros et al., 2017a). The Valley's economic engines are primarily agriculture and oil production, and given its location situated at the midpoint of two high population concentrations, the San Francisco Bay Area and Los Angeles (Jones et al., 2017), transportation is a considerable economic activity (Pat Brown Institute, 2014).

Despite existing conditions and knowledge, there is only one peer-reviewed study addressing the health burden and associated costs of air pollution specifically in the SJV region. The study was published in 2008. Hall, Brajer, & Lurmann (2008) conducted a study to measure the potential gains should the San Joaquin Valley region improve its air quality. The research estimated $PM_{2.5}$ and ozone health effects and costs for ED visits, hospital admissions, school absences, work loss days, and restricted activity days of asthma, bronchitis, respiratory symptoms, and premature mortality. They concluded that ozone-attributed health costs are $ 32.64 million per year, and $ 3,206 million per year are attributed to $PM_{2.5}$ exposures; effectively $1,000 per person in the Valley per year.

Asthma

Periods of pollution exposure are associated with increased health burden related to respiratory inflammation and undermined lung function, which aggravates respiratory diseases such as asthma and leads to symptoms such as coughing, wheezing, or difficulty breathing (Latza et al., 2009). Years of accumulating evidence supports that a significant contributor to asthma development (Holst et al., 2020; Thurston et al., 2020) and exacerbations (Guarnieri & Balmes, 2014). Children, adolescents, the elderly, and patients with cardiopulmonary diseases are particularly at risk of the deleterious effects of

exposure to concentrations of criteria pollutants (American Lung Association, 2019; Landrigan et al., 2002).

Asthma in children, adults and the elderly has been clinically defined elsewhere (Castro-Rodriguez, Forno, Rodriguez-Martinez, & Celedón, 2016; Chanez et al., 2007; Yáñez et al., 2014). Nonetheless, the American Thoracic Society recognizes outdoor air pollution as a critical trigger and irritant for asthma exacerbations, shortness of breath, and wheezing (Sockrider & Fussner, 2020). Furthermore, in 2019 the U.S. Environmental Protection Agency determined air pollutants (e.g. $PM_{2.5}$, NO_2, O_3) to be a likely cause of respiratory effects, such as asthma symptoms and exacerbations (EPA, 2019a).

In the U.S. asthma costs $82 billion annually in healthcare costs, missed work, and school absences (Nurmagambetov, Kuwahara, & Garbe, 2018). In other developed countries respiratory diseases account for 52 million DALY losses per year, a conservatively estimated value of $317 billion in healthcare costs, lost productivity, and disability (World Health Organization, 2016).

Studies conducted in the SJV region have found a positive association between short-term multi-day ground-level ozone exposure and increased emergency department visits for asthma during the warm season (Entwistle et al., 2019b), especially in children 6-18 years old (OR: 1.219) and people of color (OR: 1.159) (Gharibi et al., 2018). In addition, short-term exposure to NO_2 was linked to visits to the emergency room due to asthma during the cold season for residents of the SJV (Cisneros et al., 2021). These studies provide mounting evidence that exposure to prevalent ambient air pollution in the SJV is associated to detrimental health outcomes in respiratory health.

The prevalence of asthma has been increasing worldwide. Asthma is a chronic pulmonary disease and depending on its severity contributes to significant morbidity and mortality (Carr & Bleecker, 2016). Asthma induces inflammation of the airways in which individuals experience cough, wheezing, chest tightness, and dyspnea due to airflow obstruction. If asthma is not well managed it could lead to pulmonary fibrogenesis and airway remodeling (Del Rio et al., 2022; Savin, Markov, Zenkova, & Sen'kova, 2022).

Asthma is a ubiquitous public health issue in the San Joaquin Valley (SJV). In 2003, it was reported that 10.7% of the region's population reported asthma symptoms, one of the highest rates in California (Meng, Babey, Malcolm, Brown, & Chawla, 2003). The most recent California Health Interview Survey (UCLA Center for Health Policy Research, 2021) estimates that the prevalence of diagnosed asthma in the Valley is 17.1% for all age groups, compared to 16.6% in Bay area counties and 13.9% in Los Angeles County (see figure 2).

Figure 2. 2021 California Health Interview Survey Asthma Diagnoses per Region

Ever diagnosed with asthma	Bay Area Counties	San Joaquin Valley	Los Angeles County	All
Has asthma	16.6% (15.3 - 17.8) 1,237,000	17.1% (15.4 - 18.8) 705,000	13.9% (12.8 - 15.0) 1,360,000	**15.4%** **(14.7 - 16.2)** **3,302,000**
Does not have asthma	83.4% (82.2 - 84.7) 6,231,000	82.9% (81.2 - 84.6) 3,423,000	86.1% (85.0 - 87.2) 8,418,000	**84.6%** **(83.8 - 85.3)** **18,073,000**
Total	**100.0%** **7,468,000**	**100.0%** **4,128,000**	**100.0%** **9,779,000**	**100.0%** **21,375,000**

Nevertheless, the SJV substantially differs in topography, persistent air pollution levels, and demographics from the countries and regions in which those studies were conducted. Considered one of the most polluted region's in the United States (American Lung Association, 2019, 2022; Y.-Y. Meng et al., 2010; K. M. Zhang et al., 2005), several studies, conducted in the Valley, have found increased likelihood for emergency room visits and asthma events due to ground-level ozone (O_3) and nitrogen dioxide (NO_2) among SJV residents (Cisneros et al., 2021; Entwistle et al., 2019a; Gharibi et al., 2018).

Aims and Research Questions

The aim of this study is to combine public health and economic methods into a comprehensive approach to evaluate health from the epidemiological perspective of the exposure assessment, to assessing the burden of disease and economic costs of air pollution related asthma and upper respiratory infections and identify factors that predict support for public health air pollution control and mitigation efforts.

Dissertation Research Central Question: What are the health and economic costs of air pollution related asthma and upper respiratory illnesses (URIs) in the San Joaquin Valley?

The specific research questions of this work are:

I. Do SJV residents exposed to higher concentrations of NO_2, $PM_{2.5}$ and O_3 have increased odds of having a visit to the emergency department and hospitalizations for asthma and upper respiratory complications within 14 days of exposure.

II. What are the asthma and URI direct and indirect health costs of SJV residents exposed to higher concentrations of NO_2, $PM_{2.5}$, and O_3?

III. What is the effect of reducing pollution concentrations of O_3, NO_2 and $PM_{2.5}$ in the attributable cases of asthma and URI ED visits and hospitalizations?

IV. Are there differences in air pollution-related quality of life for SJV residents with asthma and other air pollution-sensitive chronic conditions?

V. Do SJV residents with asthma and chronic diseases report different air quality-related costs and mitigation policy favorability compared to SJV residents without asthma and chronic diseases?

Research Study Justification

To answer the aforementioned inquiry, this work follows the logical progression in three research studies:

Study 1. This study will determine if elevated concentrations of three criteria air pollutants (NO_2, $PM_{2.5}$, O_3) are associated with increases in the number of asthma and URIs-related ED visits and hospitalizations in the SJV for all ages.

Study 2. This study will estimate air pollution-related asthma and URIs-related health costs for the SJV population using cost of illness (COI) economic evaluation methodology.

Study 3. This study will assess the distribution equity of health utility values of the health impacts of air pollution for SJV residents.

First, this study is an epidemiological examination of the transient effects of three criteria air pollutants on health endpoints: asthma and upper respiratory infections (URIs). Ground-level ozone and $PM_{2.5}$ are interrogated to assess its effects in asthma and upper respiratory morbidity given the region's endemic standing on Extreme nonattainment and nonattainment status. NO_2 is included to investigate if within emissions attainment stage, short-term adverse outcomes are associated with the pollutant reported levels. This epidemiological study employs reported 2016 linked emergency department (ED) and hospital discharge data from HCAI, formerly known as the Office of Statewide Health Planning and Development (OSHPD).

Second, employing a societal perspective, a cost-of-illness (COI) study was employed to analyze the economic impact (CDC, 2017; Jo, 2014) of air pollution-related adverse health outcomes, asthma and upper respiratory infections, amongst SJV residents who attended the ED and were hospitalized in 2016.

And third, evidence is needed to understand a) support among residents in the SJV region, and b) prediction and variation by socioeconomic and other factors. This research examines support for interventions and policies aimed at reducing exposure to air pollution by SJV residents. These findings were used to model health utilities by health states from three types of interventions: i) clinical and behavior change

interventions targeting high-risk individuals, ii) household-level interventions aimed at reducing the impacts from air pollution in their living space, and iii) community-level interventions aimed at reducing unhealthy air quality in the region.

In aggregate, these studies will identify health equity distributive factors and acceptance of options for mitigating the health impacts of three criteria air pollutants: nitrogen dioxide (NO_2), $PM_{2.5}$, and ground-level ozone related asthma and upper respiratory infections in the SJV for the year 2016.

Chapter II.

Review of Literature

Episodes of high air pollution compel public health agencies to propose and recommend policies and interventions that could reduce the risk of acute harm to human health. Since the preceding Clean Air Act's seminal report "Restoring the Quality of our Environment" (Presidential Science Advisory Committee, 1965), institutions such as the EPA have regulated emissions aimed at protecting health and the economy.

Although these policies have not lacked substantial criticism, measures like the catalytic converter in the 1960's and pivotal updates to the Act in the 1990's (EPA, 1990) have been deliberated and implemented to address environmental concerns such as acid rain, toxic air emissions, stratospheric ozone depletion, and address the effects of urban air pollution and haze.

These environmental efforts to regulate air quality have been evaluated and found to have an economic value of $2 trillion, since inception until 2020, in air quality improvements hence supporting that its benefits to outweigh its costs (McCarthy, 2019). The Office of Management and Budget estimated in 2018 that the ranges of costs in the Obama Presidential era for environmental protection policies were between $88 and $598 billion, while its benefits were between $219 and $695 billion in 2001 USD (OMB, 2018).

Despite implementation of structural policies and regulations to curb toxic air emissions there is evidence that our societies have a lot more work to do to improve outdoor air pollution-related ill health. Furthermore, climate change has imposed new challenges to decreasing the burden of disease from air pollution, and long-standing environmental injustices have created inequities in the distribution of both bad air and access to mitigation measures.

More research is needed to study how different mitigation strategies and efforts could play a role in complementing existing regulations to continue reducing air pollution emissions and increase the efficiency of public health protections in the long-term and considering compounding crises.

Air Pollution Mitigation Strategies

Sofia, Gioiella, Lotrecchiano, & Giuliano (2020) compiled a list or approaches in three fields of application: i) final stakeholders, ii) emission sources, and iii) of the field of implementation. The authors recommend that citizens can mitigate the air pollution problem through behavioral changes by reducing their energy consumption using public and active transportation, in their household by changing to more efficient burning fuels for heating and investing in internal climatization, such as painting outer walls in lighter colors, and adopt a diet that increases the intake of antioxidants, low in animal sources, to decrease the potential for injury to the respiratory system. Their suggestions for large, medium, and small companies in the industrial, agriculture, and shipping sectors include improvements of the efficiency of stock farming and manure management, and electrification of ports. For the industrial and manufacturing sector reduction of fossil

fuels for power generation is recommended, as well as changes in average working hours (working hours, telecommuting, etc) to avoid congestion, and reduce travel times. For the agriculture and food sector better livestock management and waste is proposed. These changes would reduce NH_3 from entering the atmosphere and is a primary formation component for some criteria pollutants such as NO_2. The authors also suggest supporting local farmers' markets and community gardens to reduce produce travel times. This paper compels the movement towards a framework of *"preventive approach to the emergency" (p.19230),* which entails monitor and sensor networks that reflect spatial and temporal pollutant levels and appropriate measures are applied when levels of pollutants reach thresholds of safety and thus protect the health of the citizens of those areas. Because traffic congestion may follow a time and period pattern, the researchers suggest the design of *"smart city" (p. 19231),* to reduce traffic by planning urban context with smart mobility including supporting public transportation, increase bicycle lanes and safety, and access to pedestrians. Lastly, the authors encourage the mobilization of hybrid vehicles adoption via tax incentives and lower prices, as well as laws to encourage zero-emissions and electric mobility.

In their paper, Carlsten, Salvi, Wong, & Chung (2020) summarize advice for the public, providers and patients to minimize the effects on respiratory health from air pollution. From their perspective the central point is that individuals can make personal choices to reduce their exposure to air pollution taking advantage on an increase global awareness of rising air pollution. Through a literature search from year 2013 and 2019, the authors first recommend using close-fitting N95 facemasks when air pollution exceeds recommended levels, however their findings indicate that the mask comfort and acceptability are essential for its "effectiveness" to properly filtrate pollutants. In regards of transportation, the authors identify that persons could switch from motorized to active transportation, such as walking or cycling, and that local agencies should prioritize infrastructure to support these modes of transport. The third recommendation is to choose routes to minimize near-road air pollution exposure and give preference to low-traffic areas and spaces, this is accompanied by decreasing traveling during peak times, and avoid delays in areas of high air pollution. To further their recommendations on transport, when a person must drive, it is suggested to drive with windows closed and maintain car air filtration, and also to avoid engine idling. Recommendation to regularly exercise but moderate physical activity when air pollution levels are high is included. Moreover, checking local air pollution levels in the 6th suggestion from the authors. At the household-level, the researchers suggest using clean fuels and ventilate the home where is possible during cooking or heating, as well as the combining the use of portable air cleaners to reduce indoor pollution. The authors also document that the effective management of respiratory and cardiopulmonary diseases will reduce the overall burden of air pollution as well as a modified diet which include antioxidants and anti-inflammatory agents.

The World Health Organization issued a report to summarize personal interventions for air pollution (WHO, 2020). In their report WHO's scientific panel discusses emission control sources nevertheless their foci were on creating communication strategies on personal interventions related to toxic air exposure. They emphasized that risk communication should make particularly distinction for populations

with modified associations between exposure to air pollutants, such as those with increased *susceptibility* and those with increased *vulnerability*. The panel reviewed evidence on staying indoors, avoid highly polluted places, and reduce physical activity when elevations of air pollution trigger health agencies' alerts and suggest that more evidence is needed to measure the consequences of exposure for groups at risk, and in low and middle-income countries because some of the research has been performed in high income populations. Their evidence also suggest that air filters can reduce the indoor pollution concentrations resulting from outdoor bad air but in different degrees. Lastly, respirators as opposed to surgical masks and cloth masks have been found to have the greater efficacy to protect for ambient air pollution, however five factors (fitting and use adequacy) must be incorporated to maximize efficacy.

Examining interventions against outdoor and indoor air pollution, a review of the most recent (2017 and beyond) peer-reviewed literature the research by Allen & Barn (2020) summarizes individual and household level strategies into three categories: air purifiers, facemasks, and behavior change. The authors found that consistent use of high-efficiency particulate air arresting (HEPA) filter, HVAC and portable, air purifiers can reduce indoor $PM_{2.5}$ concentrations and improve systolic blood pressure, endothelial function, and systemic inflammation. Specifically, a study in Beijing, the study found that portable HEPA filters 2-week use reduced $PM_{2.5}$ concentrations from 60 to 24 $\mu g/m^3$ in nonsmoking seniors' homes. Another study among healthy young adults, portable air filters reduced an average of particulate matter concentrations from 47 to 9 $\mu g/m^3$ in their college dormitories. Along with lowering particulates, the researchers reported improvements in their blood pressure, insulin resistance, oxidative stress, inflammation, and stress hormones over 9 days of use. Comparable protective effects were found from well-fitted N95 masks and respirators but evidence for other types of masks was limited. A randomized controlled trial was included in this paper conducted in Mongolia, which is a largely polluted area. Their research aimed to assessing the effectiveness of HEPA filter air purifiers use during pregnancy on fetal growth and childhood development. The study found that air purifiers changed concentrations of $PM_{2.5}$ from 25 to 17 $\mu g/m^3$ (29%) and that the greatest efficiency of portable air purifiers was shown at the beginning of their use compared to after five months of use. Overall, the intervention let to an increase in mean term birth weight of 85g at 95% level of confidence with a wide interval of 3 to 167 grams. This paper also reports two recent studies conducted in Detroit and Beijing have found limited merits of HEPA filters to limit average personal exposures, however these findings do not include time spent indoors for the participants or are attributed to movement to other household microenvironments, or other environments. When it comes to behavior changes, the study assessed available literature on staying indoors and closing windows, travel modes and routes, and vehicle ventilation and filtration. The paper found that studies looking at the most typical advice from public health agencies to protect people from high air pollution events is to stay indoors and keep windows closed. Only two studies investigated this claim and reported that when this occurred indoor $PM_{2.5}$ concentrations had little effect, unless closing windows was accompanied by turning on air conditioners; markers for inflammation oxidative stress and systemic inflammation decreased in the latter intervention. In an Australian community impacted by prescribed burns and bushfires, seven homes were monitored, and particulate matter concentrations

were reduced by 12 to 76% when windows and closed were closed, but that after the smoke events, $PM_{2.5}$ indoors had increased signaling of the particulates remaining trapped when the event ended. This suggestive potential from buildings is to be balanced relative to other factors of indoor sources such as physical activity, cooking and heating. In Beijing, authors found that just designing airtight buildings without proper mechanical ventilation and filtration systems would be problematic and lead to higher pollutant concentrations. It has been suggested that traveling through areas with less pollution will yield reductions in exposure to air pollutants for travelers and commuters, the researchers even mentioned online tools to help them select alternate routes to their destinations. However, the findings indicated that active commuters had higher inhaled doses due to longer trip durations, but that physically active people may still gain from the increased health benefits of engaging in an active lifestyle. The findings are mixed on benefits of walking and cycling as means to reduce exposure because studies have not been randomized and routes have not been uniformed. Some studies have found that the changes in air pollution exposures are related to concentrations of black carbon and carbon monoxide rather than $PM_{2.5}$. Lastly, the review found that using high efficiency cabin filters in vehicles with windows closed reduced mean ultrafine (47%) and particulate matter (37%) concentrations but did not change oxidative stress indicators. Moreover, one piece of evidence mentions when trying to avoid $PM_{2.5}$ exposure there are tradeoffs between closing windows and recirculating cabin air, since in long-distance trips and multiple passengers CO_2 exceeded thresholds found to impair mental performance.

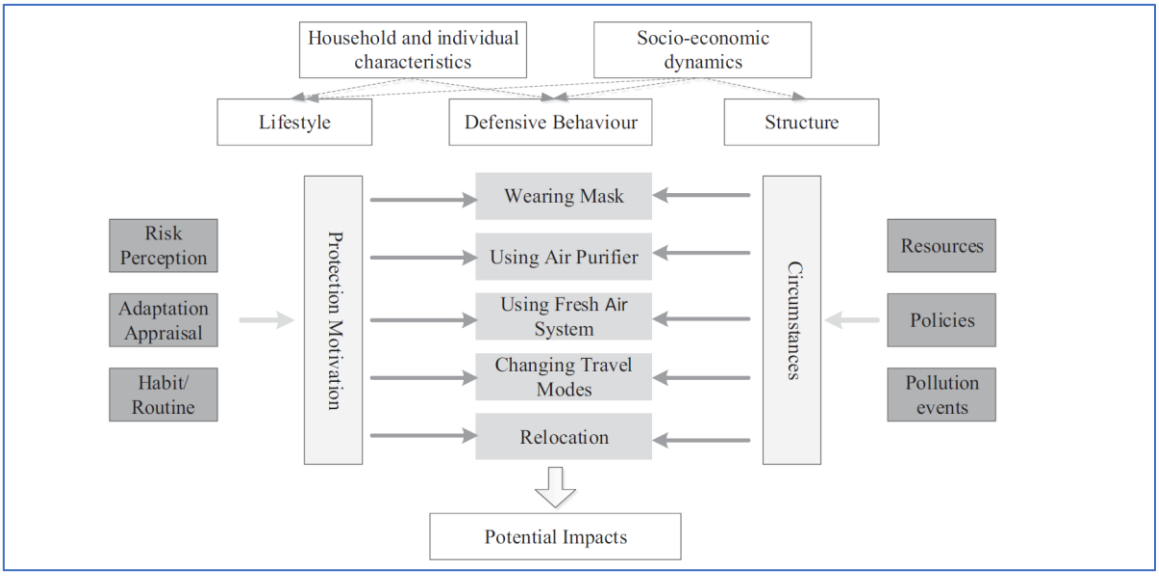
James et al. (2019) studied the impact of HEPA filtration from traffic emissions and effects on children 10 to 16 years of age with asthma using a double-blind placebo-controlled cross over design and measuring control of asthma and quality of life. HEPA filtration systems were placed in the participants' bedrooms in the greater Cincinnati area for 4 weeks, and then switched after an additional month to the other arm of the study which consisted in a sham HEPA air cleaner. Forty-four children participated in the study and were randomly assigned to either arm. Their findings suggest that median indoor concentrations of outdoor vehicle-related particles, $PM_{2.5}$ and black carbon, was reduced with the HEPA filters relative to the dummy treatment of sham filters and that participants with baseline measures of poor asthma control (ACQ 1.3 to 0.9) and impaired quality of life (AQLQ 4.9 to 5.5) were improved after the treatment. Highest improvements in asthma control scores were for males who lived in a home were nonsmoking is present, use inhaled corticosteroids and no allergy medication.

A study in Fresno, California (Park, Cheng, Tetteh, Hildemann, & Nadeau, 2017) researched the effectiveness of air purifiers on health outcomes for children 6 to 18 years of age with allergic diseases, and indoor particles. The authors included a total of 16 children and randomly placed 8 children in the intervention group which consisted in placing air purifiers in their living room and bedrooms, the other children were placed in the control group and were not provided air purifiers. Purifiers were on continuously for the duration of the 12-week trial period (April – July 2015), air filters were replaced at week 6. All houses had whole-house air conditioning units. The results showed a decrease in cACT scores and peak flow in the group of children assigned to the intervention compared to the control group, as well as nasal symptoms. Furthermore, the

average $PM_{2.5}$ concentration in the active group was reduced from 7.42 $\mu g/m^3$ at week 0 to 4.76 $\mu g/m^3$ at week 6, and 4.28 $\mu g/m^3$ at week 12, which represents a 43% reduction. The study also reports the average energy consumption of the air purifiers in the active group which varied from 68.65kWh and 68.53kWh depending on the unit's model. There are no reports of what the relationship of this cost relative to the household income in this study is, and socioeconomic data is not reported, as well as location of the households within the most polluted city in the U.S. for particulate matter.

Liu, Du, Chu, & Wang (2021) explored the notion of "inverted quarantines" which are individual-initiated defensive behaviors to self-protect from air pollution. Per the authors *"inverted quarantine explains how healthy individuals isolate themselves from their disease-inducing surroundings by erecting barriers or enclosures and withdrawing behind or inside them"* and it was first proposed by Andrew Szasz (2007) in his book "Shopping our way to safety: How we changed from protecting the environment to protecting ourselves". This study provides an analytical framework (Figure 3) to understand and evaluate five adaptive behaviors at the core which individuals may adopt to protect themselves from pollutants in ambient environments. The authors state that the field lacks systematic awareness on how individuals adjust their behaviors when they are concerned with health threats associated with severe air pollution, and which mechanisms

Figure 3. Analytical Framework for Pollution Defensive Behaviors by Liu, Du, Chu et al.



motivate these responses and changes. Their research applied the revised framework of the *Protection Motivation Theory*, which includes self-efficacy and response costs, and has been used to address natural phenomena and climate change. Thus, by conducting a survey in 2018, they found that residents in China (N=1,723) use a wide array of avoidance behaviors and often in combination, whereas 29% of the sample did not adopt any protective measures. Facemasks were the most widely used protective measure to combat air pollution (69%), 11% said that they combined masks and air purifiers to

protect the members of their household, and 6% combined masks with fresh air systems. The authors found that the preferences of individuals were associated with their perceptions of those measures' costs, being that masks were both the least expensive and the most widely adopted. The sample was divided into low, medium, and high-income groups and found that the medium income group included fewer residents that do not use any protective measures, and the high-income group had fewer people who only used masks to defend themselves from air pollution and had the largest proportion of people who used combined masks, air purifiers and home fresh air systems. Using an econometric model, individual's concern with air pollution was significantly correlated with household expenditure on protective measures, suggesting that knowledge may encourage the use of pollution avoidance behavior. Household income, education, elderly members in the household, and allergy history were associated with the adoption of air purifiers and fresh air systems, as opposed to lower cost masks. Children in the household was not significant in the family's adoption and purchase of air purifiers and fresh air systems. In addition, residents with lower confidence in their government adopted more defensive behaviors, and city-level air quality, measured by AQI, was correlated with the adoption of air purifiers and fresh air systems. The latter finding is explained by the authors because residents may perceive that their local-level circumstances affect their ability to avoid pollution. Lastly, the study reports that the average increase in electricity consumption due to the use of air purifiers and fresh air systems was in the range of 3.7% to 5.2% per capita.

In conclusion, there is general acceptance by researchers that the evidence evaluating the effectiveness of routinely suggested individual, household, and behavior change strategies is yet *'surprisingly'* limited. In this body of research is suggested to further, *carefully designed*, research studies in this area. Most studies make emphasis on the need for inclusion of diverse communities, including willingness to pay, the acceptance (short term and long term) and availability of the suggested exposure reduction approaches, and particularly measuring effects on health.

Ostensibly, climate change is poised to increase the relative impact of outdoor air pollution in human health and although there is no substitute for macrolevel environmental protection regulations to control sources and quantity of emissions, these policies tend to attain benefits in the long-term. Public health research has a lot more to do in the expedient evaluation of approaches to protect health in the short- and mid-term. Furthermore, these are timely observations particularly for areas of the country enduring ubiquitous bad air, and where, as of lately, have endured additional events of high pollution, such as forest fires.

Cost effectiveness Evidence of Air Pollution Interventions and Policies

Cost Effectiveness, Cost Utility, and Cost Benefit Analyses

A scoping literature review of articles published was chosen as an appropriate approach for this examination of available scientific studies. The intent of this approach is to provide a description of the available evidence rather than provide a critical evaluation of the quality of evidence.

There was no year or date restrictions to identify published articles. The Pubmed online catalog, EconLit, and Google scholar databases were used to conduct the search. The following key terms were included in the first search “cost effectiveness” “cost utility” “cost benefit” and “outdoor air pollution” and “mitigation” and “control” and “qaly” and “daly” and “icer”. A total of nine published articles were listed in Pubmed; one study in EconLit; and three hundred and forty and four in Google scholar.

A total of 353 journal articles were identified for the initial review. To be included in the review, articles had to be published in English, Spanish or Portuguese given the linguistic ability of the researcher. Most of the articles resulting from the search included research conducted in diverse countries such as the US, Canada, Europe, Asia, and the Middle East. Articles that have different titles but were duplicates (5) were removed, forty-six articles were removed after reviewing the abstract and title. Additionally, 32 studies were removed for not including ambient or outdoor air pollution or to not be related to human health (health or clinical endpoints), referring to tobacco smoking related disease, tuberculosis, lacking air pollution modeling, not including economic evaluation, and monetizing treatment of outdoor air pollution. A total of 85 studies were reviewed by abstract to include specific cost and human health-related measures that can be analyzed and included in this review.

Studies that presented plausible economic evaluation methodology to analyze the relationships between costs and health outcomes related to the effects of outdoor air pollution were selected for the final review. A summary of each article identifying authors, year, location, study type, methods, population characteristics, cost and outcome measures, and findings is included in Table 1.

Findings

In a study conducted in Northern California among pear packers (Chang, Zivin, Gross, & Neidell, 2016) researchers aimed at estimating marginal product of labor by determining costs and productivity from fine particulate matter in a single packing house. Using payroll records from 2001, 2002 and 2003 seasons, the study found that an increase of 10 $\mu g/m^3$ in $PM_{2.5}$ pollution reduced productivity of workers by $0.41 per hour, or 6% of average hourly earnings. The authors examined different productivity loss events of indoor pollution and found that potential threshold effect is present when $PM_{2.5}$ exceeds 15 $\mu g/m^3$. However, loss of productivity occurred at pollution levels well below current national ambient air quality standards (NAAQS).

Neighborhood Slow Zones (NSZs) are defined as areas where speed is determined at 20 miles per hour (mph). Evidence is well established for their reduction of traffic crashes and encourage active transportation, thus potentially reducing air pollution. Jiao et al., (2019) studied New York City crash data from 2009 – 2016 for fatal and nonfatal injuries. The researchers selected control neighborhoods for each NSZs and evaluated health outcomes and costs pre-intervention and post to measure their cost-effectiveness. Their findings indicated that road casualties fell by 8.74% in the case NSZs but increased in the control neighborhoods. Injury costs outweighed intervention costs, with a net savings of $15 per resident and a gain of 0.002 of QALY over the lifetime of the average

NSZ resident. There was a 97.7% chance of NSZs being cost-effective if $50,000 per QALY gain threshold was chosen.

An article by Griffin et al. (2020), the cost-effectiveness of low emissions zones, which are defined as reductions of NO_2 and $PM_{2.5}$ emissions. This study was conducted in one of England's most polluted areas, West Yorkshire. Utilizing NHS healthcare use data from 2010 – 2014 and a list of emission-reduction strategies estimated costs in UK£, as well as healthcare expenses and opportunity costs from all CHD mortality events, chronic bronchitis, asthma, preterm and low-weight births. QALYs were estimated and the threshold was a consumption value of at least £16,895 per QALY in order to select a particular low emission reduction strategy (return to petrol over diesel) over another (update all vans to Euro VI standards) relative to their impact on economic activity and health. The authors did not recommend having a societal perspective due to multiple stakeholders and budgets. One unique aspect of this study was the construction of *deprived* health inequality geographical areas using the index of multiple deprivation in terms of socioeconomic factors. These areas were evaluated in terms of QALE or Quality Adjusted Life Expectancy. The inclusion of these areas in the analysis significantly affected prioritization of strategies towards less population health but towards increasing attention on social welfare from reducing inequality in health.

Cost-benefit of the policy to reduce emissions from small coal plants in China (J. Gao et al., 2016). Their study demonstrated that these policies are economically feasible, and the estimated benefit-cost ratio is 6.32. The costs were calculated with equations which included the elimination of small coal boilers that produce energy plus regressive productivity, as well as the costs to mitigate different pollutants at macrolevel. Health benefits comprised of averted excess deaths and the mean number of life years lost due to excess deaths (18 mean average). Total cost and total benefit are 118.39 and 748.15 billion Yuan. The emission-reduction potential of energy- saving policy is greater than that of emission-reduction policy. Furthermore, the study found that there are regional disparities of the benefit-cost ratios of implementing these policies.

Janke (2014) analyzed the cost-benefit of air pollution warnings using a *"simple"* method. The health effects of NO_2 and O_3, were included in the benefits for averted burden of asthma and respiratory infections in children aged 5-19 in 89 local authorities in England. The costs of producing the air pollution forecasts were equivalent to 500,000 British pounds for the period from 2003 – 2007. The proxy for avoidance behavior due to the air pollution event forecasts and accounted for visits to an outdoor attraction by two groups, children with asthma and children without asthma. The incidence was obtained from local authority NHS data. Their findings concluded that the direct effect of an air pollution warning was 8% in asthma admissions and found evidence of avoidance behavior. The conclusion is that for families with children with asthma the cost of avoidance is low because sufficient response to air pollution warnings is adjusting the dose of their reliever medicine and making sure they carry their inhaler.

A cost-effectiveness analysis of indoor portable air purifiers was conducted by Y. Liu et al. (2021) relative to fine particulate matter. The costs included initial market price for air purifiers, electricity use, and price of filters. In the benefits section, attributable avoidable number of $PM_{2.5}$ related deaths using the value of a statistic life (VSL) were included. Their findings show that deaths attributable to $PM_{2.5}$ decreased by 30% if

indoor concentrations are reduced to 10 $\mu g/m^3$ or lower concentrations using air purifiers. Four different scenarios at total annual costs of using purifiers were 82, 175, 438, 798 billion Chinese Yuan (RMB). Costs were highest in provinces with largest benefits, also relative costs to the proportion of per capita disposable income. This can be demonstrated by the following, in cities with highest per capita annual, costs are 11.2% of local income at 1800 RMB, whereas those cities with the highest relative cost were 13.7% of local income or 1300 RMB in absolute terms. Also, costs varied across cities with low, moderate, and high outdoor $PM_{2.5}$ levels.

In this review the only clinical intervention included in the literature search is the peer reviewed study by Mohammadi et al. (2021). Using a cost-utility analysis, Canadian researchers used British Columbia asthma data converted into 2018 Canadian dollars to compare three different strategies: i) no preventive intervention, ii) preventive health strategy based on information from genotype testing followed with treating high risk patients, and iii) standard prescriptions to all patients with mild asthma. The researchers did not conduct an exposure assessment and claim the increased risks of recent forest fires in the area, particularly for patients with asthma. The costs included exacerbation and hospitalizations and emergency department use from previous studies, and the benefits were measured in terms of change in QALY losses using probabilistic analysis. The study concluded that precision health intervention is cost-effective compared with no intervention. Incorporation of genomic testing to stratify risk of asthmatics to pollution-driven exacerbations and tailoring a preventive intervention accordingly may be cost-effective relative to untailored methods. Comparing no intervention with targeted therapy shows that using a preventive intervention only for the estimated patients with genetic abnormality is expected to cost more than no intervention ($150.5 versus $42) but it yields QALY gains (decrease in QALY loss from 0.0024 to 0.00021). The incremental cost-effectiveness ratio (ICER) was $49 555 per QALY. At a willingness-to-pay threshold of $50 000 per QALY, the personalized intervention is considered cost-effective. Also, projected that 27 093 extra pollution-induced exacerbations can be avoided in 1 year by using additional medication as a preventive intervention.

Levy et al. (2001) investigated the potential health benefits of hypothetical reductions of ground-level ozone in the United States. Using costs from literature driven willingness-to-pay from ozone emissions, benefits were avoided premature mortality, chronic asthma, respiratory hospital admissions, and minor restricted activity days on a projected at-risk population of 345 million. Their findings included a central estimate 1 $\mu g/m^3$ decrease in annual average ozone concentrations would have an annual benefit of $10 per individual and 90% of this effect is related to premature mortality. Also, the estimated average length of life lost in O_3 related deaths (constant value per YLL assumptions individuals with COPD) ~10 years of life lost (YLL) per death given age distribution of deaths for COPD in the U.S.

In Thailand, McGuinness et al. (2020) assessed the cost only of using officially certified respirators during heavy smog events. The initial cost was included, and the longevity of respirator was assigned an end-cost score. Using scenarios for respirator effectivity, the researchers found that during haze periods, the average cost of reusable respirators was 8 and 9 times higher than disposable respirators. Integrated scores suggest model DR1 (disposable) respirator is the optimal choice ($0.97 dollars per respirator) for

short term. For long term RR2 (re-usable) is the optimal choice at $12.96 per respirator. In this study, no health end points were assessed.

Hubbell (2006) reviewed evidence in the implementation of QALYs in the analysis of air pollution regulations, specifically from the control of emissions from heavy duty engines and diesel fuel (HDE). The analysis is referred as both performing cost-effectiveness and cost-utility evaluations of the policy using $PM_{2.5}$ concentrations, related premature death, as well as chronic bronchitis. The prevalence rates were extracted from CDC estimates and were stratified by age. The total cost used for the HDE policy was $4.2 billion, and on benefits WTP for avoided incidences of chronic bronchitis were valued at $331,000 in 1999 dollars. A discount rate of 3% was applied. The weight applied to QALYs were 0.95 because the general population is likely to be on average at somewhat less than perfect health. Bronchitis RR of 1.0086 for the HDE reduction in $PM_{2.5}$ of 0.65 $\mu g/m^3$. Incidence estimate of 3.78 cases per 1,000. Chronic bronchitis is assumed to have the same age-specific life expectancy as the general population no loss of life. QALY weight of 0.69. The study found that the QALY analysis of mortality risks gained from reductions in $PM_{2.5}$ related mortality is projected to be 88,000 (discounted) and 116,000 (undiscounted) by 2030. Highest gains at ages 55 and over, reaching upward trends until 85+ years of age. QALYs gained from reductions in chronic bronchitis are 34,000. In the cost-utility portion, total cost per discounted QALY is $35,710. HDE also resulted in $3.8 billion in other health and environmental benefits, or net costs of $0.4 billion. Thus, estimated net cost per discounted QALY was $3400.

In the U.S. there has been growing attention to high polluting events, such as forest and wildfires and their effect on human health (Sengupta, 2020). In southern California, Fisk & Chan (2017) designed a study to evaluate the operation of HVAC system fans and portable air cleaners to reduce indoor exposure to $PM_{2.5}$ during at 10-day wildfire event. In the economic evaluation phase, costs of portable air cleaners and HVAC use incremental energy costs, as well as filters were included. Health related benefits included models with all respiratory diseases, one with the sum of four respiratory health outcomes, as well as another model with all respiratory and mortality combined. All the reference health parameter values were obtained from literature and included respiratory admissions to the hospital and premature deaths. The findings concluded that for the intervention applied for all homes, the economic benefits from avoided respiratory hospitalizations during the wildfire period range from $1 to $5.5 million and from reduced mortality a range of $75 to $416 million. Operating portable air cleaners' energy expenditures are lowest compared to energy costs for continuous HVAC fans $2.3 vs $16 per house. Intervention costs were calculated to be approximately from $1.7 to $4.4 trillion for all homes (6.2 million homes). Interventions only in elderly housing, economic benefits are similar in magnitude and the intervention costs decrease 80%, if the elderly remain at home during the wildfire smoke period than the intervention to reduce $PM_{2.5}$ concentrations is cost-effective relative to hospitalizations. In the other hand, mortality-related benefits were not sufficient to pay for portable air cleaners' total utilization (purchase and operation), however benefit is greater to the cost of operating air purifiers.

Lastly, in the study by Martenies & Batterman (2018), the researchers evaluated the effectiveness of three interventions in schools and in homes of children with asthma (11.3%) in Detroit, Michigan and nearby areas. The cost of the interventions to reduce indoor air pollution from outdoor sources: i) cost of drop-in filters (MERV 5, 8, 12, and 14) for unit ventilators (UV) providing ventilation and filtration in classrooms, ii) drop-in filters for homes with forced-air systems, and iii) three-compartment model for free-standing air cleaners (bedroom, living room, and remainder of the house model) were considered, as well as increased electricity. Schools show greater reductions in indoor/outdoor (I/O) ratios from using MERV 5 to 8 (46%), 12 (80%), and 14 (83%). This reduction is higher than in homes. In homes the I/O ratios see a reduction of 34%, 54% and 56%. Air purifiers reduce them by 84% in bedrooms and 88% in living rooms. The 3rd air cleaner showed a modest I/O ratio reduction. In total, $PM_{2.5}$ exposures cause an estimated 110 DALYs and $6 million in monetized impacts per year. Replacing filters with 8, 12 or 14 MERV filters in schools reduce asthma burden up to 14% annually (or up to 30% of the school year) and is this benefit was monetized at $0.5 – 0.9 million in avoided health impacts. Schools that are near road DALYs are reduced by 10-17%. At home, filters avoid 12 to 18 DALYs per year representing $0.7 – 1 million per year ($63-93 per child with asthma per year). MERV 8, 12, 14 reduce asthma burden by 11% to 17%, not a significant difference from 12 to 14. Assuming 20 students in each classroom and 2 with asthma, the marginal cost is $2 – 3 per students per year or $20-$32 per student per asthma per year. This is below the benefits of asthma exacerbations. At home filters costs exceed ($1.4-$1.6 million per year for homes with forced air systems and $800,000 per year for homes using air cleaners) the monetized benefit of avoided asthma impacts from resulting lower exposures.

Economic evaluations of individual, household, and community-level strategies to mitigate exposures to outdoor air pollution use different methods selected by the researchers in different geographical areas worldwide. There was no uniform method to analyze cost-effectiveness, cost-utility, or cost-benefit of policy and protective behavior interventions. Furthermore, my review found that those terms are used interchangeably.

Most of the studies reviewed that included indoor pollutant concentration reduction strategies, such as indoor portable air purifiers and MERV filters, based their concentration response models in outdoor air pollutants and presented evidence supporting that infiltration from ambient sources into homes and buildings is known problem for respiratory health.

This dissertation seeks to understand how economic evaluation is used in public health to assess the impact of outdoor air pollution in human health, and analyses the evidence available regarding individual, household, and community-level health protections. Individual, personal, household, and regulatory strategies have evolved over time in their efficacy and understanding on how they individually operate to prevent illnesses and death associated to bad air. Little is known about how they work in combination and their synergistic effect.

Most economic burden of disease studies used in environmental health focused on acute or short-term health outcomes, other economic evaluations measuring the cost of environmental health protections relative to their long-term effectiveness, utility, and benefit, generally include premature mortality.

Cost of illness studies rely in the human capital theory (T. W. Schultz, 1961), and cost-effectiveness, cost-utility and cost-benefit analyses use Bentham and Hill's (1861) (Stanford University, 2014) utilitarian theory to treat air pollution as a negative externality from human economic activity and an apology to *'polluter-pays'* regulatory schemes. Thus, these type of economic evaluations analyses values the cost of potential protections of health relative to their estimated direct benefits or avoided ill health outcomes.

This paper presents a review of the critical components of the performance of status quo air pollution control measures in terms of valuation the health effects, and burden to the healthcare system and different populations. The evidence gathered may provide the bases for designing optimal prospective studies which are urgently needed to better establish and validate integrated approaches that benefit human respiratory health and reduce the impacts of outdoor air pollution. This is without a doubt more urgent for communities with historically high air pollution-related burden of disease.

Gaps in the Literature: Equity and Region

Despite existing knowledge, there is only one (1) study addressing the health burden and associated costs of air pollution specifically in the SJV region. The study was published in 2008. Thus, it is proposed that a burden of disease, a comprehensive health economics study of air pollution for the region is long overdue and data is available to conduct a health economics study of this proportion.

The paucity of economic evaluation, specifically of cost-effectiveness, cost-utility and cost-benefit, analyses on the public health implications of individual, household, community and structural outdoor air pollution mitigation and control policies is both vastly concerning and an opportunity for the field of health economics.

Equity has been a chief concern for public health, and in the field of decreasing the effects of air pollution and minimizing its deleterious health outcomes, this is not absent. Policies and laws regulating air pollution have been pointed at in responsibility for their delay in addressing ongoing environmental injustices due to their benefits realizing long-term. This evidence also shows that other structural socioeconomic factors, such as income, stand in the way of individuals and households to implement defensive behaviors from air pollution equitably. For economists the health equity questions to potentially answer should include: who pays? the most affected (susceptible)? Who can afford it? Who knows the risk? Who has more risk (vulnerable)?

Most of the studies in this paper highlight the need for well-designed prospective studies to better establish and validate interventions that benefit respiratory health and puts them in the balance with their cost relative to different groups ability to use and adopt them. Considering climate change, increasing events worsening air pollution for some communities, such as forest fires, that is a resounding suggestion, accurate, and timely.

As previously stated, there has only been one peer-reviewed burden of disease study for the San Joaquin Valley and one study assessing the effectiveness of portable air purifiers in the improvement of respiratory measures and illness.

Nevertheless, there is evidence that this region is overburdened by both air pollution and related ill health. The California's San Joaquin Valley (SJV) is one of the most polluted regions in the U.S., exceeding state and national standards for ozone (O_3) and particulate matter (PM) 2.5 (Barboza, 2013; Gharibi et al., 2018; Y.-Y. Meng et al., 2010). In 2019, the American Lung Association gave every major city in the SJV a failing grade -*F*- in their 'State of the Air' report for high ozone days, 24-hour particulate matter pollution, and annual particle pollution.

Gharibi et al. (2018) found a positive association between ground-level ozone exposure and increased emergency department visits, especially in children 6-18 years old (OR: 1.219) and people of color (OR: 1.159). Using the pollution burden score of the California Office of Environmental Health Hazard Assessment, researchers found that for every unit increase of pollution burden hospitalizations increased from 21% to 32% for preventable causes, especially in lower income and children under 4 years of age living in the San Joaquin Valley region (Lessard, Alcala, & Capitman, 2016).

The SJV is comprised by eight counties: Kern, Tulare, Kings, Fresno, Madera, Merced, Stanislaus, and San Joaquin. The region is the home of approximately 4.3 million residents (PPIC, 2018) . The SJV has an intricate topography and it is situated at midpoint of two high population concentrations, the San Francisco-Bay Area and Los Angeles (Jones, Duncan, Elkind, & Hanson, 2017).

The SJV is an air basin with unique meteorological conditions that combined with its arid and semi-arid geography, traps pollution emitted by sources, and gusted from contiguous regions (Schoups et al., 2005). The Valley's economic engines are primarily agriculture, oil production, and given its location connecting two of the largest regions in the world, transportation is a considerable economic activity (Pat Brown Institute, 2014).

As evidence suggests, cars and trucks that combust fuels emit smog forming pollutants such as nitrogen oxide, particulate matter, formaldehyde, and non-methane organic gases (Hodan & Barnard, 2004). In California's Central San Joaquin Valley, the sources of air pollution are related to its most intense and lucrative economic activities, 1) farms and agriculture, 2) cars and trucks, 3) pollution blown from the bay area, and 4) forest fires are the top contributors of air pollutants in the region (Cisneros et al., 2017a).

Ahead of its time and due to its unique topographic conditions, climate and growing population California decided to design its own "Clean Air Act" legislation before the equivalent federal legislation was signed. California was given a waiver to address its own pollution problems because state legislation was as far-reaching, if not stricter, than national law (Barboza, 2013; Hankins & Bryner, 2018).

Federal and State laws require emission control measures in areas where air pollution exceeds standards or non-attainment areas (US EPA, 2017). The San Joaquin Valley Air Pollution Control District is the public health entity entrusted to develop local plans and implement air pollution control measures. The SJV Air Pollution Control District is funded by DMV fees, stationary sources and permit fees, and federal/state grants and is governed by an appointed board made of elected officials and two public members appointed by the Governor (San Joaquin Valley Air Pollution District, 2019).

In the other hand, local county public health departments are also commissioned to protect the public's health, prevent illnesses, surveil, and respond to endemic factors that complicate the attainment of their constituency's full health. Several departments

have found that their communities would like specific diseases, such asthma, and air pollution to be addressed in their action plans (FCDPH, 2013; MCDPH, 2019; TCHHSA, 2017).

Chapter III.

Study #1

Rationale

There is robust scientific evidence supporting that anthropogenic air pollution is a serious public health and environmental problem. Increases in air pollution are associated with polyclinic attendance for asthma, upper respiratory infections, acute conjunctivitis, bronchitis, emphysema, pneumonia, and lung disease (Sheldon & Sankaran, 2017).

Worldwide, the concentrations of two criteria air pollutants, $PM_{2.5}$ and ozone, resulted in 7.8 million years of life lost (YLL) and approximately US$1 trillion in health damages (Anenberg et al., 2019; A. Gao et al., 2021). Asthma in children, adults and the elderly has been clinically defined elsewhere (Castro-Rodriguez, Forno, Rodriguez-Martinez, & Celedón, 2016; Chanez et al., 2007; Yáñez et al., 2014). Nonetheless, the American Thoracic Society recognizes outdoor air pollution as a critical trigger and irritant for asthma exacerbations, shortness of breath, and wheezing (Sockrider & Fussner, 2020). Furthermore, in 2019 the U.S. Environmental Protection Agency determined air pollutants (e.g. $PM_{2.5}$, NO_2, O_3) to be a likely cause of respiratory effects, such as asthma symptoms and exacerbations (EPA, 2019a).

Considered one of the most polluted region's in the United States (American Lung Association, 2019, 2022; Y.-Y. Meng et al., 2010; K. M. Zhang et al., 2005), several studies, conducted in the Valley, have found increased likelihood for emergency room visits and asthma events due to ground-level ozone (O_3) and nitrogen dioxide (NO_2) among SJV residents (Cisneros et al., 2021; Entwistle et al., 2019a; Gharibi et al., 2018).

The U.S. Environmental Protection Agency (EPA) monitors and regulates over 189 hazardous contaminants including six criteria pollutants: ground-level ozone, particle pollution, carbon monoxide, sulfur dioxide, lead, and nitrogen dioxide (EPA, 2018). In spite of federal and state emission standards, the region has achieved attainment status for NO_2, and was classified a non-attainment area since 1997 for particulate matter (SJV Air Pollution Control District, 2021). In 2019, the EPA pronounced its decision to reclassify the SJV as an Extreme non-attainment area for 8-hour ozone in the federal register (EPA, 2019b).

Federal and State laws require emission control measures in areas where air pollution exceeds standards or non-attainment areas (US EPA, 2017). The San Joaquin Valley Air Pollution Control District is the public health entity entrusted to develop local plans and implement air pollution control measures. The SJV Air Pollution Control District is funded by DMV fees, stationary sources and permit fees, and federal/state grants and is governed by an appointed board made of elected officials and two public members appointed by the Governor (San Joaquin Valley Air Pollution District, 2019). In the other hand, local county public health departments are also commissioned to protect the public's health, prevent illnesses, surveil, and respond to endemic factors that complicate the attainment of their constituency's full health. Several departments have found that their communities would like specific diseases, such asthma, and air pollution to be addressed in their action plans (FCDPH, 2013; MCDPH, 2019; TCHHSA, 2017).

This study is an examination of the transient effects of three criteria air pollutants on health endpoints: asthma and upper respiratory infections (URIs). Ground-level ozone and $PM_{2.5}$ are interrogated to assess its effects in asthma and upper respiratory morbidity given the region's endemic standing on Extreme nonattainment and nonattainment status. NO_2 is included to investigate if within emissions attainment stage, short-term adverse outcomes are associated with the pollutant reported levels. The central research question of the study is: do SJV residents exposed to higher concentrations of NO_2, $PM_{2.5}$ and O_3 have increased odds of having a visit to the emergency department and hospitalizations for asthma and upper respiratory complications within 14 days of exposure.

Methods

Data and Participants

The data for this study is the California Department of Health Care Access and Information (HCAI) -formerly known as OSHPD- non-public Emergency Department (ED) and hospitalization health care utilization reports for 12 months of 2016. SJV residents' visits seen at local hospitals for selected health endpoints: asthma (ICD-10: J45), upper respiratory infections (ICD-10: J00-J06) and contact with air pollution ICD-10: (Z77.110), were used to select patient records (date of visit/admission, sex, age, race, ethnicity, and zip code).

Exposures to air pollutants were assigned based on each asthma and URI patient's residential zip code and extrapolated within a radius of 15 kilometers from the closest monitoring station. Based on previous studies, it is expected that an extensive proportion of the SJV region is covered by this methodological grid (Entwistle et al., 2019a; Gharibi et al., 2018).

Cases Inclusion and Exclusion Criteria

For both ED visits and hospitalizations datasets criteria for inclusion and exclusion is as follows:

The cases inclusion criteria included: 1) Having an HCAI unique identifier assigned known as record linkage number (RLN); 2) Patients older than 2 years of age; and 3) cases with selected health endpoints ICD-10 codes as principal diagnosis.

The exclusion criteria were: 1) All duplicate cases identified through RLN; 2) Cases without RLN; 3) Patients younger than 2 years of age; and 4) cases without a selected health endpoint as principal diagnosis.

Study Design

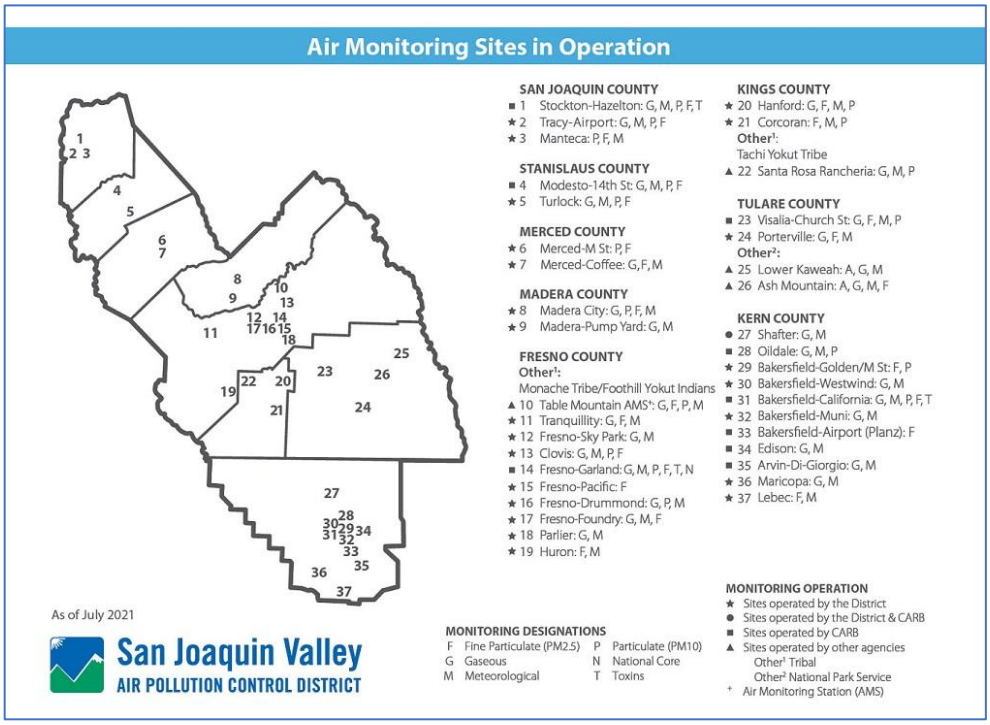
This epidemiological exposure assessment is a time-stratified case-crossover study design which is appropriate for analyzing associations between exposures and adverse health outcomes (Maclure, 1991; Malig et al., 2016). This strategy minimizes endogeneity as each case serves as its own control when comparing the exogenous exposure variables during the day of the health event to 3 or 4 similar periods calculated on the same days of each week during the same month of the hazard period (e.g., reported date of admission/visit).

To replicate prevalent polluting conditions in the SJV, single day lags up to 14 days prior to the event day were estimated for each pollutant, and cumulative lags were calculated to investigate the acute role of $PM_{2.5}$, O_3 and NO_2 in asthma hospital admissions and emergency room visits.

Exposure Assessment

The SJV Air Pollution Control District's air quality monitoring system, see figure 1 from "Air Monitoring Sites in Operation", was the source of air pollutant (O_3, NO_2, $PM_{2.5}$) data, which is publicly available in the EPA's National Ambient Air Quality Standards (NAAQS), 40 CFR part 50. The study utilized the pollutant concentrations and meteorological data from 18 sampling stations in the region's system to create exogenous variables of exposure for each pollutant and meteorological indicators.

The measure for NO_2 and $PM_{2.5}$ are the daily average values; and the measure for ground-level ozone was the daily 8-hour average. The meteorological variable temperature was computed as the mean daily degrees Celsius (C°).



Statistical Analysis

Conditional logistic regression was used to estimate the association between O_3, NO_2 and $PM_{2.5}$ with asthma and URI related visits to the ED and hospitalizations we will. Because this study aimed to estimate the transient acute effects of three criteria air pollutants in attendance to emergency room and hospitalizations for 2016, it was appropriate to employ a time stratified case-crossover analysis. Lags -up to the 14th were estimated to capture the acute health effects and presentation to the ED and hospitalizations after exposures above averages.

All the exposure models are adjusted for meteorological conditions in temperature using the method of restricted cubic spline (RCS) with 3 degrees of freedom (3 df). Its function (see Equation 1) is based on prior work (Cisneros et al., 2021; Entwistle et al., 2019a; Gharibi et al., 2018):

$$l_c(\beta) = \sum_{k=1}^{n} Y_k \times \{ \left(\beta_1 \times O_{3\,(k-l)1}\right) + \left(\beta_2 \times PM_{2.5(k-l)1}\right) + \left(\beta_3 \times NO_{2(k-l)1}\right) + \left(\beta_* \times spline\left(T_{(k-l)j}\right)\right) - \log\left[\sum_{j=2}^{5} exp\left(\left(\beta_1 \times O_{3\,(k-l)j}\right) + (\beta_2 \times PM_{2.5(k-l)j}) + \left(\beta_3 \times NO_{2(k-l)j}\right) + \left(\beta_* \times spline\left(T_{(k-l)j}\right)\right)\right)\right] \} \quad [1]$$

Y_k is daily counts of asthma and URI events on k-th day.
$\left(O_{3(k-l)1}\right), \left(PM_{2.5\,(k-l)1}\right), \left(NO_{2(k-l)1}\right), and\ \left(spline\left(T_{(k-l)1}\right)\right)$ stand for the case covariates i.e. control day or the day that a patient attended the ED or hospitalization; $\left(O_{3(k-l)j}\right), (PM_{2.5\,(k-l)j}), \left(NO_{2(k-l)j}\right), and \left(spline\left(T_{(k-l)1}\right)\right)$ are covariates for up to four matched controls within the same month.
l is the number of days before the event day (*l = 1 to 14 days before the event day).* Furthermore, match control days are shifted subsequently by *l day* $((k-l)j)$. *β = β1, β2, β3* refers to the coefficient for each covariate. Lastly, β_* denotes meteorological variables paired coefficients included in the RCS. Noted that this RCS with k-knots is equal to 3 in this study. Seasonality is a major factor in the presence and effects for each of the pollutants included in this study, specifically for ozone in the prolonged regional summer months and the winter season for $PM_{2.5}$. Therefore, the analyses were stratified by regional warm (June, July, August, September) and cold (November, December, January, February) seasons to measure temporal effects. To avoid case duplication, each data set for ED visits and hospitalizations will be analyzed individually.

The study received IRB approval from the State of California Health and Human Services Agency Committee for the Protection of Human Subjects (CPHS) #2021-051. All analyzes were conducted using STATA V. 17 (College Station, TX).

Results

Demographics of ED and Hospital Data in 2016

Table 2 presents the patient characteristics of asthma and URI visits to the emergency room and hospital admissions for SJV residents. The study included 34,591 ED visits and 4,693 hospitalizations in all 12-months of 2016. For both ED visits and hospitalizations there were more females (56.4% and 51.4%) than males (43.5% - 48.6%). The proportion of patients by race and ethnicity for ED visits and hospitalizations show that most patients who visited the emergency rooms in the Valley were Hispanic (46.2%), and for hospitalizations the majority of patients were White

(50.1%). African Americans were approximately 13% of the patient ED visits and hospitalizations, and Asian Americans had higher proportion of hospitalizations (9.2%) and were 5.4% of 2016 emergency room visits for asthma and URIs. By age and age group, the mean age for patients who went to the ED for an asthma and URI event was 36.06 years old (+/- 23.87), and for admitted to the hospital the mean was 60.63 years old (+/- 22.28). The highest proportion with ED visits were patients from 19-40 years old (31.5%), and for hospitalizations whose who were older than 65 years old (49.2%), which accounted for almost half of all hospital admissions. Lastly, Medi-Cal accounted for 58.9% by payer source for all ED visits, and Medicare was the insurer for 54.9% of hospital admissions due to asthma and URIs.

Table 2. Characteristics of ED and Hospitalizations for Asthma/URIs

Characteristics	ED Visits Total, n	(%)	Hospitalizations Total, n	(%)
Sex				
Female	19,515	(56.4)	2,414	(51.4)
Male	15,076	(43.5)	2,279	(48.6)
Race				
White	11,356	(32.8)	2,351	(50.1)
African American	4,665	(13.5)	641	(13.7)
Hispanic	15,267	(46.2)	1,144	(24.3)
Asian	1,878	(5.4)	431	(9.2)
Age				
Mean	36.06	(+/-23.87)	60.63	(+/-22.28)
2-5	2,605	(7.5)	143	(3.0)
6-18	4,644	(13.4)	218	(4.7)
19-40	10,903	(31.5)	383	(8.1)
41-64	9,785	(28.2)	1,640	(34.9)
65+	4,742	(13.7)	2,309	(49.2)
Payer				
Medi-Cal	20,386	(58.9)	1,559	(33.2)
Medicare	5,913	(17.1)	2,577	(54.9)
Private	6,816	(19.7)	520	(11.1)
Self-Pay	1,476	(4.2)	37	(0.8)
Total Visits	34,591		4,693	

Descriptive analysis of criteria air pollutants and meteorological factors

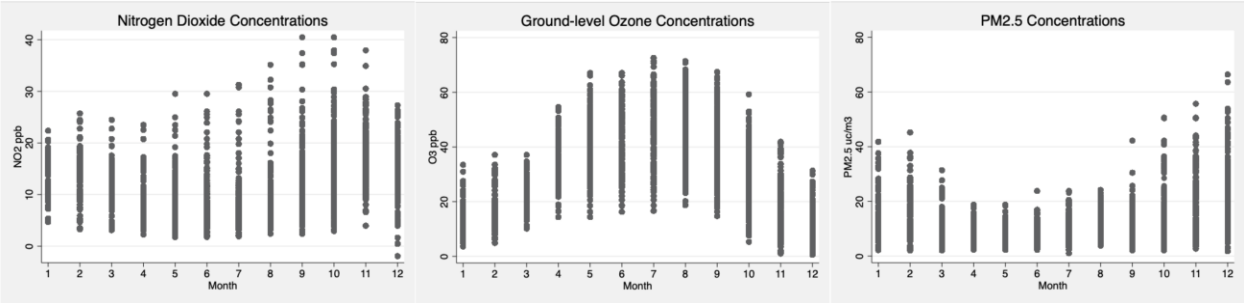
Table 3 describes the daily 8-hour concentration of O_3, the daily mean concentrations of $PM_{2.5}$, NO_2, and temperature from sampling stations in the SJV during 2016. Adjusting for seasonality, mean concentrations for cold and warm seasons are included based on temporal pollutant and primary/secondary behavior. Temporal relationship for each pollutant concentration was investigated and collinearity of temperature and independent variables prior to conditional logistic regression estimations and the restricted cubic spline was applied (see figure 4). In sensitivity analysis, humidity and wind were found to have moderating effects causing asymptotic errors, thus were removed from the spline.

The federal and state standards for 8-hour maximum O_3 should not exceed 70 ppb, however Tulare County exceeded the standard 66 times, Kern County 26 times, and Fresno County 5 times in 2016. NO_2 federal standards (100 ppb 24-hr mean) were not exceeded by measure of any sampling station for the included cases. Lastly for $PM_{2.5}$, federal and state standards (35μg/m^3 24-hr mean) were exceeded 111 times in Fresno County, 57 times in Kings County, 47 times in Stanislaus County, 41 times in Kern County, 26 times in San Joaquin County, 20 times in Madera County, 12 times in Merced County, and 8 times in Tulare County.

Table 3. Distribution of air pollutants in the SJV from sampling stations

Pollutant	Mean	SD	Minimum	25%	50%	75%	Maximum	IQR
O_3 (ppb) - Annual	27.2	14.8	0.5	15.5	26.4	36.3	72.5	-
O_3 (ppb) - Warm	41.0	12.7	14.7	30.8	39.0	51.4	72.5	20.6
$PM_{2.5}$ (μg/m^3) - Annual	13.3	8.2	1.03	7.9	11.2	15.9	66.4	-
$PM_{2.5}$ (μg/m^3) - Cold	18.3	10.1	1.8	10.6	15.6	25.1	66.4	14.5
NO_2 (ppb) – Annual	11.6	5.9	0.0	7.1	10.6	15.5	40.4	-
NO_2 (ppb) – Warm	8.4	4.8	1.7	5.4	7.3	9.9	40.4	4.5
NO_2 (ppb) – Cold	15.0	5.2	0.0	11.8	15.1	18.5	37.9	6.7
Temperature (C°) Annual	17.4	6.6	3.9	12.3	16.8	22.5	34.7	-
Temperature (C°) Warm	25.0	3.7	13.9	22.4	25.2	27.7	34.7	5.3
Temperature (C°) Cold	11.4	3.6	3.9	8.6	11.2	14.1	22.5	5.5

Figure 4. Temporal Distribution of Pollutant Concentrations for the SJV region in 2016



The cases included in this case-crossover sample were evaluated for associations between socio-demographic characteristics of the SJV residents who were patients in the emergency department or were hospitalized in 2016 for an asthma or URI event. A categorical variable was created from the continuous values of each pollutant concentrations at the low and highest percentiles.

Table 4 reports the characteristics of emergency room and hospitalization patients who were exposed to the 75th percentile to the maximum level registered by sample monitoring stations in 2016, and the estimated p value. The likelihood-ratio test was used to estimate the associations between exposure to ambient air pollution and SJV patients' county of residence, sex, race and ethnicity, age group, and payer source for the visit and hospitalization.

The patients' county of residence, race and ethnicity, and age groups are likely to be associated with exposure to the highest level of every pollutant registered in 2016

included in the study. The probability of sex association was only statistically significant with the highest exposure to ozone percentiles for patients hospitalized and for ED patients for exposure to high levels of nitrogen dioxide. Also, for patients who were hospitalized the association to high exposure to all three pollutants was likely significant. For patient who visited the emergency department, only the relationship with high exposure to $PM_{2.5}$ was found to be significant. The payer source in this study is utilized as a potential proxy for income levels and access to care in the SJV, which could be demonstrative of why the largest percentage of patients in the sample reportedly were self-pay at the time of visit or admission.

Table 4. Patient Characteristics for Exposure to Highest Pollutant Concentration Percentiles

Characteristics	Ozone (75% to Maximum)		$PM_{2.5}$ (75% to Maximum)		NO_2 (75% to Maximum)	
	ED % (p)	Hosp % (p)	ED % (p)	Hosp % (p)	ED % (p)	Hosp % (p)
County	0.000	0.000	0.000	0.000	0.000	0.000
Fresno	52.64	53.24	35.52	34.35	24.88	23.34
Kern	59.21	66.99	54.08	51.57	56.76	51.51
Madera	52.89	49.81	27.24	28.78	0.00	0.00
Merced	49.28	47.33	26.88	28.28	0.64	1.00
San Joaquin	11.19	7.98	29.78	29.44	41.07	42.36
Tulare	7.02	11.23	88.11	86.30	90.71	93.40
Sex	0.649	0.000	0.068	0.967	0.042	0.203
Female	34.64	32.96	34.99	34.62	34.70	34.64
Male	34.53	36.11	34.29	34.64	34.79	34.83
Race/Ethnicity	0.000	0.000	0.000	0.049	0.000	0.000
White	38.09	34.42	34.70	34.98	32.86	33.86
African American	27.14	29.17	32.32	32.32	36.83	35.34
Hispanic	39.07	39.50	35.44	36.06	33.27	34.03
Asian	29.39	30.95	31.80	32.95	32.85	33.64
Native American	28.16	19.61	36.53	37.93	41.43	47.17
Age	0.000	0.000	0.000	0.011	0.000	0.020
2-5	33.40	46.51	40.27	37.70	37.70	31.38
6-18	37.88	36.62	34.61	35.57	34.27	32.65
19-40	34.16	37.16	33.56	37.10	34.24	35.71
41-64	33.93	34.15	33.44	33.30	34.38	34.80
65+	34.90	33.31	34.30	34.86	34.93	34.94
Payer	0.370	0.022	0.000	0.003	0.108	0.045
Medi-Cal	34.82	35.93	34.87	33.99	34.96	34.50
Medicare	34.33	34.24	33.64	34.83	34.68	34.68
Private	34.14	31.05	35.16	34.72	34.51	35.10
Self-Pay	34.61	38.61	34.09	49.47	32.92	44.79

Unadjusted and Adjusted pollutant models for ground-level Ozone

Table 5 shows the association of ozone to ED visits and hospitalizations for SJV residents in warm season months. The unadjusted single pollutant model estimated a 0.3% (95% CI: 1.000, 1.006) increased odds of visiting the ED for asthma at lag 0. No other lag was statistically significant. In the model for hospitalizations the lag 0 had 0.5% increased odds of being admitted for asthma but the estimate was not statistically significant.

Table 5. Single Ozone Pollutant Exposure Models (Warm season)

Single and Cumulative Lags	ED Visits Single Pollutant Model O_3 (ppb)			Hospitalizations Single Pollutant Model O_3 (ppb)		
	OR	95%	CI	OR	95%	CI
Lag 0	1.003*	1.000	1.006	1.005	0.993	1.017
Lag 1	1.000	0.995	1.006	0.999	0.985	1.013
Lag 2	1.001	0.996	1.006	1.007	0.993	1.021
Lag 3	0.999	0.993	1.004	0.99	0.976	1.004
Lag 4	1.003	0.998	1.008	1.000	0.986	1.014
Lag 5	0.995	0.990	1.001	0.999	0.985	1.013
Lag 6	1.001	0.995	1.006	1.000	0.986	1.014
Lag 7	0.999	0.994	1.004	1.000	0.985	1.014
Lag 8	1.001	0.996	1.006	0.995	0.981	1.009
Lag 9	1.002	0.997	1.008	1.001	0.986	1.015
Lag 10	1.001	0.996	1.007	1.003	0.989	1.018
Lag 11	0.997	0.992	1.003	1.005	0.990	1.020
Lag 12	1.000	0.995	1.006	0.991	0.977	1.006
Lag 13	0.998	0.993	1.004	1.008	0.993	1.023
Lag 14	0.996	0.992	1.001	1.000	0.988	1.012
Lag 0-1	0.999	0.981	1.017	0.984	0.938	1.031
Lag 0-7	0.983	0.916	1.056	1.036	0.855	1.257
Lag 0-14	0.951	0.888	1.018	1.004	0.835	1.206

*Levels of significance: *p<.05; **p<.01; ***p<.001*

Table 6 shows the asthma ED visit and hospitalization associations with ozone models adjusted for temperature. The second model adjusted concomitantly in a multi-pollutant scenario with temperature and NO_2. None of the estimates for admission and emergency rooms visits were statistically significant for the warm season.

Table 6. Multi-pollutant Ozone Exposure Models (Warm season)

Single and Cumulative Lags	ED Visits Adjusted and Multi-Pollutant Models						Hospitalizations Adjusted and Multi-Pollutant Models					
	O_3 Adjusted for C^o			O_3 Adjusted for C^o and NO_2			O_3 Adjusted for C^o			O_3 Adjusted for C^o and NO_2		
	OR	95%	CI	OR	95%	CI	OR	95%	CI	OR	95%	CI
Lag 0	0.987***	0.982	0.991	0.987***	0.982	0.991	0.990	0.980	1.000	0.992	0.980	1.005
Lag 1	0.993	0.988	0.999	0.995	0.989	1.000	0.992	0.978	1.005	0.994	0.980	1.005
Lag 2	0.998	0.993	1.003	0.998	0.993	1.004	1.004	0.990	1.018	1.005	0.991	1.019
Lag 3	0.998	0.993	1.004	0.999	0.994	1.004	0.988	0.974	1.002	0.988	0.974	1.002
Lag 4	1.002	0.997	1.008	1.003	0.998	1.009	1.001	0.987	1.015	1.002	0.988	1.017
Lag 5	0.998	0.993	1.004	0.998	0.992	1.003	1.000	0.986	1.014	0.999	0.985	1.013
Lag 6	1.002	0.996	1.007	1.002	0.997	1.007	1.002	0.988	1.016	1.003	0.989	1.017
Lag 7	0.998	0.993	1.003	0.998	0.993	1.003	0.999	0.985	1.013	0.999	0.984	1.013
Lag 8	1.001	0.995	1.006	1.002	0.996	1.007	0.995	0.981	1.009	0.996	0.982	1.010
Lag 9	0.998	0.993	1.004	0.997	0.992	1.002	0.996	0.982	1.010	0.994	0.980	1.008
Lag 10	1.004	0.999	1.009	1.004	0.999	1.010	1.007	0.992	1.010	1.008	0.993	1.023
Lag 11	0.999	0.993	1.004	0.998	0.993	1.004	1.005	0.990	1.020	1.005	0.990	1.020
Lag 12	1.002	0.997	1.008	1.002	0.997	1.008	0.993	0.978	1.008	0.993	0.978	1.008
Lag 13	0.994	0.989	1.000	0.995	0.989	1.001	1.005	0.990	1.020	1.006	0.991	1.021
Lag 14	0.996	0.992	1.001	0.997	0.992	1.002	1.000	0.987	1.012	1.001	0.988	1.013
Lag 0-1	0.990	0.973	1.008	0.992	0.975	1.010	0.975	0.930	1.023	0.978	0.932	1.025
Lag 0-7	0.979	0.912	1.051	0.969	0.902	1.040	1.030	0.850	1.249	1.020	0.841	1.236
Lag 0-14	0.954	0.890	1.022	0.962	0.898	1.032	1.000	0.830	1.206	1.012	0.839	1.220

*Levels of significance: *p<.05; **p<.01; ***p<.001*

Unadjusted and Adjusted pollutant models for NO_2 (Warm season)

Further unadjusted estimates, shown on table 7, of associations between air pollution and asthma found that NO_2 is associated to ED visits and hospital admissions in the warm season. For ED visits lags 0-5, 7, and 14 were statistically significant with the highest increased odds of having an ED visit for an asthma event at lag 0 of 3.1% (95% CI: 1.026, 1.037) to 1.2% (95% CI: 1.005, 1.020) in lag 7. Acute effects of NO_2 for cumulative lag 0-7 shows 12.8% (95% CI: 1.029, 1.238) increased odds and 24.7% (95% CI: 1.116, 1.393) at lag 0-14 to attend the emergency room for asthma and URIs. The model for hospitalizations associated with NO_2 showed that lags 0, 1, and 7 were statistically significant, thus the odds of being hospitalized during the warm season for asthma due to air pollution was 3.6% (95% CI: 1.017, 1.048) on lag 0, and 2.6% (95% CI: 1.007, 1.046) on lag 7. Cumulative lag 0-7 of NO_2 exposure is associated with 37.7% (95% CI: 1.082, 1.753) increased in the odds of being hospitalized for asthma in the warm season.

Table 7. Single NO_2 Pollutant Exposure Models (Warm Season)

Single and Cumulative Lags	ED Visits Single Pollutant Model NO_2 (ppb)			Hospitalizations Single Pollutant Model NO_2 (ppb)		
	OR	95%	CI	OR	95%	CI
Lag 0	1.031***	1.026	1.037	1.036***	1.017	1.048
Lag 1	1.028***	1.021	1.035	1.031***	1.014	1.049
Lag 2	1.023***	1.016	1.029	1.005	0.987	1.022
Lag 3	1.022***	1.015	1.029	1.015	0.996	1.035
Lag 4	1.016***	1.009	1.023	1.013	0.993	1.032
Lag 5	1.011**	1.004	1.018	0.999	0.981	1.018
Lag 6	1.004	0.998	1.011	1.004	0.986	1.022
Lag 7	1.012**	1.005	1.020	1.026**	1.007	1.046
Lag 8	0.997	0.990	1.004	0.986	0.967	1.005
Lag 9	1.008	1.001	1.015	0.993	0.974	1.012
Lag 10	1.005	0.998	1.012	1.007	0.988	1.027
Lag 11	1.004	0.997	1.011	1.015	0.996	1.034
Lag 12	0.998	0.991	1.005	1.003	0.984	1.022
Lag 13	0.999	0.992	1.006	1.004	0.985	1.023
Lag 14	1.015***	1.007	1.022	1.017	0.997	1.038
Lag 0-1	1.011	0.990	1.032	1.054	0.998	1.113
Lag 0-7	1.128*	1.029	1.238	1.377**	1.082	1.753
Lag 0-14	1.247**	1.116	1.393	1.298	0.957	1.760

*Levels of significance: *p<.05; **p<.01; ***p<.001*

Adjusted models for NO_2 associations with asthma and URIs ED visits and hospitalizations included temperature, and a multi-pollutant model which adjusted for temperature, ozone, and $PM_{2.5}$, see table 8. When controlling for temperature, in lag 0 SJV residents had a 2.1% (95% CI: 1.015, 1.027) increased odds of vising the ED. In the multi-pollutant model and controlling for temperature, during the warm season, increases in NO_2 exposure increased odds of having an ED visit ranged from 1.3% (95% CI: 1.006, 1.020) in lag 5 to 2.4% (95% CI: 1.017, 1.031) in lag 1. Lags 2, 3, 4, 5, 7, 9, and 14 were

statistically significant for increased odds estimates to having an ED visit due to NO_2 pollution. The cumulative lag 0-14 provided the estimate of 27.4% (95% CI: 1.140, 1.424) increased odds in visiting the ED for an asthma exacerbation or a URI.
The adjusted single and multi-pollutant model for hospitalizations is also included in table 7. When controlling for temperature, at lag 0 the exposure to NO_2 is associated with a 2.3% (95% CI: 1.006, 1.040) higher odds to being hospitalized due to an asthma or URI event during the warm season. Including ozone and $PM_{2.5}$ modifies the significance of lags 1 (95% CI: 1.007, 1.045) and 7 (95% CI: 1.007, 1.046) to 2.6% higher odds, as well as cumulative lag 0-7 (95% CI: 1.073, 1.737) to 36.5% higher odds in being hospitalized for an asthma or URI event. Lag 0 increases in magnitude to 2.8% (95% CI: 1.008, 1.048) higher odds.

Table 8. Multi-Pollutant NO_2 Exposure Model (Warm Season)

Single and Cumulative Lags	ED Visits Adjusted and Multi-Pollutant Models						Hospitalizations Adjusted and Multi-Pollutant Models					
	NO_2 Adjusted for C^o			NO_2 Adjusted for C^o, O_3 and $PM_{2.5}$			NO_2 Adjusted for C^o			NO_2 Adjusted for C^o, O_3 and $PM_{2.5}$		
	OR	95%	CI	OR	95%	CI	OR	95%	CI	OR	95%	CI
Lag 0	1.021***	1.015	1.027	1.023***	1.015	1.030	1.023**	1.006	1.040	1.028**	1.008	1.048
Lag 1	1.009***	1.005	1.014	1.024***	1.017	1.031	1.004	0.992	1.016	1.026**	1.007	1.045
Lag 2	1.004	0.999	1.008	1.019***	1.012	1.026	0.989	0.978	1.001	1.000	0.982	1.018
Lag 3	1.005	1.000	1.009	1.020***	1.013	1.027	1.002	0.990	1.014	1.012	0.993	1.032
Lag 4	0.997	0.993	1.002	1.015***	1.008	1.022	0.998	0.987	1.010	1.011	0.992	1.031
Lag 5	1.003	0.998	1.007	1.013***	1.006	1.020	1.004	0.992	1.016	1.002	0.983	1.021
Lag 6	1.000	0.996	1.004	1.008	1.001	1.015	0.997	0.986	1.009	1.007	0.989	1.026
Lag 7	1.004	1.000	1.009	1.012**	1.004	1.019	1.009	0.998	1.021	1.026**	1.007	1.046
Lag 8	1.002	0.998	1.006	0.998	0.991	1.006	0.991	0.980	1.002	0.987	0.968	1.007
Lag 9	1.007	1.003	1.011	1.010**	1.003	1.017	0.999	0.987	1.010	0.994	0.975	1.014
Lag 10	1.002	0.998	1.006	1.005	0.998	1.012	1.006	0.994	1.018	1.008	0.989	1.028
Lag 11	0.998	0.993	1.002	1.007	1.000	1.014	1.001	0.989	1.012	1.020*	1.001	1.040
Lag 12	0.999	0.995	1.003	1.002	0.995	1.009	0.991	0.979	1.002	1.007	0.988	1.027
Lag 13	0.998	0.994	1.002	1.003	0.996	1.011	1.005	0.994	1.017	1.009	0.989	1.028
Lag 14	0.998	0.994	1.001	1.016***	1.009	1.024	1.000	0.989	1.010	1.019	0.998	1.040
Lag 0-1	1.011	0.997	1.026	1.010	0.989	1.032	1.029	0.991	1.070	1.052	0.996	1.112
Lag 0-7	1.017	0.962	1.076	1.112*	1.013	1.220	1.158	0.994	1.349	1.365*	1.073	1.737
Lag 0-14	0.965	0.912	1.021	1.274***	1.140	1.424	1.001	0.856	1.171	1.335	0.984	1.812

*Levels of significance: *p<.05; **p<.01; ***p<.001*

Unadjusted and Adjusted pollutant models for PM2.5 (Cold season)

The unadjusted estimates for ED visits associated with PM2.5 exposure in table 9, were significant for all lags except for lag 4, ranging from 0.05% (95% CI: 1.001, 1.009) to 1.7% (95% CI: 1.013, 1.020) increased odds. The cumulative lag 0-14 is associated with 28.1% (95% CI: 1.219, 1.346) increased odds of having a visit to the ED during the cold season. For hospitalizations, the unadjusted estimate for lag 0 was associated with 1.9% (95% CI: 1.010, 1.029) increased odds for having been admitted to the hospital due to an asthma exacerbation or an URI. The cumulative exposure lag 0-14 was found to be associated with 17.3% (95% CI: 1.016, 1.353) increased odds for hospitalizations.

Table 9. Single $PM_{2.5}$ Pollutant Exposure Models (Cold Season)

Single and Cumulative Lags	ED Visits Single Pollutant Model $PM_{2.5}$ (μg/m3)			Hospitalizations Single Pollutant Model $PM_{2.5}$ (μg/m3)		
	OR	95%	CI	OR	95%	CI
Lag 0	1.015***	1.012	1.018	1.019***	1.010	1.029
Lag 1	1.006**	1.002	1.010	0.994	0.982	1.006
Lag 2	1.010***	1.006	1.014	1.005	0.993	1.017
Lag 3	1.010***	1.007	1.014	1.006	0.995	1.017
Lag 4	0.998	0.994	1.002	0.997	0.986	1.008
Lag 5	1.005**	1.001	1.009	1.004	0.992	1.015
Lag 6	1.005*	1.001	1.009	1.007	0.996	1.019
Lag 7	1.014***	1.010	1.019	1.007	0.996	1.017
Lag 8	1.006**	1.001	1.010	1.004	0.991	1.017
Lag 9	1.010**	1.006	1.015	1.006	0.994	1.019
Lag 10	1.004*	1.000	1.008	1.008	0.997	1.020
Lag 11	1.007**	1.003	1.011	1.004	0.993	1.015
Lag 12	1.004*	1.000	1.008	1.009	0.997	1.020
Lag 13	1.009***	1.005	1.013	1.014*	1.002	1.025
Lag 14	1.017***	1.013	1.020	1.010*	1.001	1.020
Lag 0-1	0.992	0.978	1.005	0.978	0.939	1.020
Lag 0-7	1.074*	1.014	1.138	1.026	0.864	1.218
Lag 0-14	1.281***	1.219	1.346	1.173*	1.016	1.353

*Levels of significance: *p<.05; **p<.01; ***p<.001*

Table 10 includes adjusted models for ED visits and hospitalizations when controlling for temperature during the cold season, and concomitant NO_2. The estimates of association between exposures to $PM_{2.5}$ and asthma or URI health endpoints continued to be significant for all lags except for lags 4 and 12. The cumulative lag 0-14 found a similar association as the single pollutant unadjusted model in which the SJV residents had 28.0% increased odds to attending the emergency room due to asthma or URIs. For hospitalizations lag 0 while controlling for temperature and NO_2 shows a significant 1.5% (95% CI: 1.004, 1.026) increased odds in having a hospitalization. The cumulative lag 0-14 shows an association of 16.5% (95% CI:1.009, 1.345) increased odds to having a hospitalization after cumulative exposure to $PM_{2.5}$.

Table 10. Multi-Pollutant $PM_{2.5}$ Exposure Models (Cold Season)

Single and Cumulative Lags	ED Visits Adjusted and Multi-Pollutant Models						Hospitalizations Adjusted and Multi-Pollutant Models					
	$PM_{2.5}$ (µg/m3) Adjusted for C°			$PM_{2.5}$ (µg/m3) Adjusted for C° and NO_2			$PM_{2.5}$ (µg/m3) Adjusted for C°			$PM_{2.5}$ (µg/m3) Adjusted for C° and NO_2		
	OR	95%	CI	OR	95%	CI	OR	95%	CI	OR	95%	CI
Lag 0	1.012***	1.009	1.015	1.012***	1.008	1.015	1.018***	1.008	1.028	1.015**	1.004	1.026
Lag 1	1.009***	1.005	1.013	1.009***	1.005	1.013	0.996	0.984	1.007	0.995	0.984	1.007
Lag 2	1.010***	1.006	1.014	1.010***	1.006	1.014	1.006	0.994	1.017	1.005	0.993	1.017
Lag 3	1.010***	1.007	1.014	1.010***	1.007	1.014	1.006	0.995	1.017	1.006	0.995	1.017
Lag 4	0.999	0.995	1.003	0.999	0.995	1.003	0.997	0.986	1.008	0.997	0.986	1.008
Lag 5	1.005**	1.001	1.009	1.005**	1.001	1.009	1.003	0.992	1.015	1.004	0.992	1.015
Lag 6	1.006**	1.002	1.010	1.006**	1.002	1.010	1.009	0.997	1.021	1.009	0.997	1.021
Lag 7	1.014***	1.010	1.018	1.014***	1.010	1.018	1.006	0.995	1.018	1.006	0.995	1.018
Lag 8	1.006**	1.001	1.010	1.006**	1.001	1.010	1.004	0.992	1.017	1.004	0.992	1.017
Lag 9	1.013***	1.009	1.017	1.013***	1.009	1.017	1.008	0.996	1.021	1.008	0.995	1.021
Lag 10	1.006**	1.002	1.010	1.006**	1.002	1.010	1.009	0.998	1.021	1.010	0.998	1.021
Lag 11	1.006**	1.003	1.010	1.007**	1.003	1.010	1.004	0.993	1.015	1.004	0.993	1.015
Lag 12	1.004	1.000	1.008	1.004	1.000	1.008	1.008	0.997	1.020	1.007	0.996	1.019
Lag 13	1.009***	1.005	1.013	1.009***	1.005	1.013	1.014*	1.002	1.025	1.014*	1.002	1.025
Lag 14	1.017***	1.013	1.020	1.016***	1.013	1.020	1.010*	1.001	1.020	1.010*	1.000	1.020
Lag 0-1	0.997	0.984	1.011	0.997	0.984	1.011	0.981	0.941	1.022	0.981	0.999	1.039
Lag 0-7	1.070*	1.011	1.133	1.070*	1.011	1.133	1.014	0.855	1.203	1.014	0.855	1.203
Lag 0-14	1.280***	1.218	1.345	1.278***	1.216	1.344	1.171*	1.015	1.352	1.165*	1.009	1.345

*Levels of significance: *p<.05; **p<.01; ***p<.001*

Conclusions and Limitations

As a first step and to contribute new knowledge to the health economics literature, this study posed the research question when SJV residents were exposed to higher concentrations of three criteria pollutants, $PM_{2.5}$, O_3, NO_2, would the odds of ED visits and hospitalizations increase for asthma and URI exacerbations within 14 days of exposure. The results confirm that SJV residents are increasingly vulnerable to short-term increases in outdoor pollution and asthma and URIs. The study also reports patient characteristics of Valley residents who were exposed to higher pollution, in which relative differences between counties, age groups and race/ethnicity are likely to be significant. Sex was not significant, but payer source yielded mixed estimations. Payer source was utilized as a proxy for income level of patients and illustrated that emergency rooms and hospitals may be the only source of care for uninsured SJV residents when asthma and respiratory health is exacerbated by pollution exposure. Inquiring the effect modification in the association between exposure to ambient pollution and asthma by socioeconomic variables, and its mechanisms, were not part of this study but could be worth interrogating in future work.

For the year 2016, the cases included in this time stratified case-crossover study found an unadjusted association between higher levels of exposure to ground-level ozone during lag 0, in the warm season, with 0.3% increased odds of visiting the emergency department (ED) for an asthma or URI event and not for hospitalizations. The adjusted and multi-pollutant O_3 models did not estimate associations between higher exposures and attendance to the ED or hospital admissions. These findings differ from previous studies conducted in the region, but those analyses included 11-year pooled data (Entwistle et al., 2019a; Gharibi et al., 2018), and this study includes reported hospital data for a single year. Because this analysis did not investigate variation in O_3 distribution by rural and urban areas, due to the lack of pollutant data from important rural population centers in the region, the ozone paradox was not investigated (Cisneros & Perez, 2007; Malashock et al., 2022); alas could have been a contributor to the modest health outcome effects. However, similar exposure studies conducted in Northern California, France and a meta-analysis did not find conclusive association between asthma and exposure to ozone (Anderson, Favarato, & Atkinson, 2013; Chang, Graff Zivin, Gross, & Neidell, 2016a; Laurent et al., 2008).

In federal standard attainment status, NO_2 emerges as the cause in the increases of asthma ED visits and hospitalizations during the warm season for SJV residents exposed to marginal elevations of pollutant concentration. Ozone and NO_2 concentration distributions in the region were inverse due to the relationship in their chemical reactions, as nitrogen dioxide is a precursor of ozone formation. These findings are consistent with existing epidemiological studies (Brandt, Vásquez Lavín, & Hanemann, 2012a; Cisneros et al., 2021; Tavallali et al., 2020). Thus, during the 2016 warm season, NO_2 estimates indicated that increases in exposure raised the odds of hospitalizations and ED visits for asthma and URIs in the single, adjusted, and multi-pollutant models. The estimates increased in magnitude when the model is adjusted for $PM_{2.5}$ and O_3 and controlled for temperature, which may be indicative of the synergistic effect that NO_2 and concomitant pollutants have on human health. While studying the cumulative effects of NO_2, the

multi-day lag of the precedent two-week exposure indicates 27.4% increased odds to have an emergency visit for asthma or URI.

Whereas $PM_{2.5}$ has been associated with mortality [and higher monetization], its transient effects on SJV cases of nonfatal asthma and URI-related morbidity were studied. Modeling included adjusting for the cold season to address nonlinearity of the pollutant and meteorological factors. Other studies have included temporal interactions in their exposure modeling to determine if regional seasons are mediators of health outcomes association and several studies have found the relationship with asthma and the impact of $PM_{2.5}$ as an irritant (Fan, Li, Fan, Bai, & Yang, 2016; Gleason, Bielory, & Fagliano, 2014).

The single pollutant model for $PM_{2.5}$ indicate that during the cold season in the SJV every single day exposure to $PM_{2.5}$ is significantly associated with increases in the odds of ED visits, except for lag 4. The cumulative effects of 14 days of precedent exposure estimates a 28% increase in the odds of visiting the ED for an asthma exacerbation. Single-day estimates of $PM_{2.5}$ exposure (lag 0, 13 and 14) show increased odds for hospitalizations due to asthma and URIs, and cumulative exposure (lag 0-14) increased the odds of hospitalization for asthma in 17.3%. The adjusted model, controlled for NO_2 and temperature, had similar magnitude of effects for each single and multi-day exposures to $PM_{2.5}$. Short-term exposures to ambient particulate matter has been linked to children and adult hospitalizations for respiratory disease and this study findings are consistent with existing literature (Li et al., 2018; Tian et al., 2019; Wang et al., 2021). Because $PM_{2.5}$ may be emitted as a primary pollutant through combustion of fossil fuels, and as a secondary through the chemical process interacting with other pollutants present, makes evidence that microscopic particulate matter is deterministic for adverse respiratory health outcomes. Furthermore, due to the unique geography of the SJV, during the cold season $PM_{2.5}$ is sequestered by temperature inversion layers resulting in concentration and distribution spikes.

Limitations

The limitations of this study include issues related to the inclusion of adverse health events for important rural population centers in the region. Because pollutant data within 15 km radius from any sample station was not available from important population centers in the SJV, such as Los Banos City and the town of Oakhurst in the hills of Madera County, the odds of attending the ED or being hospitalized due to asthma and URIs could have been underestimated. The lack of pollutant data for some rural areas, allowed for the exclusion of ED visits and hospitalizations for respiratory effects of their residents. Federal pollution monitoring is absent in place despite the importance of these communities in the region.

Misclassification could have occurred since levels of ambient pollution is used to ascertain personal exposure of residents. The air pollution exposures were assigned to each of the patient's residential zip code given a 15 km of the sampling station, this could have caused weak correlations between pollutant concentrations and health endpoints included in the study.

Another limitation is the potential for cases exclusion since only principal diagnosis codes were used, and selected health endpoints reported as secondary or third

were not included in the analysis. This may produce lack of specificity, but it was a tradeoff in the selection of inclusion/exclusion criteria to avoid non-ambient air pollution related outcomes.

Chapter IV.

Study #2

Rationale

Compelling scientific literature has demonstrated the detrimental effects on human health of primary and secondary anthropogenic ambient air pollution: nitrogen dioxide (NO_2), particulate matter ($PM_{2.5}$), and ground-level ozone (O_3) (Billionnet, Sherrill, & Annesi-Maesano, 2012; Kampa & Castanas, 2008; Kelly & Fussell, 2015). Children, adolescents, the elderly, and patients with cardiopulmonary diseases are particularly at risk of the deleterious effects of exposure to concentrations of criteria pollutants (American Lung Association, 2019; Landrigan et al., 2002).

Periods of pollution exposure are associated with increased health burden related to respiratory inflammation and undermined lung function, which aggravates respiratory diseases such as asthma and leads to symptoms such as coughing, wheezing, or difficulty breathing (Latza et al., 2009). Furthermore, the U.S. Environmental Protection Agency (EPA) has recognized that human exposure to air pollutants, such as particular matter and ground-level ozone, are likely causes of asthma and respiratory infections (EPA, 2019a). In the U.S. asthma costs $82 billion annually in healthcare costs, missed work, and school absences (Nurmagambetov, Kuwahara, & Garbe, 2018). In other developed countries respiratory diseases account for 52 million DALY losses per year, a conservatively estimated value of $317 billion in healthcare costs, lost productivity, and disability (World Health Organization, 2016).

By 2050, global health-related costs from ozone exposure will be estimated to reach $580 billion (Selin et al., 2009). For Etchie et al. (2017), in just one region of India, economic losses due to PM2.5 pollution were valued at US$ 2.2 billion in 2013. NO_2 has been deemed the "most harmful" of all nitrogen oxide compounds that humans are exposed to daily (UN, 2021), and the National Health Service (NHS) of England has estimated that by 2025, NO_2 will cost US$ 3.29 billion in healthcare and social costs for childhood asthma, coronary heart disease, stroke, and lung cancer (Public Health England, 2018).

A scoping literature review of articles published was chosen as an appropriate approach for this examination of available scientific studies. The intent of this approach is to provide a description of the available evidence rather than provide a critical evaluation of the quality of evidence.

There was no year or date restrictions to identify published articles. The Pubmed online catalog, EconLit, and Google scholar databases were used to conduct the search. The following key terms were included in the first search "cost of illness" and "outdoor air pollution"; a total of eighty-three published articles were listed. One article identified in a local agency advertisement was included in the search.

A total of 84 journal articles were identified for the initial review. To be included in the review, articles had to be published in English, Spanish or Portuguese given the linguistic ability of the researcher. Most of the articles resulting from the search included research conducted in diverse countries such as the US, Western Europe, Asia and the Middle East. Articles that have different titles but were duplicates (3) were removed,

forty-six articles were removed after reviewing the abstract and title. Additionally, 24 studies were removed for not including ambient air pollution, referring to tobacco smoking related disease, tuberculosis, lacking air pollution modeling, not including economic evaluation, and monetizing treatment of air pollution.

Studies that presented plausible methodology to identify costs related to the health effects of outdoor air pollution were selected for the final review. A summary of each article identifying authors, year, location, study type, methods, aim, population characteristics, and findings is included in Table 11.

In 1999, D. Zmirou examined the health effects and costs of particulate air pollution in France. The researcher found that in a population of 1 million residents who lived nearby a power plant, the cost of exposure to particulate matter oscillated between 79 to 135 million francs annually. Those costs were related to medical care, drugs, labs, and x-rays for exacerbations of asthma, bronchitis, and other respiratory conditions.

El-Fadel & Massoud (2000) made a health-based economic assessment of PM exposure in urban areas of Lebanon and found that for people ages 40-59 there was a loss of productivity of 20 years associated to pneumonia, COPD and emergency department visits related to PM. The total range of economic losses due to the health burden of particulate matter in Lebanese residents was USD$2,700,000 - USD$126,000,000.

India and China have the fastest growing populations and economies in the world (International Monetary Fund, 2019; World Health Organization, 2016). Estimations from the World Bank indicate that air pollution costs India the equivalent of 8.5% of its annual growth domestic product (The World Bank, 2016). Patankar, Trivedi, & Somaiya (2011) studied the costs of bronchitis, asthma, and other acute symptoms related to PM, nitrogen dioxide, sulfur dioxide, and ammonia. The researchers noted that for a period of 13-months the costs associated to these health issues were $113.08 million USD for PM, and $218.1 million USD for NO_2.

China is at a similar juncture and many studies have been conducted to determine the costs and the burden of health in its residents. Niu, Chen, & Kan (2017) estimated that excess deaths, premature mortality, hospital care, medicines and outpatient visits for bronchitis and asthma related to $PM_{2.5}$ resulted in welfare loss of $126.6 billion - $1,589.8 billion USD. The labor output lost was in the range of $12.5 - $44.6 billion USD. Similarly, another study calculated that in 2013 prices, asthma, acute and chronic bronchitis associated to $PM_{2.5}$ exposure costed China $55.01 billion USD for one year. The costs were due to hospital care, outpatient visits and labor income losses.

In the US and for the last 40 years, stationary sources (i.e., power plants) have been the largest emitters of greenhouse gases until recently. The U.S. Energy Information Administration has reported that the top spot in emissions of CO_2 are mobile sources or transportation with 1.9 million tons annually (Yale School of Forestry & Environmental Studies, 2017). The adoption of stricter fuel efficiency standards and the transition to electric-power vehicles are expected to maintain or curb this level of emissions in the nation (US Global Change Research Program, 2014).

Brandt et al. (2017, 2014) has conducted studies quantifying the costs of near roadway air pollution (NRAP) in the LA county and Southern California region. The estimations in 2010 USD were $441 million for ozone, and $202 million for nitrogen dioxide related to the cost of hospital admissions, emergency department visits,

medications, and caregiver lost wages to care for asthma exacerbations in children, as well as bronchitis. Also, the researchers found that the costs of coronary heart disease hospitalizations, treatment, and mortality associated to $PM_{2.5}$ were $16,751 million USD and for NRAP as much as $11,461 million USD only for traffic density in 2018 USD.

Hall, Brajer, & Lurmann (2008) conducted a COI study to measure the potential gains should the SJV region improved its air quality. The research estimated $PM_{2.5}$ and ozone health effects and costs for ED visits, hospital admissions, school absences, work loss days, and restricted activity days of asthma, bronchitis, respiratory symptoms, and premature mortality. They concluded that ozone attributed health costs are $32.64 million per year, and $3,206 million per year is attributed to $PM_{2.5}$ exposures; effectively $1,000 per person in the Valley per year.

Per the evidence reviewed, a COI study is a prevailing method to valuing economic burden of disease. The human capital theory is the leading approach used in COI of air pollution research. Several of the studies mentioned that willingness to pay (WTP) methods were used in combination to reduce underestimation of nonmarket costs of diseases, especially when it is related to premature mortality estimates.

Research Questions

Employing a societal perspective, a cost-of-illness (COI) study was employed to analyze the economic impact (CDC, 2017; Jo, 2014) of air pollution-related adverse health outcomes, asthma and upper respiratory infections, amongst SJV residents who attended the ED and were hospitalized in 2016. The research questions of this study were:

I. What are the asthma and URI direct and indirect health costs of SJV residents exposed to higher concentrations of NO_2, $PM_{2.5}$, and O_3?

II. What is the effect of reducing pollution concentrations of O_3, NO_2 and $PM_{2.5}$ in the attributable cases of asthma and URI ED visits and hospitalizations?

Methods

To test the research questions, the study's design included strengthening factors from past economic-based health projects: 1) A COI study is a prevailing method for valuing the economic burden of disease; 2) The human capital theory (Becker, 1975; Jo, 2014; T. W. Schultz, 1961) is the leading approach used in COI or economic burden of disease studies; and 3) the study utilized a prevalence method (Ament & Evers, 1993; Byford et al., 2000) to estimate ED and hospitalization costs related to air pollution in 2016.

Exposure Assessment

The approach for assessing exposure in the SJV is derived from study #1, an epidemiological time-stratified case-crossover study that examined the relationship between exposure to NO_2, O_3, and $PM_{2.5}$ and adverse health outcomes in asthma and upper respiratory infections (URIs) using linked ED and hospitalization records as reported to the State of California Department of Health Care Access and Information (HCAI). The estimates describe the marginal effects of the associations between pollutant concentrations and adverse health outcomes are the base for calculating population-attributable asthma outcomes. The health endpoints included in this study are shown in Table 12. For O_3, the pollution-related asthma & URI estimate selected was for the ED visits in the SJV for 2016, since the hospital admissions estimate was not statistically significant in the first study, it was not included in this study.

Table 12. Health Endpoints

Health endpoint	ß -value	Source
ED visits, O_3	1.003 per 1 ppb	Unp - Zarate-Gonzalez, Cisneros, Gharibi, Brown (2023)
ED visits, $PM_{2.5}$	1.012 per 1 μg/m3	Unp – Zarate-Gonzalez, Cisneros, Gharibi, Brown (2023)
ED visits, NO_2	1.023 per 1 ppb	Unp – Zarate-Gonzalez, Cisneros, Gharibi, Brown (2023)
Hospital visits, $PM_{2.5}$	1.015 per 1 μg/m3	Unp – Zarate-Gonzalez, Cisneros, Gharibi, Brown (2023)
Hospital visits, NO_2	1.028 per 1 ppb	Unp – Zarate-Gonzalez, Cisneros, Gharibi, Brown (2023)
Hospitalization length of service	mean 6.3 days per event	Unp – Zarate-Gonzalez, Cisneros, Gharibi, Brown (2023)
Use of controllers	mean 4.84 per event	Kattan et al. (2005)
Use of rescue inhalers	mean 5.95 per event	Kattan et al. (2005)

Cromolyn	mean 2.64 per event	Kattan et al. (2005)
Use of antibiotics	0.31 – 0.58 per event	Kattan et al. (2005)
School absences	mean 9.2 annual	Moonie, Sterling, Figgs, & Castro (2006)
Work loss days >18 - 64	0.122	CHIS (2021)
Opportunity cost > 65	mean 3.5	Van Der Zee et al. (2000)
Asthma prevalence in the SJV region 2-17	0.11	CHIS (2021)
Asthma prevalence in the SJV region 18 – 64	0.196	CHIS (2021)
Asthma prevalence in the SJV region > 65	0.175	CHIS (2021)

Air-pollution Attributable Health Effects

Based on previous studies, the background levels of pollution selected were the interquartile ranges for O_3 and NO_2 parts per billion measurements in the warm season and $PM_{2.5}$ per $\mu g/m^3$ in the cold season. The pollutant-related effects for the exposed population (P_e) were calculated per 1 interquartile range (IQR) concentration levels at the 75^{th} percentile to the maximum of each pollutant in the concentration-response function (CRF).

Using the 2016 population estimates from the California Department of Finance (2021), the proportion of exposed (P_e) was estimated for each SJV county. The attributable risk percent (AP) for case control studies (Cole & MacMahon, 1971) was estimated to demonstrate the burden of ED visits and hospitalizations that are attributed to each pollutant among the exposed.

To model the number of events that may be averted with marginal decreases of pollutant concentrations in the SJV, the population-attributable fraction was calculated using the modeled background concentration-response of exposure effects for ED visits and hospitalization cases adjusted for seasonality. The standard formula was applied for case-control designs (see Equation 2) (Hoffman, 2019; Shrier & Steele, 2006; J. Zhang & Yu, 1998).

$$RR = \frac{OR}{(1 - P_e) + (P_e \times OR)} \quad [2]$$

The data from the California Health Interview Survey (CHIS) sources were used to identify the prevalence of asthma among people in the SJV. CHIS is a statewide health survey housed at the UCLA Center for Health Policy Research. The database was queried to gather estimated asthma rates by age of survey participants residing in the counties of the SJV (UCLA, 2019).

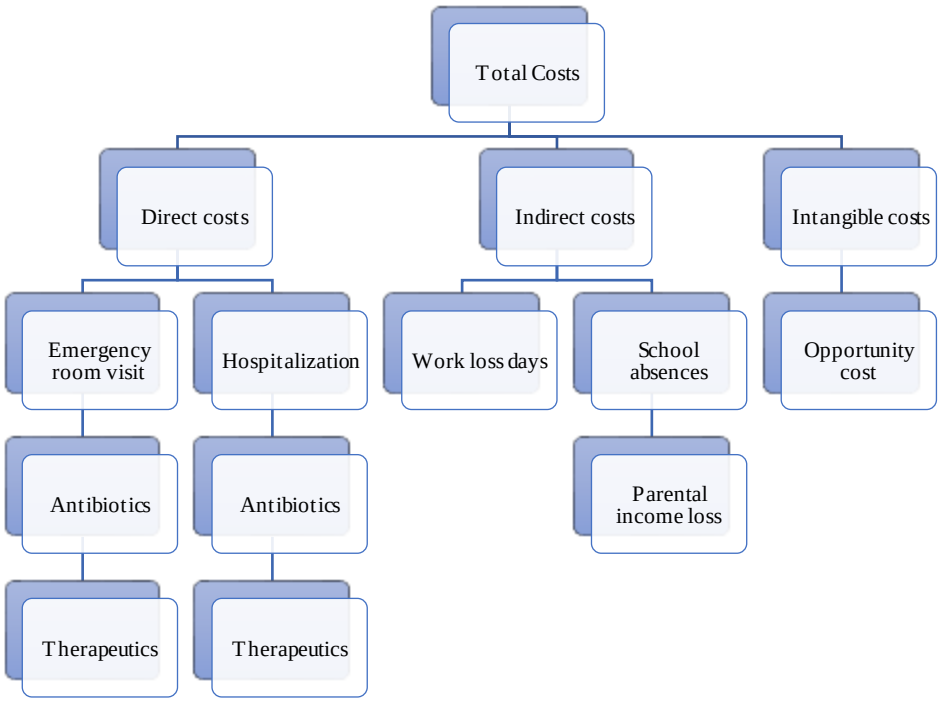
The analysis was conducted using STATA V.18 (College TX, 2021).

Monetized Value of Air pollution-related Morbidity

Cost Typology

The typology of the direct, indirect, and intangible morbidity costs attributed to O_3, NO_2, and $PM_{2.5}$ pollution exposure is found in Figure 5. This approach accounts for a comprehensive estimate of healthcare and social costs attributed to ED visits and hospital admissions.

Figure 5. Cost typology for Asthma ED visits and Hospitalizations



Economic Valuation: Direct Costs

To monetize the air-pollution-related adverse health outcomes, the direct value attributed to ED and hospitalization cases was assessed using the 2016 Medicare Physician Fee Schedule and the Medicare Inpatient Hospitals Payments dataset from the Centers for Medicare and Medicaid Services (CMS) (2019). The approach to determine the cost of ED visits included estimating the mean amount paid for each operating procedure code reported in all encounters included in the exposure assessment, see Equation 3.

$$\sum_{i=1}^{n} \frac{opr_1 + opr_2 + opr_3 \ldots + opr_n}{n} \quad [3]$$

The estimation of an economic value for each hospitalization was retrieved from HCAI-linked patient discharge data which included diagnostic-related groups (DRGs) for

asthma and URIs events in 2016. A uniform price was calculated using the CMS average paid dataset available by geography. The use of CMS payments by DRGs and procedure codes restricted potential underestimations or overestimations caused by variability in charges by providers or payments by health insurers and reduced uncertainty. Because DRGs are based on a resource-based valuation approach (Caputi & Heiss, 1984; Harada et al., 1993; Mcneil, 1985) they more accurately reflect the value of the resources associated with treatments than payments by private insurers.

The cost of medications associated with asthma management therapeutics such as antibiotics, controllers, and rescue inhalers were obtained using data from the available literature and the publicly available data. Existing literature will be used to identify the characteristics and recommended frequency of pharmaceutical use and duration, such as clinical guidelines. Market prices were used to estimate the cost of the treatments.

Undergoing this approach allowed a comprehensive inclusion of all healthcare related to an ED visit or hospitalization due to asthma exacerbations or upper respiratory infections.

Economic Valuation: Indirect and Opportunity costs

The indirect costs for ED visits and hospitalizations due to air pollution-related asthma and URI exacerbations were the value of adult (18+ years of age) SJV resident cases' time waiting and receiving care. For children 2-17 years old, the value of time included a parent or caretaker's time waiting and caring for the patient. Indirect and intangible cost data, such as loss of workdays or productivity loss, and school absences were obtained through the exposure assessment patient discharge data, peer-reviewed literature, and educational and labor agencies, such as the California Employment Development Department, see Table 13.

Table 13. Economic Values

Health endpoint	US Dollar value	Source
ED visits	427.91	CMS PFS (2016) procedures performed for ICD10 codes: J45, J06, R06-R06, Z77.1
Hospital visit	2,099.55 per inpatient day	CMS Inpatient Data (2016) for hospitalizations with ICD10 codes: J45, J06, R05-R06 and Z77.1
Controllers	281	Epocrates (2023)
Rescue inhalers	78	Epocrates (2023)
Cromolyn	332	Epocrates (2023)
Antibiotics	57-67	Epocrates (2023)
School absences	60.23	Ed-Data Education Data Partnership (2016)
Work loss days >18	80.43- 137.33	California EDD (2023) & U.S. Bureau of Labor Statistics (2018)
Opportunity cost > 65	45.33	Social Security Administration (2017)

Furthermore, for ED visits, one workday was used as the time for missed school by children and a workday or productivity loss for the parent/caretaker and valued at the state reimbursement loss for the average daily attendance reimbursement and average wage rate in California. For the population 65+ years of age, the opportunity cost for ED visits and hospitalizations was estimated to assess the value of time that could be spent doing other activities, the base of the calculation was average symptom days for ED visits obtained from the literature, and the mean length of service days for 2016 hospitalizations. The economic value was retrieved from the Social Security Administration's average retiree benefit amount in 2016.

Results

Estimates of attributable risk proportion (AR%) for asthma & URI ED visits and hospitalizations in 2016 from exposure to the three criteria pollutants included in this study are presented in Table 14 with lower and upper limits. The highest risk among the exposed is attributed to $PM_{2.5}$ in ED visits, and ground-level O_3 had the lowest risk. Because NO_2 was found to have higher odds of attending the ED and being hospitalized in the warm season of the SJV air basin, the risk for NO_2 is also higher in the exposed than the effects of exposure to O_3.

The exponential odds ratio increases per 1 IQR of each pollutant measured by federally regulated air monitors in 2016 are presented with 95% confidence intervals.

Table 14. Attributable Risk Proportion

Exposure	IQR	OR	95% CI	AP	Lower/Upper Limit
O_3 ED Visit	20.6	1.068	1.005 - 1.135	0.063	0.025 - 0.118
NO_2 ED Visit	4.5	1.149	1.121 - 1.177	0.129	0.108 - 0.151
$PM_{2.5}$ ED Visit	14.5	1.222	1.189 - 1.256	0.181	0.159 - 0.204
NO_2 Hospitalization	4.5	1.157	1.083 - 1.236	0.135	0.076 - 0.191
$PM_{2.5}$ Hospitalization	14.5	1.170	1.078 - 1.269	0.145	0.073 - 0.212

To evaluate the economic and public health impact of reducing the exposure to O_3, NO_2, and $PM_{2.5}$ in asthma & URI-related ED visits and hospital admissions, first, the population-attributable fractions were estimated for each pollutant at the IQR levels in each season of 2016. The SJV population exposed proportion and the adjusted population attributable fraction (PAF) for each pollutant in the study are shown in Table 15.

Table 15. SJV Region Population Attributable Fraction

Exposure (Background)	% of ED visits P_e	% of hospital admissions P_e	PAF (%)	95% Confidence Interval
O_3 ED Visit	33.51	-	6.31	0.40 – 11.87
NO_2 ED Visit	36.11	-	7.49	5.21 – 9.70
$PM_{2.5}$ ED Visit	36.53	-	4.75	3.80 – 5.70
NO_2 Hospitalization	-	36.52	8.39	2.09 – 14.28
$PM_{2.5}$ Hospitalization	-	36.10	3.41	0.73 – 6.03

To illustrate the SJV population residents that were exposed to each criteria pollutant included in the study, using the is available results from the unpublished study#1 for six counties of the region, the estimates are available in Table 16.

Table 16. SJV Population Exposed by County and Criteria Pollutant

	Population Exposed to Ozone		Population Exposed to $PM_{2.5}$				Population Exposed to NO_2			
	ED %	P_e	ED %	P_e	Hosp %	P_e	ED %	P_e	Hosp %	P_e
County										
Fresno	52.64	504,009	35.52	340,091	34.35	328,889	24.88	238,217	23.34	223,472
Kern	59.21	507,482	54.08	463,514	51.57	442,001	56.76	486,484	51.51	441,487
Madera	52.89	79,421	27.24	40,904	28.78	43,217	0.00	N/A	0.00	N/A
Merced	49.28	129,493	26.88	70,632	28.28	74,311	0.64	1,682	1.00	263
San Joaquin	11.19	80,254	29.78	213,579	29.44	211,141	41.07	294,550	42.36	303,802
Tulare	7.02	31,733	88.11	398,287	86.30	390,105	90.71	410,040	93.40	422,200
All SJV Residents		1,363,117		1,485,964		1,468,880		1,468,473		1,485,558

Health Outcome: Emergency Department Visits

The estimated number of ED visits attributable to exposure to background levels of O_3, NO_2, and $PM_{2.5}$ concentrations is in Table 17. The cases are categorized by age for children (2-17 years of age), adults (18-64 years old), and older adults (65 years and older). The classification of results in these age categories demonstrates the difference in health care and societal costs associated with waiting, caring for, receiving treatment, productivity loss, missed school, and opportunity costs. Hence, the monetized costs range from US$ 3,353 to US$ 5,003 per ED visit, where children's asthma & URI monetization has a higher value because of the amount of time and resources that a parent or caretaker must spend with that child during symptoms days and treatment.

In 2016, the value to society for the cases of asthma & URI due to ground-level ozone was US$ 169,428,261. Of the total population of the SJV, which was 4,067,792 in 2016, 1,064,355 were children 2-17 years old, and asthma & URI cases attributed to ground-level ozone were 7,388. Working-age adults of the SJV had the largest proportion of the population, 2,522,151, and the number of cases attributed was 31,195. Adults 65 years and older were 481,286 in 2016 and accounted for 5,315 estimated cases of emergency room visits for asthma & URI attributed to ground-level ozone exposure. Estimates of NO_2 exposure effects on ED visit cases in children were 8,764 events, for

working-age adults 37,004, and for older adults 6,305. The value of NO2 exposure-related ED events was US$ 200,978,032 for the SJV population. $PM_{2.5}$ healthcare costs and economic losses represented US$ 127,607,832, with a burden of 5,565 visits to the ED for children, 23,495 for adults 18-64 years old, and 4,003 for the elderly.

Table 17. Emergency Department Event Attributed to Pollutant Background Levels

Asthma exacerbations & URIs in:	O_3	NO_2	$PM_{2.5}$	Value in US$
	ED	ED	ED	
Children 2-17	7,388 (470-13,897)	8,764 (6,103-11,361)	5,565 (4,449-6,669)	$ 108,650,057
Adults 18-64	31,195 (1,982-58,675)	37,004 (25,768-47,971)	23,495 (18,787-28,157)	$ 336,980,497
Adults 65+	5,315 (338-9,997)	6,305 (4,390-8,173)	4,003 (3,201-4,797)	$ 52,383,571
SJV Population	43,895 (2,790-82562)	52,069 (36,259-67,501)	33,061 (26,435-39,620)	$ 498,014,124
Value in US$	$ 169,428,261	$ 200,978,032	$ 127,607,832	

Health Outcome: Hospital Admissions

The exposure assessment did not find the association between O_3 exposure and hospitalization statistically significant; thus, it was not included in this study's estimated population-attributable effects of outdoor pollutants. The estimated cases of NO_2 and $PM_{2.5}$, with lower and upper limits, attributed effects on hospital admissions are reported in Table 18.

Asthma exacerbations & URI hospital admissions estimate value range was US$ 2,584 per inpatient day for adults 65 years and older to US$ 3,023 per child. The mean length of service for 2016 hospital admissions was 6.3 days in the exposure assessment.

The estimated hospitalizations for children in the SJV attributable to NO_2 were 9,818 and 3,998 for $PM_{2.5}$ and a value of US$ 41,769,155. Working-age adults' hospital admissions burden was 41,454 events for NO_2 and 16,879 for $PM_{2.5}$, and for the elderly NO_2 and $PM_{2.5}$ contributed to 7,063 and 2,876 cases respectively.

Table 18. Hospital Events Attributed to Pollutant Background Levels

Asthma exacerbations & URIs in:	NO_2	$PM_{2.5}$	Value in US$
	Hospitalizations	Hospitalizations	
Children 2-17	9,818 (2,442-16,719)	3,998 (850-7,060)	$ 41,769,155
Adults 18-64	41,454 (10,311-70,594)	16,879 (3,589-29,809)	$ 156,102,152
Adults 65+	7,063 (1,757-12,028)	2,876 (612-5,079)	$ 25,681,413
SJV Population	58,331 (14,509-99,333)	23,751 (5,051-41,944)	$ 223,552,720
Value in US$	$ 158,866,918	$ 64,685,803	

The estimated value to society for air pollution adverse health outcomes totaled US$ 498,014,124 in ED visits and US$ 223,552,720 in hospital admissions for the SJV population in 2016.

Modeling Exposure Reduction Effects on Health Outcomes

The population-attributable fraction (PAF) estimates the amount of excess fraction that is due to the exposure in the entire population. The PAF was used to estimate the impact of marginal pollution concentration reduction of one unit measure in the cases of ED visits and hospitalizations for asthma exacerbations and URIs in the SJV population. Each outcome is valued in 2016 US$ and is presented in Table 19.

Table 19. Health Effects of Per Marginal Reduction of Pollution Concentration

	O_3		NO_2		$PM_{2.5}$	
Reduction	-1 ppb		-1 ppb		-1 $\mu g/m^3$	
	Outcomes	Cost Savings	Outcomes	Cost Savings	Outcomes	Cost Savings
ED Visits						
Children	- 350	$ 1,750,679	- 2,007	$ 10,038,758	- 1,310	$ 6,554,972
Adults	- 1,477	$ 5,429,769	- 8,472	$ 31,135,423	- 5,532	$ 20,330,386
65+	- 252	$ 844,057	- 1,443	$ 4,839,997	- 943	$ 3,160,356
Total in US$		$ 8,024,505		$ 46,014,178		$ 30,045,714
Hospitalizations						
Children			- 2,254	$ 6,813,868	- 999	$ 3,021,055
Adults			- 9,516	$ 25,465,188	- 4,219	$ 11,290,463
65+			- 1,621	$ 4,189,449	- 719	$ 1,857,470
Total in US$				$ 36,468,505		$ 16,168,988
Total ED visits & Hospitalizations		$ 8,024,505		$82,482,683		$ 46,664,702

In the model for ground-level ozone, the decrease of 1 ppb in the background concentration of air quality would result in 2,079 fewer ED visits annually for children 2-17 years old, working-age adults, and adults 65 years and older. The total cost savings to society would be valued at US$ 8,024,505 in healthcare costs, productivity loss, school absences, and opportunity costs.

Reducing the concentrations of 1 ppb in the concentrations of NO_2 from the air that SJV residents breathe would save US$ 82,482,683 annually in 4,261 fewer asthma & URI ED visits and hospitalizations for children, 17,998 for working adults, and 3,064 fewer ED visits and hospitalizations for older adults.

The concentration reduction of 1 $\mu g/m^3$ would result in 7,785 ED visit cases averted for all ages and 5,937 hospital admissions for all SJV residents. The value of averting these adverse health outcomes was US$ 46,664,702.

Conclusions and Limitations

The findings of the second step of this research is one of the first public health economics studies to estimate the healthcare and social costs of air pollution-associated asthma and upper respiratory infections (URIs).

From the societal perspective and a prevalence approach, the estimated burden of exposures to O_3, NO_2, and $PM_{2.5}$ background pollutant concentrations in asthma exacerbations & URI ED visits, and hospital admissions was valued at US$ 721,566,844 for the year 2016 in healthcare costs, missed school, productivity losses of parents, caretakers, and working-age adults, and the opportunity costs for older adults. The estimated burden of ED events attributed to the studied criteria pollutants for the whole SJV population was 129,025, and hospital admissions attributed were 82,082. Modeling marginal reductions in pollutant concentrations resulted in averting 21,786 ED adverse events and 19,328 hospitalizations for asthma & URIs per each unit measure. Averting these adverse health outcomes would save an estimated US$ 137,171,890 in health care and social costs.

One of the strengths of the study is the use of regional epidemiological data. Using the short-term concentration-response associations of an epidemiological study based on San Joaquin Valley (SJV) residents', the analysis modeled what the region may gain in averting adverse health outcomes and attendance to emergency rooms (ED) and hospitalizations to receive treatment and care. Additionally, the use of CMS resource-based pricing utilizing DRGs reduces uncertainty compared to health economics studies that use provider charges or health insurance payments that do not reflect negotiated discounts by individual entities. Lastly, the stratification of age groups in the cost analysis is supported by evidence that children and the elderly are more susceptible to pollution exposure. Furthermore, children's air pollution-related morbidity is not only costly in terms of health care but also resource-intense in social costs due to care, missed school, and productivity loss by parents and caretakers.

Nevertheless, this study did not assess the quality and access to care for children, working adults, and the elderly in the SJV which could be of influence in the accounted health endpoints included. It has been documented in the peer-reviewed literature that older adults are more likely to be underdiagnosed and undertreated during respiratory events, such as asthma (Bauer, Reed, Yunginger, Wollan, & Silverstein, 1997; Gillman & Douglass, 2012; Yáñez et al., 2014). If this phenomenon was executed in the SJV, during the period of the study, then it could have resulted in an undercount of health outcomes for this age group.

The estimated costs differ from the $193 million calculated for hospitalizations in selected California hospitals from 2005-2007 (Romley, Hackbarth, & Goldman, 2012). However, the methodology used in that study combined ED visits and hospitalizations into single events, despite the inclusion of additional health endpoints, and used linear proportional reductions to model the cost savings of hospitalizations when exposure to ground-level ozone and $PM_{2.5}$ is decreased. In contrast, to calculate the cases attributed to pollution exposure, this study accounts for ED visits and hospitalizations to avoid duplication and used *ß*-value estimates which have been adjusted for meteorological factors, temporality, and seasonality to the nonlinearity of pollutant chemistry (Unp-

Zarate-Gonzalez, Cisneros, Gharibi & Brown, 2023). Another strength of this study is the use of concentration functions in response per 1 interquartile range measurements proceeding from federally regulated monitors and of the same year as the health endpoints, this differs substantially from other studies that use mean concentrations which include the lower and highest levels, as well as health values decades older than the baseline years.

In the study conducted by Hall, Brajer, & Lurmann (2010) morbidity, in baseline years 2002-2004, was valued at $32.64 million for ozone and $3.2 billion, in morbidity and mortality, for $PM_{2.5}$. The number of morbidity cases attributed to ground-level ozone and $PM_{2.5}$ could have been underestimated due to the exposure estimates extrapolated from non-SJV geographical areas and dissimilar time periods. In addition, their study used the value of statistical life (VSL) to monetize premature mortality from exposure to $PM_{2.5}$ which is a health endpoint that this study did not include.

Nonetheless, studies of cost estimation are helpful to assist decision-makers in formulating cost-effective policies to accelerate change in the region. In the present policy conditions, the SJV pollution attainment standards of 8-hour O_3 and 24-hour $PM_{2.5}$ are in extreme non-attainment and non-attainment respectively. As the exposure assessment study and the related value in economic costs in this analysis reflect, NO_2 is associated with the highest healthcare and social costs despite being in standard attainment status. Thus, this geographically remarkable air basin needs a swift and comprehensive public health approach to decarbonize its economy.

Limitations

In terms of evaluating healthcare and social costs of air pollution, a limitation of this study is related to the lack of primary care data included in the exposure assessment which could have led to an underestimation of burden to the region's residents and healthcare providers, and value estimates. Primary care data is difficult to access for research purposes and it could be a valuable effort to conduct a future exposure assessment study to study the association of major criteria pollutants conspicuous in the SJV and health outcomes.

Another limitation was that the study included monetization of health care costs associated with asthma and URI ED visits and hospital admissions attributed to air pollution exposure in the SJV. A limitation of the study is the limited assessment of intangible costs for the elderly population similar to other studies in which days spent in the ED or hospitalized were valued as the opportunity costs of spending that time in other activities and attributed to the daily average social security retirement benefit. Monetizing the pain and suffering of people attending the ED or hospitalized for an asthma exacerbation is a patent underestimation of the costs of a social choice, ostensibly, a *best practice* for health economists is to also evaluate the disutility of the health state changes to appropriately value pain and suffering attributed to the burden of toxic exposures or any illness.

Some economic studies have reflected on the appropriateness of using COI versus contingent valuation (CV) and willingness to pay or accept (WTP/WTA) methods to monetize the burden of diseases (Attari et al., 2009; Brandt, Vásquez Lavín, & Hanemann, 2012b; Hall et al., 2008; Larg & Moss, 2011; Navrud, 2001; M. Zhang et al.,

2008). However, the limitations on inclusiveness of existing CV and WTP studies available for this type of regional study applied to a region where there is a majority-minority racial/ethnic composition, would further add to the limitations of this study. Evidently, health economics has a lot more to do to include population-representative samples in instruments meant for resources and datasets in public health economic evaluations.

Chapter V.

Study #3

Rationale

Despite structural parameters, the SJV is one of the most polluted regions in the U.S., exceeding state and national standards for ground-level ozone (O_3) and particulate matter (PM) 2.5 (Barboza, 2013; Entwistle et al., 2019; Meng et al., 2010). In 2022, the American Lung Association gave every major city in the SJV a failing grade -F- in their 'State of the Air' report for high ozone days, as well as 24-hour and annual particulate matter pollution, (American Lung Association, 2022). NO_2 has been in attainment but available research supports that even under standard levels the pollutant is linked to visits to asthma and upper respiratory infections emergency room and hospitalizations for SJV residents (Cisneros et al., 2021; Tavallali, Gharibi, Singhal, Schweizer, & Cisneros, 2020; Zarate-Gonzalez - Unpublished research 2023).

Thus, communities have a lot more work to do to improve air pollution-related ill health in the immediate term. Recent research has investigated the application of community, household, and individual-level mitigation measures to protect health from air pollution's adverse effects.

Years of accumulating evidence supports that a significant contributor to asthma development (Holst et al., 2020; Thurston et al., 2020) and exacerbations (Guarnieri & Balmes, 2014) is outdoor air pollution and the U.S. Environmental Protection Agency has deem it a likely cause of respiratory disease (EPA, 2019a). Furthermore, a recent study found that an increase deterioration in air quality is associated with increases in polyclinic attendance for upper respiratory tract infections, acute conjunctivitis, lung disease, asthma, bronchitis, emphysema, and pneumonia (Sheldon & Sankaran, 2017).

The prevalence of asthma has been increasing worldwide. Asthma is a chronic pulmonary disease and depending on its severity contributes to significant morbidity and mortality (Carr & Bleecker, 2016). Asthma induces inflammation of the airways in which individuals experience cough, wheezing, chest tightness, and dyspnea due to airflow obstruction. If asthma is not well managed it could lead to pulmonary fibrogenesis and airway remodeling (Del Rio et al., 2022; Savin, Markov, Zenkova, & Sen'kova, 2022). Asthma is a ubiquitous public health issue in the San Joaquin Valley (SJV). In 2003, it was reported that 10.7% of the region's population reported asthma symptoms, one of the highest rates in California (Meng, Babey, Malcolm, Brown, & Chawla, 2003). The most recent California Health Interview Survey (UCLA Center for Health Policy Research, 2021) estimates that the prevalence of diagnosed asthma in the Valley is 17.1% for all age groups, compared to 16.6% in Bay area counties and 13.9% in Los Angeles County.

Adoption and Adaptation to Mitigation and Control Measures

In terms of air pollution control and mitigation policies and interventions, there is a menu of economic instruments for air pollution control and those have been written about elsewhere (Klaassen & Forsund, 1994), various approaches have been proposed to reduce the burden on health from air pollution-related asthma. Recent episodes of high air

pollution (National Centers for Environmental Information, 2017; Sengupta, 2020; Warszawski, 2020) have compelled numerous public health agencies and healthcare providers to recommend policies and interventions that could reduce the risk of harm to human health but it is not well understood if people support them and whether or not individual-level factors mediate their equitable adoption. Through the implementation of behavior change interventions and policies, public health agencies should aim to accomplish two goals: i) Protect people from being exposed, and ii) Reduce overall exposure to ambient air pollutants.

Policies aimed at reducing exposure have existed since the Clean Air Act of 1970. The statute was first legislation in the U.S. authorizing the development of comprehensive federal and state regulations to limit emissions from industrial and mobile sources, as well as creating the national ambient air quality standards and the national emission standards for hazardous air pollutants. The Environmental Protection Agency (EPA) was established to consolidate environmental protection tasks: monitoring, research, setting of standards and regulations, and enforcement aimed at protecting health and the economy (EPA, 2017). Major regions and states have moved towards regulation to implement air pollution controls to protect the health of their citizens and address anthropogenic sources, as it is the case for the San Joaquin Valley Air Pollution Control District (SJV Air Pollution Control District, 2021) and the California Air Resource Board (CARB, 2023).

The scoping evidence available in table 20, describes some or all application dimensions.

Table 20. Mitigation and Exposure Control Measures and Applications

Sofia et al (2020)	Carlsten et al (2020)	World Health Organization (2020)	Allen & Barn (2020)	James et al (2019)	Park et al (2017)
Reduce energy consumption for Individuals and Households	Fitted N95 masks	Emphasize risk communication for susceptible and vulnerable populations	Use HEPA filters for HVAC systems	Use HEPA filtration to improve asthma control	Use portable air purifiers
Use public and active transportation	Switch from motorized to active transportation	Stay indoors	Use portable air purifiers		
Change to efficient burning fuels	Choose routes to minimize NRAP and traveling during peak times	Avoid highly polluted places	Use well-fitted N95 masks		

Invest in internal climatization (Painting outer walls in light colors)	Drive with windows closed and maintain car air filtration	Reduce physical activity when health alerts are triggered	Stay indoors and Keep windows closed with AC
Adopt diet to increase antioxidants intake	Avoid engine idling	Gather more evidence to measure consequence of exposure for high-risk groups	Balance indoor sources: cooking, heating, physical activity
Improve efficiency of stock farming and manure management	Exercise regularly but moderate when pollution is high	Use of air filters in buildings and homes	Buildings with proper mechanical ventilation and filtration
Electrify ports	Check air pollution levels	Use of respirators	Traveling through areas with less pollution
Reduce fossil fuels for power generation	Use clean fuels at home and ventilate during cooking or heating		Walking and cycling
Reduce work hours for congestion and travel time reductions	Use portable air cleaners		Use high efficiency cabin filters with windows closed
Monitor pollutant levels and signal thresholds of safety	Effective clinical management of respiratory and cardiopulmonary diseases		
Adoption of electric or hybrid	Diet modification to include antioxidants and		

vehicles via tax incentives	anti-inflammatory agents

Liu, Du, Chu, & Wang (2021) explored the notion of inverted quarantines which are individual-initiated defensive behaviors to self-protect from air pollution, identifying five adaptive behaviors that individuals may adopt to protect themselves from pollutants in ambient environments: i) wearing masks, ii) using air purifiers, iii) using fresh air systems, iv) changing travel modes, and v) relocation. The authors state that the field lacks systematic awareness on how individuals adjust their behaviors when they are concerned with health threats associated with severe air pollution, and which mechanisms motivate these responses and changes. Their research applied the revised framework of the protection motivation theory, which includes self-efficacy and response costs, and has been used to address natural phenomena and climate change. A 2018 survey of residents in China reported use a wide array of avoidance behaviors and often in combination, whereas 29% of the sample did not adopt any protective measures. Facemasks were the most widely used protective measure to combat air pollution (69%), 11% said that they combined masks and air purifiers to protect the members of their household, and 6% combined masks with fresh air systems. The authors found that the preferences of individuals were associated with their perceptions of those measures' costs, being that masks were both the least expensive and the most widely adopted. The sample was divided into low, medium, and high-income groups and found that the medium income group included fewer residents that do not use any protective measures, and the high-income group had fewer people who only used masks to defend themselves from air pollution and had the largest proportion of people who used combined masks, air purifiers and home fresh air systems. Individual's concern with air pollution was significantly correlated with household expenditure on protective measures, suggesting that knowledge may encourage the use of pollution avoidance behavior. Household income, education, elderly members in the household, and allergy history were associated with the adoption of air purifiers and fresh air systems, as opposed to lower cost masks. Children in the household was not significant factor in the family's adoption and purchase of air purifiers and fresh air systems. In addition, residents with lower confidence in their government adopted more defensive behaviors, and city-level air quality, measured by AQI, was correlated with the adoption of air purifiers and fresh air systems. The latter finding is explained by the authors because residents may perceive that their local-level circumstances affect their ability to avoid pollution.

There is a gap in scientific literature investigating what support exists for these policies and interventions. Some available studies have gauge individuals' disposition to accept environmental policies and interventions around the world (Alcorn, Rupp, & Graham, 2017; Ejelöv, Harring, Hansla, Jagers, & Nilsson, 2022; Noe & Snow, 2010; Parkins, Rollins, Anders, & Comeau, 2018; Rauwald & Moore, 2016; P. W. Schultz, Unipan, & Gamba, 2010), including assessing the influence of culture for minority groups to protect the environment.

Nevertheless, the SJV substantially differs in topography, persistent air pollution levels, and demographics from the countries and regions in which those studies were

conducted. Evidence is needed to understand a) Support among residents in the SJV region, and b) Variation by socioeconomic and other factors. This study examines support for interventions and policies aimed at reducing exposure to air pollution by SJV residents.

Research Questions

Evidence shows that socioeconomic factors, such as income, stand in the way of individuals and households to implement defensive behaviors from air pollution equitably. Thus, a main objective is to understand the factors associated with support of regulations and behavior interventions related to the mitigation and control of outdoor air pollution.

To examine policy favorability amongst SJV residents that would mitigate air pollution, this study proposes two research questions:

I. Are there differences in air pollution-related quality of life for SJV residents with asthma and other air pollution-sensitive chronic conditions?

II. Do SJV residents with asthma and chronic diseases report different air quality-related costs and mitigation policy favorability compared to SJV residents without asthma and chronic diseases?

Methods

The online survey included responses from 310 adult participants and residents of zip codes in the San Joaquin Valley region of California. The survey was hosted by Qualtrics during the month of November 2020. The study included 34% of participants who have been diagnosed with asthma by a medical provider. The objective was to obtain responses from a representative sample of the region's population through Qualtrics, which was monitored through real-time data gathering, however, their participant panel did not reach comparable proportions of Hispanics/Latinos/Latinas respondents. Also, the survey was available in English only. The survey instrument is available in Appendix A. Participants were compensated for their time at a rate of less than ten USD and were eligible to answer once. The study was approved by the UC Merced IRB protocol #UCM2020-88 and registered under agreement #56324 with the EuroQOL Research Foundation.

Study Design

For the development of a cross-sectional instrument, extensive peer-reviewed literature was examined to build a comprehensive structure of air pollution mitigation and control measures, as well as for household and individual-level behaviors for the region's survey participants. The final survey included the following four policy relevant areas to evaluate in this study:

1) Personal, family, and home protections
2) Perceived health effects of air pollution
3) Point source emissions mitigation and control
    a. Transportation
    b. Manufacturing
    c. Food and agriculture
    d. Forest and wildfires
4) Information availability, access, and awareness

The survey asked about their health status, self-protective behaviors, attitudes toward air pollution mitigation recommendations, air quality information knowledge, and mitigation behaviors, as well as whether their views were favorable or unfavorable. The independent variables for each component are indicated below. All statistical analyses were performed using Stata V.18 (Stata V17, 2021).

Independent

- Gender
- Age
- Health outcomes
- Ethnicity/language at home
- Income
- Distance to freeway
- Rurality
- Political views

Model
Factors (Age, gender, comorbidities etc.) -> Health outcomes
Age, gender, comorbidities etc -> Political views
Factors, Health outcomes, political views -> Support

Statistical Analysis

Demographic characteristics are reported using descriptive analysis. To test the hypothesis of whether there are differences by health status, the likelihood ratio chi-square test was conducted, and the p-values reported to accept or reject the null. Utility values will be estimated using the EQ-5D-3L results from survey questions (EuroQOL Research Foundation, 2018) which is widely used to value health and measure health status. Multivariate logistic regression was used to assess the characteristics of residents with association to health utility values, conditional on other covariates.

Lastly, to explore what policies and interventions are supported by SJV residents, principal component analysis (PCA) was used using varimax rotation. PCA is a type of multivariate analysis for feature extraction and observation of trends, clusters, and outliers. Each component is orthogonal by design and is appropriate for complex data while extemporary theoretical framework is applicable in exploratory research. Predictors of latent factors will be obtained using regression modeling to understand the characteristics, relationship, and magnitude of support for policies and interventions to mitigate air pollution exposure.

The findings and results will follow the Strengthening the Reporting of Observational Studies in Epidemiology (Von Elm et al., 2007) reporting guidelines for cross-sectional studies.

Results

Descriptive

Survey participants were between 18-83 years of age and residents of SJV zip codes. The mean age of the whole sample was 42.90 (+/- 16.84), and 40.03 (+/- 14.92) for people who have asthma themselves or have children with asthma. Table 21 summarizes the characteristics of participants and reports the p-value of likelihood ratio chi-square probability for SJV residents with asthma and the overall sample.

Table 21. Demographic Characteristics of Survey Participants

	All		Resident with asthma or Parent/Guardian of Child with asthma		
	n	%	n	%	p value
Age					
18-29	40	27.78	51	30.72	*p=0.000*
30-49	35	24.31	71	42.77	
50-64	34	23.61	33	19.88	
65+	35	24.31	11	6.63	

Sex					
Female	92	63.89	109	65.66	*p=0.946*
Male	51	35.42	56	33.73	
Non-binary	1	0.69	1	0.60	
Race/Ethnicity					
Hispanic/Latino/Latina	43	32.09	53	32.32	*p=0.684*
White	68	50.75	86	52.44	
African American	5	3.73	7	4.27	
Asian/Pacific Islander	12	8.96	8	4.88	
Native American	6	4.48	10	6.10	
Household Income					
Low	43	29.86	47	28.31	*p=0.497*
Middle	67	46.53	70	42.17	
High	34	23.61	49	29.52	
Language in Household					*p=0.805*
English	132	91.67	150	90.36	
Spanish	8	5.56	13	7.83	
Hmong	1	0.69	1	0.60	
Indigenous	3	2.08	2	1.20	
Education					*p=0.756*
High School or below	5	3.47	6	3.61	
Some College/ 2-year degree	96	66.67	104	62.65	
College degree or Graduate	43	29.86	56	33.73	
Employment Status					*p=0.045*
Full Time	38	26.39	55	33.13	
Part Time	24	16.67	34	20.48	
Unemployed Looking	27	18.75	33	19.88	
Unemployed Not Looking	14	9.72	15	9.04	
Retired	32	22.22	15	9.04	
Disabled	9	6.25	14	8.43	
Marital Status					*p=0.103*
Married/Domestic Partner	58	38.39	89	54.26	
Single/Widowed	61	44.11	50	30.18	
Separated/Divorced	25	17.78	27	15.13	
Rurality					*p=0.733*
Urban	84	58.33	100	60.24	
Rural	60	41.67	66	39.76	
Lives 1-mile from Freeway/Highway					*p=0.721*
Yes	90	62.50	107	64.46	
No	54	37.50	59	35.54	

# Of Chronic Diseases					*p=0.000*
No Conditions	59	40.97	8	4.82	
1	81	56.25	87	52.41	
2	3	2.08	60	36.14	
3	1	0.69	9	5.42	
4 or More	0	0.00	2	1.20	
Health Insurance					*p=0.000*
Medi-Cal	17	11.87	42	25.28	
Medicare	39	27.08	16	9.63	
Medicare & Medi-Cal	20	13.89	45	27.11	
Private/Employment-based	49	34.03	56	33.73	
Uninsured	19	13.15	7	4.21	
Tobacco User	28	19.44	47	28.31	*p=0.069*
Vape User	10	6.94	28	16.87	*p=0.007*
Cannabis User	23	15.97	35	21.08	*p=0.250*

Among survey participants the number of chronic diseases, health insurance type, employment status and vaping use where statistically significant in differences between the entire sample population and people who were diagnosed with asthma or have a child who has asthma. Most respondents were female, White and spoke English and share the same distribution in the group of residents who have asthma. Hispanics/Latinos/Latinas were approximately 32% of the entire sample and residents with asthma. Both groups are equally represented in the household income, with the majority reporting middle household income earnings in the past year.

Thirty percent of the sample and people with asthma reported having a college degree or higher, and the majority in both groups reported having some College education or a 2-year college degree. Most respondents in the whole sample reporting being single (44.11%) but 54.26% of people with asthma reported being married or living with a partner and being employed full or part time. The entire sample reports a higher proportion of retirees (22.22%) compared to 9.04% of people with asthma, which could be attributed to younger mean age of the group who reported the diagnosis. Fifty-eight percent to 60% live in an urban area compared to 41.67% of the sample and 39.76% of people with asthma who reported living in rural areas of the SJV.

Residents of the region who said lived within one mile from a freeway or highway were 62.50% in the entire sample, and 64.46% for people with asthma. In the entire sample 56.25% residents reported having one chronic condition that air pollution makes worse, and only 4.82% of people with asthma reporting having only that diagnosed condition, the majority reported one (1) (52.41%) other diagnosed condition, and 36.14% having two (2) other diagnosed chronic diseases. Most survey participants in both groups reported being insured by employer-based or private insurance, and 4.52% of people with asthma reported being uninsured. Remarkably, people with asthma reported tobacco use (28.31%), vape use (16.87%), and cannabis use (21.08%), proportions lower than the sample.

Air Quality Information Assessment

Having chronic diseases was found to be significant in the likelihood of variability between groups of survey respondents. Thus, table 22 describes the extent to which people with reported chronic diseases (CD) perceive air pollution, assess air quality information in the region, and trust such information compared to people without reported chronic diseases (NCD).

Table 22. Air Quality Information Assessment by Health Status Group

	All **N=310** %	No Chronic Diseases **n=205** %	Chronic Diseases **n=105** %	p-value
How informed do they feel about AQ information in your city?				*p=0.02*
Not Informed at all	2.65	2.50	3.00	
Not very informed	15.00	11.00	23.53	
Somewhat informed	56.29	60.00	49.00	
Very informed	26.16	27.00	24.51	
Don't know	-	-	-	
Rate Air Quality Information received				*p=0.9*
Inaccurate and Incomplete	3.69	3.76	3.53	
Accurate but Incomplete	38.00	37.10	40.00	
Accurate and Complete	58.30	59.14	56.47	
Don't know	-	-	-	
Trust in Air Quality Information Sources				*p=0.4*
Research institutes	5.6	3.37	9.10	
Universities	5.6	6.74	3.64	
Local Health authorities	25.00	26.97	21.82	
CBOs & Citizen groups	4.90	4.49	5.45	
Environmental protection agencies	13.89	13.48	14.55	
City government and municipalities	2.78	1.12	5.45	
Television or radio	28.47	31.46	23.64	
Internet	13.89	12.36	16.36	
Air quality in their city for past 2-weeks				*p=0.1*
Very unhealthy	6.47	8.29	2.88	
Unhealthy	17.15	17.56	16.35	
Unhealthy for sensitive groups	26.86	28.29	24.04	
Moderately healthy	35.60	31.71	43.27	
Good air quality	13.92	14.15	13.46	
Current Air quality Assessment				*p=0.3*
Very unhealthy	13.87	16.10	9.52	
Unhealthy	21.94	23.41	19.05	

Unhealthy for sensitive groups	26.45	24.88	29.52	
Moderately healthy	26.77	24.39	31.43	
Good air quality	10.97	11.22	10.48	
Time of day notice air pollution				*p=0.01*
Morning	24.52	23.90	27.71	
Afternoon	40.65	40.49	40.95	
Evening	22.90	23.41	21.90	
All day is bad	18.39	20.98	13.33	
Don't notice bad air	14.52	10.73	21.90	
Season of the year notice air pollution				*p=0.9*
Spring	25.81	24.88	27.62	
Summer	81.29	80.00	83.81	
Fall	29.03	31.71	23.81	
Winter	12.58	12.68	12.38	
Method to check Air Quality in their area				*p=0.4*
Mountain range is clear	42.58	40.49	46.67	
Valley floor is clear	17.10	18.54	14.29	
Rely in recommendations from Air District	31.29	30.24	33.33	
AQ flags in my kids' school	5.16	5.85	3.81	
Monitor at home	3.55	4.88	0.95	
Purple air website	10.32	12.68	5.51	*p=0.05*
Check the internet	14.19	13.17	16.19	
CalFire text messages	7.74	9.27	4.76	
I don't check the Air Quality	10.65	8.78	14.29	
TV, Radio, or Newspaper	2.54	2.25	1.61	
Meaning of "Bad Air" day				*p=0.6*
High mold/pollen levels in the air	39.35	38.54	40.95	
High PM counts in the air	43.87	44.39	42.86	
High Ozone levels in the air	17.42	18.05	16.19	
The air is gray or brown haze outside	43.55	43.41	43.81	
The hole in the ozone layer has made it unhealthy to be outside	5.81	6.83	3.81	
The air is dirty/polluted	59.86	60.00	59.05	
I don't know what "Bad Air" days mean	1.61	0.49	3.81	*p=0.02*

Access to information, trust, and awareness were found to be statistically significant. People with chronic diseases who are sensitive to air pollution reported feeling the least informed about the quality of the air in their cities compared to SJV residents without chronic diseases, and the entire sample. Television, radio, and local health authorities were reported to be the most trusted sources of information by all groups, and more than half of all group respondents reported the information to be accurate and complete, 40% of people with chronic diseases replied that the air quality

information they receive is accurate but incomplete. The proportion of participants who reported the air quality to be very unhealthy in the time of taking the survey doubled (All: 6.47%-13.87%, NCD: 8.29%-16.10%, CD: 2.88%-9.52%) compared to the air quality the prior 2-weeks.

In terms of air pollution awareness, all groups report that most air pollution is perceived in the afternoon, and in the summer season in the SJV; this coincides with higher levels of ozone concentrations that is perceived by haze or smog during the warm season endemic to the region. Most participants in each group responded that the method they use to check the air quality in their area is to observe if the mountain range in the region is clear (All: 42.58%, NCD: 40.49%, CD: 46.67%) with the highest proportion of people with chronic diseases indicating this as their primary option, followed by recommendations from the SJV Air District, and checking the internet.

Fourteen percent of people with chronic diseases reported not checking the air quality, compared to 8.78% in the group with no chronic diseases. In contrast to the findings related to the time of day and season of the year for heightened awareness of air pollution, high count of PM in the air (All: 43.87%, NCD: 44.39%, CD: 42.86%), as well as mold/pollen presence (All: 39.35%, NCD: 38.54%, CD: 40.95%) were deemed to be the most likely meaning of a "bad air" day by all the groups alongside seeing the air dirty or polluted.

Value of Health

The survey instrument in this study included the quality-of-life assessment tool EuroQol-5D-3L. By investigating self-reported health outcomes, utility values ranging from the maximum of 1 to 0, were estimated using the time trade-off (TTO) method. Utilizing this instrument is essential in valuing health and making comparisons by health states to evaluate health-related quality of life (HRQoL).

For this purpose, figure 6 shows that utility values differ between the entire sample, people with chronic conditions, and people with asthma. All three groups reported higher utility values when responding to the state of their current general health was excellent, and people with chronic conditions had the highest mean utility (U=.825). People with chronic conditions sensitive to air pollution also reported a higher utility when their general health was good (U=.777) compared to people with asthma (U=.747), and all (U=.763). People with asthma consistently reported the lowest mean utility values for all categories of general health status.

Figure 6. General Health Status by Health States

Table 23 reports estimated mean utility values of each health state and the entire sample by age group, sex, ethnicity, education, number of chronic conditions, rurality, proximity to freeway/highway, as well as tobacco, vape, and cannabis users. The mean utility value for all was *U*=.710, compared to people with chronic conditions *U*=.691, and the lowest reported by people with asthma (*U*=.657).

The trend of general health status was followed in the estimated mean utility values by age groups. People 60 years of age and older in the entire sample obtained the highest utility value for all (U=.778), and people 60+ with chronic diseases (*U*=.755). However, for people with asthma, the younger group 18-25 years of age, reported the highest mean utility (*U*=.711).

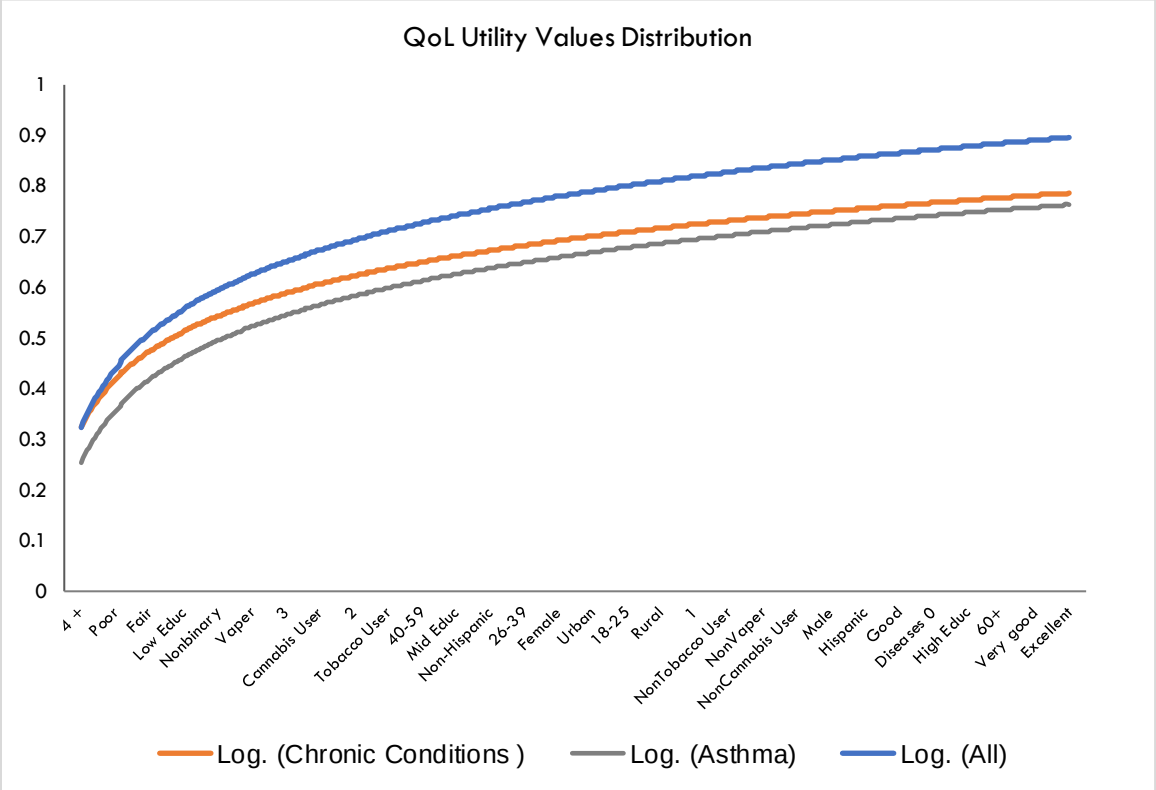
Table 23. Utility Values by Health Status

	All		Chronic Disease		Asthma	
	Mean	SD	Mean	SD	Mean	SD
Total	.710	.25	.691	.26	.657	.26
Health Status						
Excellent	.819	.21	.825	.20	.784	.24
Very good	.800	.19	.773	.21	.763	.22
Good	.763	.18	.777	.18	.747	.18
Fair	.529	.26	.481	.24	.459	.21
Poor	.385	.32	.350	.29	.327	.33
Age						
18-25	.707	.22	.707	.23	.711	.20
26-39	.693	.26	.667	.27	.646	.28
40-59	.683	.26	.662	.27	.625	.28
60+	.778	.21	.755	.22	.683	.25
Sex						
Male	.740	.25	.734	.26	.692	.27
Female	.696	.24	.670	.25	.641	.25

Nonbinary	.573	.14	.573	.14	.471	-
Ethnicity						
Hispanic	.756	.21	.730	.22	.706	.21
Non-Hispanic	.690	.26	.673	.27	.634	.28
Education						
Low	.560	.34	.499	.44	.527	.42
Mid	.686	.25	.663	.25	.621	.25
High	.777	.22	.759	.22	.737	.24
# Of Conditions						
None	.771	.23	-	-	.683	.23
1	.721	.23	.726	.24	.681	.25
2	.650	.26	.614	.28	.647	.27
3	.617	.27	.617	.27	.578	.25
4 +	.135	.28	.334	-	.135	.28
Area						
Urban	.704	.25	.760	.20	.746	.21
Rural	.719	.24	.767	.22	.735	.23
Lives within 1mile of Freeway						
Yes	.696	.26	.667	.27	.636	.27
No	.736	.22	.729	.22	.695	.23
Tobacco Use						
Yes	.664	.26	.666	.25	.628	.28
No	.725	.24	.700	.26	.668	.25
Vape Use						
Yes	.609	.24	.584	.27	.594	.23
No	.725	.24	.708	.25	.670	.26
Marijuana Use						
Yes	.645	.28	.621	.29	.585	.29
No	.726	.24	.707	.25	.676	.25

Males reported higher utility values compared to females and nonbinary residents of the SJV in every health state. People who are highly educated (bachelor's degree and above) also reported the highest utility for their current health. By the number of chronic conditions, people with no chronic conditions reported the highest utility value (U=.771), compared to people with asthma who reported comorbidities that are made worse by air pollution (U=.135). People who live in rural areas in the SJV and who have chronic conditions had a higher utility (U=.767) but people with asthma living in an urban area reported a higher utility (U=.746) compared to those with asthma living in the rural areas of the Valley. Those residents who reported not living within one mile of a freeway or highway reported higher utilities in every health state, as well as those residents who were not tobacco, vape, or cannabis users.

Figure 7. Health Utility Curves by Health State



Using the logarithmic scale transformation for estimated utilities, figure 7 shows the utility curves for each health state to compare the health outcomes of all the samples of residents, people with chronic conditions, and people with asthma.

In this analysis, the utility curve for people with asthma is lower than the curve for people with chronic conditions sensitive to air pollution and all the residents of the Valley.

Favorability of Policies and Interventions

To determine what air pollution mitigation interventions are favored by SJV residents an exploratory factor analysis was conducted using maximum likelihood estimation using 52 policy items sorted in five thematic matrices. Primary components were rotated using varimax rotation to allow for factors to correlate. Tables 24-28 show the factor loadings for each matrix after rotation, and acceptability means with corresponding standard deviation (SD).

Table 24. Hybrid and Electric Car Concerns Rotated factor loadings (Varimax)

	Factor 1	Factor 2	Factor 3	Acceptability Mean (SD)
Too Expensive	0.226	**0.656**	0.282	3.43 (1.11)
Too Complicated to Purchase	0.351	**0.697**	0.358	2.61 (1.43)
Charging Stations are not widely available in my city	**0.727**	0.397	0.328	3.28 (1.17)
Charging stations are not widely available when I travel long distances	**0.934**	0.239	0.266	3.41 (1.11)
Too small for my family/Not spacious enough	0.251	0.303	**0.651**	2.59 (1.39)
Not safe	0.200	0.322	**0.763**	2.60 (1.49)
Don't like the look	0.186	0.291	**0.816**	2.32 (1.38)
Don't go fast enough	0.244	0.170	**0.854**	2.27 (1.43)

Factor Loadings

- Factor 1 = Charge
- Factor 2 = Expense
- Factor 3 = Car attributes

The items loading into the first factor related to hybrid and electric care adoption suggest that this component corresponds to concerns about electric charge access and availability in SJV cities and when traveling long distances. The second factor represents the expense concerns that residents have in acquiring and adopting clean cars, in which the vehicle is too expensive, and the purchase process is perceived as onerous. The third factor indicates a correlation in the concerns with hybrid and electric vehicle attributes.

Table 25. Effectiveness of Organizations to Improve Air Quality Rotated factor loadings (Varimax)

	Factor 1	Factor 2	Acceptability Mean (SD)
U.S. Government	**0.638**	0.227	2.21 (0.99)
EPA	**0.876**	0.003	2.85 (0.96)
State of California	**0.800**	0.194	2.68 (0.99)
SJV Air Pollution Control District	**0.612**	0.567	2.84 (0.94)
County/City Officials	0.520	**0.609**	2.26 (0.98)
Farmers, Growers, Ranchers	0.053	**0.876**	2.65 (1.10)

Community Grassroots organizations	0.269	**0.822**	2.57 (0.97)
Environmental organizations	**0.730**	0.357	2.97 (0.96)
Scientists and Researchers	**0.675**	0.373	3.09 (0.90)

Factor Loadings:

- Factor 1 = Not Local
- Factor 2 = Local

In assessing the effectiveness of organizations working to improve air quality in the SJV in table 6, a two-factor solution was recommended in the parallel analysis. The first factor corresponded to organizations that are largely perceived as participating from a non-local perspective but rather from national, state, and regional levels which included the SJV Air Pollution Control District. The second factor correlated to stakeholders with local influence such as city and county officials, farmers, growers and ranchers, and community-based organizations.

Table 26. Cost of Policies and Factors to Consider Rotated factor loadings (Varimax)

	Factor 1	Factor 2	Acceptability Mean (SD)
Costs that it will impose on businesses	**0.810**	-0.129	3.06 (0.91)
Cost to consumers	**0.847**	-0.105	3.36 (0.99)
Reducing PM2.5	0.458	**0.523**	3.23 (0.99)
Reducing ozone	0.422	**0.534**	3.42 (1.07)
Making the air look cleaner	**0.538**	0.420	3.37 (1.11)
Having it be locally run as opposed to by the EPA	**0.653**	0.219	2.91 (1.06)
The impact it will have on low-income communities	**0.666**	0.276	3.45 (1.06)
Making sure that people in the Bay Area also have to reduce their air pollution	**0.578**	0.331	3.66 (1.01)
Getting agriculture to change its practices	0.084	**0.778**	3.15 (1.04)
Reduce heating from fireplaces or woodstoves	0.121	**0.730**	2.95 (1.20)
Eliminate or reduce large incinerators	0.155	**0.770**	3.25 (1.13)
Reduce the amount of pollution from commercial cooking	0.048	**0.814**	2.89 (1.09)
Reducing pollution from dairies	0.035	**0.841**	3.09 (1.20)
Eliminate pesticide drift	0.262	**0.685**	3.68 (0.97)

Factor Loadings:

- Factor 1 = Cost
- Factor 2 = Who Pays

This study asked about factors and costs that need to be considered when formulating air pollution control and mitigation policies for SJV residents. The midpoint for this scale was 3, and most of the mean acceptability indicators show strong support for the inclusion of these considerations in policymaking. Two solution correlated factors related to the cost to businesses and consumers, as well as making the air look cleaner, to govern

policies locally, the impact to low-income communities, and that neighbor region, the Bay Area, reduces its air pollution which travels and is accumulated in the SJV basin. A second factor correlated reduction of particulate matter 2.5 and ozone, with getting agriculture to change its practices to reduce air pollution, reducing hearing from fireplaces, eliminating, or reducing pollution from large incinerators, commercial cooking, dairies, and from pesticide drift.

Table 27. Mitigation and Control Policy Statements Rotated factor loadings (Varimax)

	Factor 1	Factor 2	Acceptability Mean (SD)
"During the COVID-19 period or shelter-in-place, I have sensed/experienced good clean air and I don't want to go back to the air pollution levels we previously had"	0.306	0.433	3.22 (1.27)
"Cities must take effective measures to protect citizens from air pollution, even if this requires reallocating public space to walking, cycling and public transport"	**0.767**	0.326	3.59 (1.21)
"Cities must take effective measures to protect citizens from air pollution, even if it means preventing polluting cars from entering the city"	**0.743**	0.256	3.23 (1.29)
"I think we need to resume our normal lives soon and must accept that air pollution will rise again"	-0.522	0.582	3.07 (1.32)
"More public space in your nearest town/ city should be reserved for public transport (e.g., by expanding bus lanes)"	0.316	**0.690**	3.30 (1.05)
"More public space in your city and nearest towns should be reserved for cycling"	0.415	**0.742**	3.51 (1.03)
"More public space should be reserved for pedestrians"	0.380	**0.724**	3.62 (1.00)
"More policies should be adopted to stop polluting cars and trucks from entering the city, for example through Zero-Emission Zones"	**0.743**	0.269	3.28 (1.21)
"More companies should allow their workers to continue working from home or telecommuting"	**0.542**	0.288	3.96 (0.98)
"More cities and counties should work together to create clean, fast and reliable regional transportation systems to connect the Central Valley"	**0.714**	0.250	4.11 (1.01)

Factor Loadings:

- Factor 1 = Air Pollution Control
- Factor 2 = Public Space

The strongest support was reported in the section on policy mitigation and control statements. The scale also had a midpoint of 3, and all attitudes were favored with the highest mean acceptability for the creation of a clean, fast, and reliable regional transportation system to connect the SJV for its residents. A component correlated statements directly addressing strong action for air pollution control to protect the health SJV residents. The second factor corresponded to the preservation of public space for public transportation, cycling, and pedestrians.

Table 28. Persistence of Poor Air Effects Rotated factor loadings (Varimax)

	Factor 1	Factor 2	Acceptability Mean (SD)
Breathlessness/having more difficulty in breathing	**0.689**	0.330	2.73 (1.09)
Doing less outdoor activities	**0.667**	0.387	3.13 (1.27)
Doing more to look after my skin	0.361	**0.731**	2.87 (1.24)
Doing more to stay healthy	0.180	**0.793**	3.29 (1.17)
Feeling Depressed	**0.653**	0.214	2.69 (1.23)
Irritation to eyes/nose/throat	**0.736**	0.138	3.21 (1.16)
Skin problems	**0.741**	0.349	2.45 (1.23)
Wanting to move to other less polluted place	**0.706**	0.207	2.91 (1.44)
Asthma incidents or attacks	**0.747**	0.139	2.18 (1.28)
Poor visibility	**0.700**	0.126	2.57 (1.14)
Worrying about the living environment for children	**0.588**	0.277	2.97 (1.39)

Factor Loadings:

- Factor 1 = Symptoms
- Factor 2 = Personal Actions

Lastly, the study sought to understand the degree to which air pollution has influenced the persistence of disease outcomes and self-protective behaviors. Factor 1 correlated symptoms related to poor air such as difficulty breathing, doing fewer outdoor activities, feeling depressed, irritation to eyes, nose, and throat, skin problems, wanting to move to a less polluted place, asthma exacerbations, poor visibility, and worry for the environment that SJV children will inherit. The second factor corresponded to having to do more to care for one's skin and to stay healthy overall.

Predictors of Latent Factors

Table 29. Predictors of Latent Factors

Predictors	Charge		Expense		Car Attributes		Not Local		Local		Cost		Who pays		Air Pollution Control		Public Space		Symptoms		Personal Actions	
	β (SE)		β (SE)		β (SE)		β (SE)		β (SE)		β (SE)		β (SE)		β (SE)		β (SE)		β (SE)		β (SE)	
Age (c)	.009*	(.00)	.016**	(.00)	.003	(.00)	.000	(.00)	.002	(.00)	.007*	(.00)	.002	(.00)	.001	(.00)	.001	(.00)	-.003	(.00)	.004	(.00)
Male	-.448**	(.16)	-.303*	(.14)	-.323*	(.15)	.172*	(.08)	.133	(.10)	-.045	(.08)	-.092	(.08)	.005	(.10)	.085	(.10)	-.270**	(.08)	-.358**	(.12)
NH White	-.053	(.13)	-.282*	(.14)	-.165	(.15)	-.163	(.09)	-.174	(.10)	-.076	(.09)	-.115	(.09)	-.109	(.10)	-.156	(.15)	.100	(.08)	.008	(.12)
Rural	-.156	(.13)	.003	(.13)	.258*	(.14)	.004	(.08)	-.024	(.10)	.044	(.08)	-.072	(.08)	-.006	(.09)	.073	(.10)	-.062	(.14)	.027	(.12)
Political Views (c)	-.071*	(.03)	-.019	(.03)	-.124**	(.04)	.040	(.02)	-.059*	(.03)	-.008	(.02)	.155***	(.02)	.161***	(.03)	.139***	(.03)	.068**	(.02)	.111**	(.03)
Married	-.009	(.13)	-.134	(.15)	-.106	(.14)	.110	(.09)	.174	(.10)	.110	(.09)	.204*	(.09)	.011	(.10)	.117	(.10)	.143	(.08)	.116	(.12)
Lives 1-mile from Freeway	-.107	(.13)	-.138	(.13)	-.071	(.14)	.141	(.08)	.203*	(.10)	.031	(.08)	.154*	(.08)	-.048	(.09)	-.135	(.10)	.143	(.08)	.110	(.12)
Years of Education (c)	.034	(.13)	.208	(.14)	.237*	(.14)	-.013	(.08)	-.138	(.10)	-.007	(.08)	-.105	(.08)	-.067	(.10)	-.112	(.10)	.162*	(.08)	.103	(.12)
Health Utility Value (c)	-.163	(.28)	-.274	(.30)	-.031	(.30)	.155	(.18)	-.075	(.20)	-.051	(.18)	-.034	(.18)	-.079	(.21)	-.046	(.21)	-1.06***	(.17)	-.098	(.25)
Have Asthma	-.025	(.16)	-.050	(.16)	.087	(.17)	.118	(.10)	.068	(.11)	.206*	(.10)	.143	(.10)	.016	(.11)	.167	(.12)	.447***	(.09)	.336*	(.14)
Have Chronic Diseases	-.032	(.09)	-.126	(.10)	-.186*	(.10)	-.027	(.06)	-.085	(.07)	-.034	(.06)	.045	(.06)	.117	(.07)	-.090	(.07)	.036	(.05)	.024	(.08)
Child has Asthma	-.031	(.08)	.028	(.08)	.147*	(.08)	.010	(.05)	-.019	(.06)	.030	(.05)	.001	(.05)	-.025	(.06)	.093	(.06)	.182***	(.05)	.277***	(.07)
Public Health Insurance	-.132	(.14)	-.141	(.15)	.131	(.15)	.083	(.09)	.260*	(.11)	-.073	(.09)	.035	(.09)	-.012	(.11)	-.170	(.11)	.015	(.08)	-.047	(.13)
Low Income	-.073	(.16)	.023	(.08)	.135	(.18)	-.035	(.10)	.462***	(.08)	.129	(.11)	.016	(.10)	-.041	(.12)	.089	(.12)	-.032	(.10)	.125	(.14)
Employed	-.134	(.14)	.071	(.14)	-.005	(.15)	-.106	(.14)	.228*	(.11)	-.045	(.09)	-.115	(.09)	-.016	(.10)	-.050	(.11)	.044	(.09)	-.006	(.13)

*Levels of significance: *p<.05; **p<.01; ***p<.001*

To understand what factors, predict the favorability of air pollution mitigation and control policies in the SJV region, the analysis included a stepwise regression with all the factors included in the survey. All the unobserved factors in Table 29 were accepted at p-value $\leq .10$ using the forward selection method.

Multiple regressions were conducted for each latent factor to estimate the effect of categorical variables sex, race, rurality, political views, marital status, proximity to the freeway, asthma, chronic conditions, having a child with asthma, being insured by a public health program, low-income level, and employment. Age, years of education, health utility values, and political views were included as continuous variables.

Age had a positive predicting relationship to all latent factors, except for experiencing more symptoms related to poor air quality. Increases in years of education favored charge, expense, and car attributes as concerns for the adoption of hybrid and electric vehicles, as well as experiencing more symptoms due to poor air and having to take more personal actions to protect themselves.

Decreases in estimated health utility values predicted favorability for all latent factors with the highest magnitude for experiencing symptoms due to bad air. Higher utilities were positively associated with supporting agencies like the EPA, the State, and the U.S. government to control and mitigate air pollution in the region, but the finding was not statistically significant.

Five latent factors were negatively predicted by political views indicating that neutral to more conservative leaning SJV residents, compared to liberal residents who were more likely to prefer non-local organizations to regulate air quality, to favor polluters to pay for their contamination, for strong air pollution control regulation, preservation of public space, and to report more symptoms or having to take more personal actions due to poor air quality. Whereas low-income, being fully employed, and insured by a public health program predicted favorability to having local agencies, such as farmers and ranchers, community-based organizations, and city/county governments regulate and control air pollution in the region.

Living 1-mile from a freeway or highway followed those same predictions and favored who pays for the pollution that is produced in the region.

Males, non-Hispanic Whites, and people who are employed negatively predicted the acceptability of most factors except for males and people who are employed by the effectiveness of local and non-local organizations, air pollution control measures, and preserving public space for pedestrians, cyclists, and public transportation. Whites were likely to have pervasive symptoms related to poor air and having to take more personal actions to protect their health.

Having a child with asthma and rurality positively predicted the importance of car attributes in the adoption of hybrid and electric vehicles. Having asthma and having a child with asthma were also significant factors in predicting experiences of air quality-related symptoms and having to do more to protect their health. Nevertheless, having asthma predicted favorability to accounting for costs that air pollution control will impose on businesses and consumer.

Conclusions and Limitations

The final step of this work aims to understand how San Joaquin Valley (SJV) residents assess air quality, what air pollution mitigation efforts and interventions are favored in the region, and which factors predict differential responses in their support. Per the evidence in this study, the SJV region's residents report a sensory relationship to attune with the state of air quality in their community, as most participants in the study reported observing the clarity of the mountain range and valley floor as their preferred way to check air quality. This is consistent with findings in studies of environmental risk (Evans & Evans, 2017; Sih, Ferrari, & Harris, 2011; Velarde, Fry, & Tveit, 2007) where sensory evaluation has been associated with perceptions of climate change, personal health, and public health adverse effects from exposure such as noise pollution. The interaction of sensorial identification of exposure risks could be a factor denoting reasons why most SJV residents in this study perceive summer as the season of the year and the afternoons as the time of day with the highest pollution. Evidently, the presence of ground-level ozone and its conspicuous hazy characteristics mediates this relationship and heavily moderates the possible response to mitigate personal and family pollution exposure during the region's winter season in which "invisible" $PM_{2.5}$ emissions and levels are pervasive and even short-term exposures have been associated with asthma and upper respiratory infection emergency department visits and hospitalizations found in the exposure assessment of this research (unpublished Zarate-Gonzalez, G., 2023; Tavallali et al., 2020)

Furthermore, this evidence demonstrates the existence of robust regional identity in the concern of air pollution among SJV residents. In scientific examinations of general environmental policy support researchers have investigated the relationship between environmental concerns and the favorability of policies, findings support that regional identity is a driving factor for pro-environmental attitudes and to a degree could lead to potential behavior change (Blake, 1999; Carrus, Bonaiuto, & Bonnes, 2005; X. Liu, Vedlitz, & Shi, 2014; Nilsson, Hansla, Heiling, Bergstad, & Martinsson, 2016). Ostensibly, a potential avenue facilitating this common stance is the dissemination of air quality information through radio and news, in which the relational attribution of air pollution concentrations in one community and its application to others within the region may be occurring.

Of particular importance are differences found between people with chronic diseases and those without. Residents who had one or more chronic conditions sensitive to air pollution were found to report differences in how informed they feel about the air quality of their community, the time of the day when they notice air pollution, access to internet tools to get real-time air pollution data (Purple Air), and now knowing what a "bad air" day means. These differences are consistent with a previous study (Veloz, Gonzalez, Brown, Gharibi, & Cisneros, 2020) underlining the need to increase outreach to vulnerable populations to whom air pollution is causing higher susceptibility to adverse health outcomes. Removing limitations of awareness with accurate and complete availability of air pollution data by community-defined areas would better serve the mediation between the "localization" of air quality information and residents' risk assessment (Bickerstaff & Walker, 2001).

In further studying if air pollution elicits differential responses from groups in the SJV region, people who reported having asthma or having a child with asthma saw a log-scale utility curve lower than people with chronic conditions and the entire sample. The study findings demonstrate that air pollution-associated health outcomes, such as asthma, have higher costs in quality of life than other chronic conditions. To the extent of available studies, this evidence is the first of its kind for the SJV region to incorporate utility-based quality-of-life assessment to measure the impact of air pollution on populations in different health states. This study adds to the body of knowledge investigating health-related quality of life for people with asthma or chronic conditions, as well as their perceptions, and policy support (Song, Blake, Wilson, Winterstein, & Park, 2021; Sullivan & Ghushchyan, 2006).

Policy Favorability

Based on a wide range of mitigation and control air pollution policies, this study indicates that the current policy and environment in the SJV can be explained by eleven (11) factors or concerns through five different domains of the air pollution emissions and control landscape: 1) electric vehicle (EV) charge, 2) EV expense, 3) EV attributes, 4) Local organizations regulating emissions, 5) Not local organizations regulating emissions, 6) what are the costs of reducing air pollution in the region, 7) who pays for those costs, 8) air pollution control, 9) preservation and promotion of public space, 10) health symptoms from air pollution exposure, and 11) personal actions taken to protect own's health from air pollution damages.

Whereas the majority of existing research suggests that ideology and socioeconomic factors predict the acceptability of environmental policies (Finkelstein, Luttmer, & Notowidigdo, 2013; Harring, Jagers, & Matti, 2017) this analysis indicates that the health state of SJV residents is also a significant predictor of favorability and concern for air pollution control and mitigation policies and interventions. Thus, people who have asthma and those who have children with asthma seem to be highly concerned with the adverse health effects and symptoms that air pollution is producing, as well as the need to do more to maintain their health while living in these environmental conditions. Moreover, quality of life, as measured by health utility, appears to be a negative predictor for almost all air pollution policy and concern categories, and a positive predictor in favor of regulation of the region's air pollution emissions by not local organizations.

In the existing body of knowledge political ideology has been found deterministic in the acceptability or rejection of environmental policy. Whereas right wing or conservative leanings are suggested to reject policies to protect the environment (Ejelöv et al., 2022; Harring & Jagers, 2013), our study only finds right wing ideology to be a significant negative predictor for EV charge, EV attributes and having local organizations intervening in air pollution emissions. Left wing ideologies significantly predict favorability for policies that charge polluters to clean the air, control air pollution emissions, preserves public space, and interventions that reduce air pollution health symptoms and eases the burden on health.

Limitations

California's SJV is a region where Latinos/Latinas/Latinx are 50.2% of the approximately 4.3 million residents, Whites/Caucasians 60%, Asians and Pacific Islanders 5%, and African Americans and Native Americans 1% (PPIC, 2018). A limitation of this cross-sectional study is that the sample did not reflect this racial and ethnic composition. Given the heterogeneity of the ethnic group future research should increase the participation of Hispanics in sample size to evaluate air pollution-related quality of life and policy favorability, particularly of AB617 communities, which are characterized excess vulnerability due to endemic exposure to air pollutants and precarious socioeconomic factors. Furthermore, the measurements presented in the context of evaluating environmental policy related to air pollution need to be replicated in new regional studies to examine its validity to represent orthogonal constructs involved in air pollution as a ubiquitous public health issue.

Chapter VI.

Conclusion

Contribution to the Literature

The first study in this body of research adds to the knowledge available to monitor and surveil adverse health outcomes and morbidity attributed to air pollution. This evidence is particularly important because the San Joaquin Valley (SJV) is a region of California that is disproportionally affected by poor air quality. Compared to 2015, California experienced considerably less wildfires in 2016 compared to the previous record setting year (NCEI, 2017). This fact could have affected this study ozone exposure association estimates which had modest effects on asthma and URIs ED visits and no association with hospitalizations. Including the unavailability of pollutant data from notable rural population centers of the region, consequential in the exclusion of their residents' ED visits and hospitalizations.

Despite being within federal standards attainment status, exposure to single and multi-day exposure to NO_2 was associated with increased odds of ED visits for asthma and URIs, as well as hospitalizations. This suggests that nitrogen dioxide is the cause of most ED visits and hospitalizations for asthma exacerbations during the warm season in the SJV at levels considered "Good" in the established air quality index.

Further research is needed to estimate air pollution's tangible and intangible costs to the region's residents to support the inclusion of non-fatal health endpoints in decision making, as well as evaluating what mitigation and control efforts are more likely to be supported by SJV residents.

Study 2 estimated the monetized burden of three criteria pollutants O_3, NO_2, and $PM_{2.5}$ in asthma exacerbations and upper respiratory infections emergency room visits, and hospitalizations for all SJV residents. This analysis is one of the first to utilize an association of exposure with a societal perspective and a prevalence approach to cost-of-illness studies to value the causal burden. What is notable is that the adverse health outcomes overburdening the SJV region, and its healthcare system are broadly preventable.

Cost of illness studies rely in the human capital theory (Schultz, 1961) and is the prevailing method to valuing the economic burden of diseases. Since air pollution is recognized as a negative externality resulting from human economic activity (Laffont, 1989; Meade, 1979; Shibata & Winrich, 1983), these type of economic evaluations analyses values the cost of potential protections of health relative to their estimated direct benefits or avoided ill health outcomes and play a key part in the classic public health model for prevention (CDC, 2017). By identifying and measuring direct and indirect health costs of outdoor air pollution-related asthma and URIs using this economics technique, this study added to the body of health economics literature overdue in the SJV.

Often recognized as one of the most polluted regions in the U.S., the SJV is at a juncture to protect its public health by preventing adverse health outcomes. From a health economics perspective, this analysis has furthered the evidence that air pollution is a negative externality that imposes substantial social, environmental, and healthcare costs

to the SJV. This analysis also provides economic and health outcome evidence of the benefits in reducing air pollution in the geographically unique air basin of the SJV.

Since virtually every human activity produces air pollution, the research of Study 3 examined what air pollution control and mitigation measures would SJV residents support or oppose to inform public health agencies accountable for regulating air quality and t encouraging behavior change to avoid ill health. This study provides analytical evidence of health disutility related to endemic poor air in the SJV region of California. People with asthma and chronic conditions report higher costs in quality of life. Local policymakers could invest in cohesive and democratic public health strategies that encourage trust in agencies and stakeholders, with the end goal of promoting adoption of individual, household and community protective policies and behaviors for populations that are overburdened by our region's air pollution adverse health outcomes. Equitable decisions are to be made under symmetry of information, but this evidence points at existing asymmetric information conditions.

Ostensibly, climate change is poised to increase the relative impact of outdoor air pollution in human health and although there is no substitute for macrolevel environmental protection regulations to control sources and quantity of emissions, these policies tend to attain benefits in the long-term. Public health research has a lot more to do in the expedient evaluation of approaches to protect health in the short- and mid-term.

Furthermore, these are timely observations particularly for areas of the country enduring ubiquitous bad air, and where, as of lately, have endured additional events of high pollution, such as forest fires. Whether is at the macroeconomic (structural) or microeconomic (individual and household) level, health economics offers a lens in which preferences of decision-makers, health outcomes, and health costs (Yazdi & Khanalizadeh, 2017) can be assessed to adopt cost-effective mitigation and control measures of air pollution and avoid ill health.

Strengths of Study Design

The strengths of this research constitute a comprehensive approach to evaluate health from the epidemiological perspective of the exposure assessment, to assessing the burden of disease and economic costs of air pollution related asthma and URIs, to a cost-effectiveness analysis to measure and compare the efficiency of different air pollution mitigation and control interventions.

Among other advantages is the availability of State data for emergency room visits and hospital patient discharge data. Also, the use of one-price format, as it is CMS Medicare reimbursement, will control for charge overestimations pertaining to multiple health insurances in the US healthcare system and provider surcharges. Another strength of this study is that the exposure-response coefficients were directly obtained in the epidemiological study of the region's population and measure exposures with the federally regulated monitoring system located within the SJV region. Furthermore, the focused and pragmatic approach to review economic evaluations in a systematic way yielded an economic analysis that addresses key factors in current air pollution mitigation and control practice and its effect in public health.

Limitations

The limitations of this study are associated with unavailable outpatient data for the health endpoints selected in the acute exacerbations of air pollution. These data are heavily controlled by health plans administering local Medicaid plans and are not publicly available for research. For this purpose, prevalence rates were retrieved from the UCLA's California Health Interview Survey. Nevertheless, the extent of these data does not cover all the residents who are experiencing air pollution-related asthma and URI that went to outpatient primary care providers and clinics to obtain care.

Also, air pollution is not a direct measure. Other constraints are: i) OSHPD data does not have patient addresses and air pollutant monitors can be directly linked, ii) we have no data on daily activities patterns, and iii) neither for air conditioning use. Nevertheless, this research study presents a critical component of the performance of status quo air pollution control measures in terms of valuation the health effects, and burden to the healthcare system and its population. The results of these studies will show the impacts and economic cost of the health burden due to air pollution in the SJV region.

Implications for Future Research: Next Steps

This work has critical implications for public health agencies, whose pivotal role is to prevent illness and disease using an equity framework, as well as for regulators who develop and revise standards using evidence of pollutants effects on health outcomes.

The paucity of economic evaluation, specifically of cost-effectiveness, cost-utility and cost-benefit, analyses on the public health implications of individual, household, community and structural outdoor air pollution mitigation and control policies is both vastly concerning and an opportunity for the field of health economics. Thus, it is proposed that a burden of disease, a comprehensive health economics study of air pollution for the region is long overdue and data is available to conduct a health economics study of this proportion.

There is general acceptance by researchers that cost-effectiveness evidence to estimate the value of routinely suggested individual, household, and behavior change strategies is highly needed and currently is scarce. As health economics makes inroads in public health decision-making, is imperative to embed cost-effectiveness evaluation of pollution mitigation interventions and policies, particularly of those publicly financed. In reviewing the available literature (Chang, Graff Zivin, Gross, & Neidell, 2016b; Fisk & Chan, 2017; A. Gao et al., 2021; Griffin et al., 2020; Hubbell, 2006; Janke, 2014; Jiao et al., 2019; Levy et al., 2001; Y. Liu et al., 2021; Martenies & Batterman, 2018; McGuinness et al., 2020; Mohammadi et al., 2021) most cost-effectiveness studies make emphasis on the need for the inclusion of diverse communities, short and long-term support, and availability of the suggested pollutant exposure reduction approaches.

Carefully designed studies are needed to determine how different mitigation strategies and interventions could play a role in complementing existing regulations to continue reducing air pollution emissions and increase the efficiency of public health protections in short and mid-term considering compounding crises.

The San Joaquin Valley Air Pollution Control District is the public health entity designated to enforce structural resolutions and develop local plans to implement air pollution control measures and is governed by an appointed board made of elected

officials and two public members appointed by the Governor (San Joaquin Valley Air Pollution District, 2019). On the other hand, local county public health departments are also commissioned to protect the public's health, prevent illnesses, surveil, and respond to endemic factors that complicate the attainment of their constituency's full health. Several departments have found that their communities would like air pollution and asthma to be addressed in their action plans (FCDPH, 2013; MCDPH, 2019; TCHHSA, 2017).

Furthermore, climate change has imposed new challenges to decreasing the burden of disease from air pollution, and long-standing environmental injustices have created inequities in the distribution of both bad air and equitable access to mitigation measures.

While this study is a leap forward in establishing an empirical organization of various air pollution policies and interventions, there is still a long way in investigating the potential drivers, acceptance, and sustainability in a range of contexts within the SJV region that would facilitate improvement of this endemic public health issue. As with any policy and intervention, systematic economic evaluation in the context of true conditions for SJV's residents is vital for ensuring adherence and sustaining the behavior change. A common goal for all the region's stakeholders should be achieving air quality equity.

Implications for Policy Makers

This research includes evidence of policy-relevant factors aim at protecting health and mitigating exposure from detrimental air quality. These results could be adopted in decision-making processes that concerned communities and policy makers who are charged with preventing negative health outcomes from exposure to air pollutants, promoting and protecting public health undertake to reduce disparities and achieve air quality equity.

Equity has been a chief concern for public health, and in the field of decreasing the effects of air pollution and minimizing its deleterious health outcomes, this is not absent. Policies and laws regulating air pollution have been pointed at in responsibility for their delay in addressing ongoing environmental injustices due to their benefits realizing long-term.

Based on the theoretical framework included in this work, these findings presented proof of the need for well-designed prospective studies to better establish and validate interventions that benefit respiratory health and puts them in the balance with their cost relative to different groups ability to use and adopt them. Considering climate change, increasing events worsening air pollution for some communities, such as forest fires, that is a resounding suggestion, accurate, and timely.

Against the backdrop of continued deterioration of air quality in the SJV region (American Lung Association, 2022), evidence shows that socioeconomic factors, such as income, stand in the way of individuals and households to implement defensive behaviors from air pollution equitably. Thus, a recommended ongoing public health objective is to study the factors associated with support of regulations and behavior interventions related to the mitigation and control of outdoor air pollution.

References

Alcorn, J., Rupp, J., & Graham, J. D. (2017). Attitudes Toward "Fracking": Perceived and Actual Geographic Proximity. *Review of Policy Research*, *34*(4), 504–536. https://doi.org/10.1111/ROPR.12234

Ali, M. U., Liu, G., Yousaf, B., Ullah, H., Abbas, Q., & Munir, M. A. M. (2018). A systematic review on global pollution status of particulate matter-associated potential toxic elements and health perspectives in urban environment. *Environmental Geochemistry and Health*. https://doi.org/10.1007/s10653-018-0203-z

Allen, R. W., & Barn, P. (2020). Individual- and Household-Level Interventions to Reduce Air Pollution Exposures and Health Risks: a Review of the Recent Literature. *Current Environmental Health Reports 2020 7:4*, *7*(4), 424–440. https://doi.org/10.1007/S40572-020-00296-Z

Almaraz, M., Bai, E., Wang, C., Trousdell, J., Conley, S., Faloona, I., & Houlton, B. Z. (2018). Agriculture is a major source of NOx pollution in California. *Science Advances*, *4*(1), 1–8. https://doi.org/10.1126/SCIADV.AAO3477

Ament, A., & Evers, S. (1993). Cost of illness studies in health care: a comparison of two cases. *Health Policy*, *26*(1), 29–42. https://doi.org/10.1016/0168-8510(93)90076-2

American Lung Association. (2018). Ozone. Retrieved April 25, 2019, from https://www.lung.org/our-initiatives/healthy-air/outdoor/air-pollution/ozone.html

American Lung Association. (2019). *State of the Air 2019*. Washington DC. Retrieved from www.stateoftheair.org

American Lung Association. (2022, May). State of the Air 2022. Retrieved May 19, 2022, from https://www.lung.org/research/sota

American Thoracic Society. (1996). Health effects of outdoor air pollution. Committee of the Environmental and Occupational Health Assembly of the American Thoracic Society. *American Journal of Respiratory and Critical Care Medicine*, *153*(1), 3–50. https://doi.org/10.1164/ajrccm.153.1.8542133

Anderson, H. R., Favarato, G., & Atkinson, R. W. (2013). Long-term exposure to outdoor air pollution and the prevalence of asthma: Meta-analysis of multi-community prevalence studies. *Air Quality, Atmosphere and Health*, *6*(1), 57–68. https://doi.org/10.1007/S11869-011-0145-4/TABLES/4

Anenberg, S., Miller, J., Henze, D., & Minjares, R. (2019). *A global snapshot of the air pollution-related health impacts of transportation sector emissions in 2010 and 2015*. Washington, DC. Retrieved from www.theicct.org

Ashton, T. (1997). The Industrial Revolution 1760-1830. In *OUP Catalogue*. Oxford: Oxford University Press. Retrieved from https://ideas.repec.org/b/oxp/obooks/9780192892898.html

Attari, S. Z., Schoen, M., Davidson, C. I., DeKay, M. L., Bruine de Bruin, W., Dawes, R., & Small, M. J. (2009). Preferences for change: Do individuals prefer voluntary actions, soft regulations, or hard regulations to decrease fossil fuel consumption? *Ecological Economics*, *68*(6), 1701–1710. https://doi.org/10.1016/J.ECOLECON.2008.10.007

Bachmann, T. M., & van der Kamp, J. (2017). Expressing air pollution-induced health-

related externalities in physical terms with the help of DALYs. *Environment International*, *103*, 39–50. https://doi.org/10.1016/j.envint.2017.03.020

Barboza, T. (2013). San Joaquin Valley officials fight with EPA over air quality - latimes. Retrieved November 8, 2018, from http://articles.latimes.com/2013/dec/22/local/la-me-valley-air-20131223

Bauer, B. A., Reed, C. E., Yunginger, J. W., Wollan, P. C., & Silverstein, M. D. (1997). Incidence and Outcomes of Asthma in the Elderly: A Population-Based Study in Rochester, Minnesota. *Chest*, *111*(2), 303–310. https://doi.org/10.1378/CHEST.111.2.303

Becker, G. S. (1975). *Human Capital: A Theoretical and Empirical Analysis, with Special Reference to Education.* (2nd ed.). New York: Columbia University Press for NBER.

Bernstein, H. T. (1975). The Mysterious Disappearance of Edwardian London Fog. *The London Journal*, *1*(2), 189–206. https://doi.org/10.1179/ldn.1975.1.2.189

Bickerstaff, K., & Walker, G. (2001). Public understandings of air pollution: The "localisation" of environmental risk. *Global Environmental Change*, *11*(2), 133–145. https://doi.org/10.1016/S0959-3780(00)00063-7

Billionnet, C., Sherrill, D., & Annesi-Maesano, I. (2012). Estimating the health effects of exposure to multi-pollutant mixture. *Ann Epidemiol*, *22*(2), 2. https://doi.org/10.1016/j.annepidem.2011.11.004

Blake, J. (1999). Overcoming the "value-action gap" in environmental policy: Tensions between national policy and local experience. *Local Environment*, *4*(3), 257–278. https://doi.org/10.1080/13549839908725599

Brandt, S., Dickinson, B., Ghosh, R., Lurmann, F., Perez, L., Penfold, B., … McConnell, R. (2017). Costs of coronary heart disease and mortality associated with near-roadway air pollution. *Science of The Total Environment*, *601–602*, 391–396. https://doi.org/10.1016/j.scitotenv.2017.05.073

Brandt, S., Perez, L., Künzli, N., Lurmann, F., Wilson, J., Pastor, M., & McConnell, R. (2014). Cost of near-roadway and regional air pollution-attributable childhood asthma in Los Angeles County. *The Journal of Allergy and Clinical Immunology*, *134*(5), 1028–1035. https://doi.org/10.1016/j.jaci.2014.09.029

Brandt, S., Vásquez Lavín, F., & Hanemann, M. (2012a). Contingent valuation scenarios for chronic illnesses: the case of childhood asthma. *Value in Health*, *15*(8), 1077–1083. https://doi.org/10.1016/J.JVAL.2012.07.006

Brandt, S., Vásquez Lavín, F., & Hanemann, M. (2012b). Contingent valuation scenarios for chronic illnesses: the case of childhood asthma. *Value in Health : The Journal of the International Society for Pharmacoeconomics and Outcomes Research*, *15*(8), 1077–1083. https://doi.org/10.1016/J.JVAL.2012.07.006

Brimblecombe, P. (1995). History of Air Pollution. *Composition, Chemistry, and Climate of the Atmosphere*. Retrieved from https://www.epa.gov/air-research/history-air-pollution

Brimblecombe, Peter. (2006). *The Clean Air Act after 50 Years* (Vol. 61). East Anglia, Norwich. Retrieved from www.metoffice.com/education/

Brown, P. M., Cameron, L. D., Wilkinson, M., & Taylor, D. (2020). Economic and Behavioral Economic Approaches to Behavior Change. In M. S. Hagger, L. D.

Cameron, K. Hamilton, N. Hankonen, & T. Lintunen (Eds.), *The Handbook of Behavior Change* (pp. 617–631). Cambridge, UK: Cambridge University Press. https://doi.org/10.1017/9781108677318.042

Brown, P, Gonzalez, M., & Sandhu, R. (2015). Economic Burden of Chronic Disease in California. Retrieved June 2, 2022, from https://cbcd.ucmerced.edu/

Brown, Paul, Cameron, L., Cisneros, R., Cox, R., Gaab, E., Gonzalez, M., … Song, A. (2016). Latino and Non-Latino Perceptions of the Air Quality in California's San Joaquin Valley. *International Journal of Environmental Research and Public Health*, *13*(12), 1242. https://doi.org/10.3390/ijerph13121242

Burns, J. H. (2005). Happiness and Utility: Jeremy Bentham's Equation. *Utilitas*, *17*(1), 46–61. https://doi.org/10.1017/S0953820804001396

Byford, S., Torgerson, D. J., & Raftery, J. (2000). Economic note: cost of illness studies. *BMJ (Clinical Research Ed.)*, *320*(7245), 1335. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10807635

California EDD. (2023, August). 2016 Average Weekly Earnings, Annual Average.

Canada. (2016). Common air pollutants: ground-level ozone - Canada.ca. Retrieved November 8, 2018, from https://www.canada.ca/en/environment-climate-change/services/air-pollution/pollutants/common-contaminants/ground-level-ozone.html

Caputi, M. A., & Heiss, W. A. (1984). The DRG Revolution. *Health & Social Work*, *9*(1), 5–12. https://doi.org/10.1093/HSW/9.1.5

Carande-Kulis, V. G., Getzen, T. E., & Thacker, S. B. (2007). Public Goods and Externalities: A Research Agenda for Public Health Economics. *Journal of Public Health Management and Practice*, *13*(2), 227–232. Retrieved from https://journals.lww.com/jphmp/fulltext/2007/03000/public_goods_and_externalities__a_research_agenda.24.aspx

CARB. (2023). History of the California Air Resources Board. Retrieved April 25, 2023, from https://ww2.arb.ca.gov/about/history

Carlsten, C., Salvi, S., Wong, G. W. K., & Chung, K. F. (2020). Personal strategies to minimise effects of air pollution on respiratory health: advice for providers, patients and the public. *European Respiratory Journal*, *55*, 1–21. https://doi.org/10.1183/13993003.02056-2019

Carr, T. F., & Bleecker, E. (2016). Asthma heterogeneity and severity. *World Allergy Organization Journal*, *9*(1). https://doi.org/10.1186/S40413-016-0131-2

Carriazo, F. (2016). Economics and Air Pollution. *Air Quality - Measurement and Modeling*. https://doi.org/10.5772/65256

Carrus, G., Bonaiuto, M., & Bonnes, M. (2005). Environmental concern, regional identity, and support for protected areas in Italy. *Environment and Behavior*, *37*(2), 237–257. https://doi.org/10.1177/0013916504269644

Castro-Rodriguez, J. A., Forno, E., Rodriguez-Martinez, C. E., & Celedón, J. C. (2016). Risk and Protective Factors for Childhood Asthma: What Is the Evidence? *Journal of Allergy and Clinical Immunology: In Practice*, *4*(6), 1111–1122. https://doi.org/10.1016/J.JAIP.2016.05.003

CDC. (2017). *Economic Impact Analysis, Cost of Illness*. *Center for Disease Control and Prevention*. Retrieved from

https://www.cdc.gov/dhdsp/programs/spha/economic_evaluation/docs/podcast_ii.pdf

Chanez, P., Wenzel, S. E., Anderson, G. P., Anto, J. M., Bel, E. H., Boulet, L. P., … Vachier, I. (2007). Severe asthma in adults: What are the important questions? *Journal of Allergy and Clinical Immunology*, *119*(6), 1337–1348. https://doi.org/10.1016/J.JACI.2006.11.702

Chang, T., Graff Zivin, J., Gross, T., & Neidell, M. (2016a). Particulate Pollution and the Productivity of Pear Packers. *American Economic Journal: Economic Policy*, *8*(3), 141–169. https://doi.org/10.1257/pol.20150085

Chang, T., Graff Zivin, J., Gross, T., & Neidell, M. (2016b). Particulate Pollution and the Productivity of Pear Packers. *American Economic Journal: Economic Policy*, *8*(3), 141–169. https://doi.org/10.1257/POL.20150085

Chang, T., Zivin, J. G., Gross, T., & Neidell, M. (2016). Particulate pollution and the productivity of pear packers. *American Economic Journal: Economic Policy*, *8*(3), 141–169. https://doi.org/10.1257/POL.20150085

Cisneros, R., Brown, P., Cameron, L., Gaab, E., Gonzalez, M., Ramondt, S., … Schweizer, D. (2017a). Understanding Public Views about Air Quality and Air Pollution Sources in the San Joaquin Valley, California. *Journal of Environmental and Public Health*, *2017*, 1–7. https://doi.org/10.1155/2017/4535142

Cisneros, R., Brown, P., Cameron, L., Gaab, E., Gonzalez, M., Ramondt, S., … Schweizer, D. (2017b). Understanding Public Views about Air Quality and Air Pollution Sources in the San Joaquin Valley, California. *Journal of Environmental and Public Health*, *2017*, 1–7. https://doi.org/10.1155/2017/4535142

Cisneros, R., Gharibi, H., Entwistle, M. R., Tavallali, P., Singhal, M., & Schweizer, D. (2021). Nitrogen dioxide and asthma emergency department visits in California, USA during cold season (November to February) of 2005 to 2015: A time-stratified case-crossover analysis. *Science of The Total Environment*, *754*, 142089. https://doi.org/10.1016/J.SCITOTENV.2020.142089

Cisneros, R., & Perez, M. A. (2007). A comparison of ozone exposure in Fresno and Shaver Lake, California. *Journal of Environmental Health*.

Cisneros, R., Schweizer, D., Zhong, S., Hammond, K., Perez, M. A., Guo, Q., … Bennett, D. H. (2012). Analysing the effects of the 2002 McNally fire on air quality in the San Joaquin Valley and southern Sierra Nevada, California. *International Journal of Wildland Fire*. https://doi.org/10.1071/WF11025

CMS. (2019, November 27). Inpatient Charge Data FY 2016. Retrieved November 28, 2020, from https://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/Medicare-Provider-Charge-Data/Inpatient2016

Cole, P., & MacMahon, B. (1971). Attributable risk percent in case-control studies. *British Journal of Preventive & Social Medicine*, *25*(4), 242–244. https://doi.org/10.1136/jech.25.4.242

D. Zmirou, A. D. F. B. C. B. J. D. (1999). Health Effects Costs of Particulate Air Pollution. *Journal of Occupational &amp*, *41*(10), 847–856. Retrieved from https://insights.ovid.com/pubmed?pmid=10529940

Dawson, K. W. (2018). *Death in the air : the true story of a serial killer, the great London smog, and the strangling of a city* (1st ed.). Hachette Books. Retrieved from

https://www.barnesandnoble.com/w/death-in-the-air-kate-winkler-dawson/1125684223#/

Del Rio, P. R., Liu, A. H., Borres, M. P., Södergren, E., Iachetti, F., & Casale, T. B. (2022). Asthma and Allergy: Unravelling a Tangled Relationship with a Focus on New Biomarkers and Treatment. *International Journal of Molecular Sciences 2022, Vol. 23, Page 3881*, *23*(7), 3881. https://doi.org/10.3390/IJMS23073881

Department of Finance. (2021). *Population Estimates for Cities, Counties, and the State, 2011-2020 with 2010 Census Benchmark*. Sacramento, CA, USA. Retrieved from https://dof.ca.gov/forecasting/demographics/estimates/e-4-population-estimates-for-cities-counties-and-the-state-2011-2020-with-2010-census-benchmark-new/

Ebenstein, A., Fan, M., Greenstone, M., He, G., Yin, P., & Zhou, M. (2015). Growth, Pollution, and Life Expectancy: China from 1991–2012. *American Economic Review*, *105*(5), 226–231. https://doi.org/10.1257/aer.p20151094

Ed-Data Education Data Partnership. (2016). General Fund Revenues: Financial Data .

Ejelöv, E., Harring, N., Hansla, A., Jagers, S., & Nilsson, A. (2022). Push, Pull, or Inform - an Empirical Taxonomy of Environmental Policy Support in Sweden. *Journal of Public Policy*, *42*(3), 529–552. https://doi.org/10.1017/S0143814X21000271

El-Fadel, M., & Massoud, M. (2000). *Particulate matter in urban areas: health-based economic assessment. The Science of the Total Environment* (Vol. 257). Retrieved from https://ac.els-cdn.com/S0048969700005039/1-s2.0-S0048969700005039-main.pdf?_tid=b1242171-3ac3-4f8f-9710-b7df333966b0&acdnat=1541702241_ed1f30da42200e970e24d820fc47ac6b

England, P. H. (2018). *Estimation of costs to the NHS and social care due to the health impacts of air pollution*. London, UK. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/708855/Estimation_of_costs_to_the_NHS_and_social_care_due_to_the_health_impacts_of_air_pollution_-_summary_report.pdf

Entwistle, M. R., Gharibi, H., Tavallali, P., Cisneros, R., Schweizer, D., Brown, P., & Ha, S. (2019a). Ozone pollution and asthma emergency department visits in Fresno, CA, USA, during the warm season (June-September) of the years 2005 to 2015: a time-stratified case-crossover analysis. *Air Quality, Atmosphere and Health*, *12*, 661–672. https://doi.org/10.1007/s11869-019-00685-w

Entwistle, M. R., Gharibi, H., Tavallali, P., Cisneros, R., Schweizer, D., Brown, P., & Ha, S. (2019b). Ozone pollution and asthma emergency department visits in Fresno, CA, USA, during the warm season (June–September) of the years 2005 to 2015: a time-stratified case-crossover analysis. *Air Qual Atmos Health*, *12*(6), 661–672. https://doi.org/10.1007/s11869-019-00685-w

EPA. The Clean Air Act - Highlights of the 1990 Amendments (1990). Washington DC: Executive.

EPA. (2018). Criteria Air Pollutants. Retrieved November 8, 2018, from https://www.epa.gov/criteria-air-pollutants

EPA. (2019a). *Integrated Science Assessment for Particulate Matter, US EPA*. Research Triangle Park, NC. Retrieved from https://www.epa.gov/isa/integrated-science-assessment-isa-particulate-matter

EPA. Ozone Nonattainment Area Requirements San Joaquin Valley, California, Pub. L.

No. 40 CFR Part 52, U.S. Federal Register Rules and Regulations Vol. 84, No. 57 11198 (2019). Federal Register. Retrieved from https://www.federalregister.gov/documents/2019/03/25/2019-05159/clean-air-plans-2008-8-hour-ozone-nonattainment-area-requirements-san-joaquin-valley-california

Epocrates. (2023). Drug Formulary Lookup .

Etchie, T. O., Sivanesan, S., Adewuyi, G. O., Krishnamurthi, K., Rao, P. S., Etchie, A. T., … Smith, K. R. (2017). The health burden and economic costs averted by ambient PM2.5 pollution reductions in Nagpur, India. *Environment International*, *102*, 145–156. https://doi.org/10.1016/j.envint.2017.02.010

EuroQOL Research Foundation. (2018). *EQ-5D-3L User Guide V6.0*. Rotterdam, The Netherlands. Retrieved from https://euroqol.org/publications/user-guides/

Evans, A., & Evans, A. (2017). Environmental Noise Pollution: Has Public Health Become too Utilitarian? *Open Journal of Social Sciences*, *5*(5), 80–107. https://doi.org/10.4236/JSS.2017.55007

Fan, J., Li, S., Fan, C., Bai, Z., & Yang, K. (2016). The impact of PM2.5 on asthma emergency department visits: a systematic review and meta-analysis. *Environmental Science and Pollution Research*, *23*(1), 843–850. https://doi.org/10.1007/S11356-015-5321-X/FIGURES/1

FCDPH. (2013). *Fresno County Community Health Needs Assessment*. Fresno, CA.

Finkelstein, A., Luttmer, E. F. P., & Notowidigdo, M. J. (2013). What Good is Wealth Without Health? The Effect of Health on the Marginal Utility of Consumption. *Journal of the European Economic Association*, *11*(Supplement 1), 221–258. https://doi.org/10.1111/J.1542-4774.2012.01101.X

Fisk, W. J., & Chan, W. R. (2017). Health benefits and costs of filtration interventions that reduce indoor exposure to PM2.5 during wildfires. *Indoor Air*, *27*(1), 191–204. https://doi.org/10.1111/INA.12285

Gandini, M., Scarinzi, C., Bande, S., Berti, G., Carnà, P., Ciancarella, L., … LIFE MEDHISS collaborative Group. (2018). Long term effect of air pollution on incident hospital admissions: Results from the Italian Longitudinal Study within LIFE MED HISS project. *Environment International*. https://doi.org/10.1016/j.envint.2018.10.020

Gao, A., Wang, J., Luo, J., Wang, P., Chen, K., Wang, Y., … Zhang, H. (2021). Health and economic losses attributable to PM 2.5 and ozone exposure in Handan, China. *Air Quality, Atmosphere & Health*, *14*, 605–615. https://doi.org/10.1007/s11869-020-00964-x/Published

Gao, J., Yuan, Z., Liu, X., Xia, X., Huang, X., & Dong, Z. (2016). Improving air pollution control policy in China-A perspective based on cost-benefit analysis. *Science of the Total Environment*, *543*, 307–314. https://doi.org/10.1016/J.SCITOTENV.2015.11.037

Gharibi, H., Entwistle, M. R., Ha, S., Gonzalez, M., Brown, P., Schweizer, D., & Cisneros, R. (2018). Ozone pollution and asthma emergency department visits in the Central Valley, California, USA, during June to September of 2015: a time-stratified case-crossover analysis. *Journal of Asthma*, 1–12. https://doi.org/10.1080/02770903.2018.1523930

Gillman, A., & Douglass, J. A. (2012). Asthma in the elderly. *Asia Pacific Allergy*, *2*(2),

101. https://doi.org/10.5415/APALLERGY.2012.2.2.101

Gleason, J. A., Bielory, L., & Fagliano, J. A. (2014). Associations between ozone, PM2.5, and four pollen types on emergency department pediatric asthma events during the warm season in New Jersey: A case-crossover study. *Environmental Research*, *132*, 421–429. https://doi.org/10.1016/J.ENVRES.2014.03.035

Godish, T. (2014). *Air quality*. (T. Godish, W. Davis, & J. Fu, Eds.) (5th ed.). CRC Press Taylor & Francis Group.

Griffin, S., Walker, S., & Sculpher, M. (2020). Distributional cost effectiveness analysis of West Yorkshire low emission zone policies. *Health Economics*, *29*(5), 567–579. https://doi.org/10.1002/HEC.4003

Guarnieri, M., & Balmes, J. R. (2014). Outdoor air pollution and asthma. *The Lancet*, *383*(9928), 1581–1592. https://doi.org/10.1016/s0140-6736(14)60617-6

Guo, X. R., Cheng, S. Y., Chen, D. S., Zhou, Y., & Wang, H. Y. (2010). Estimation of economic costs of particulate air pollution from road transport in China. *Atmospheric Environment*, *44*(28), 3369–3377. https://doi.org/10.1016/J.ATMOSENV.2010.06.018

Hall, J. V, Brajer, V., & Lurmann, F. W. (2008). Measuring the gains from improved air quality in the San Joaquin Valley. *Journal of Environmental Management*, *88*, 1003–1015. https://doi.org/10.1016/j.jenvman.2007.05.002

Hall, J. V, Brajer, V., & Lurmann, F. W. (2010). Analysis Air pollution, health and economic benefits-Lessons from 20 years of analysis. *Ecological Economics*, *69*, 2590–2597. https://doi.org/10.1016/j.ecolecon.2010.08.003

Hankins, M., & Bryner, N. (2018). Can the EPA Roll Back California's Clean Air Standards? Retrieved May 17, 2019, from https://prospect.org/article/can-epa-roll-back-californias-clean-air-standards

Hanlon, W. W. (2016). *Coal Smoke and the Costs of the Industrial Revolution*. Los Angeles, CA. Retrieved from https://www.econ.ucla.edu/whanlon/papers/hanlon_coal_and_the_costs_of_the_IR.pdf

Harada, N., Kominski, G., & Shoshanna, S. (1993). Development of a Resource-Based Patient Classification Scheme for Rehabilitation. *Inquiry*, *30*(1), 54–63. Retrieved from http://www.jstor.org/stable/29772349

Harring, N., & Jagers, S. C. (2013). Should We Trust in Values?: Explaining Public Support for Pro-Environmental Taxes. *Sustainability*, *5*(1), 210–227. https://doi.org/10.3390/su5010210

Harring, N., Jagers, S. C., & Matti, S. (2017). Public Support for Pro-Environmental Policy Measures: Examining the Impact of Personal Values and Ideology. *Sustainability*, *9*(5), 1–14. https://doi.org/10.3390/su9050679

Hensher, M. (2020). Incorporating environmental impacts into the economic evaluation of health care systems: Perspectives from ecological economics. *Resources, Conservation and Recycling*, *154*, 104623. https://doi.org/10.1016/J.RESCONREC.2019.104623

Hodan, W. M., & Barnard, W. R. (2004). *Evaluating the Contribution of PM2.5 Precursor Gases and Re-entrained Road Emissions to Mobile Source PM2.5 Particulate Matter Emissions Prepared by MACTEC Under Contract to the Federal*

Highway Administration. Retrieved from https://www3.epa.gov/ttnchie1/conference/ei13/mobile/hodan.pdf

Hoffman, J. I. E. (2019). Odds Ratio, Relative Risk, Attributable Risk, and Number Needed to Treat. *Basic Biostatistics for Medical and Biomedical Practitioners*, 295–310. https://doi.org/10.1016/B978-0-12-817084-7.00020-6

Holcombe, R. G., & Sobel, R. S. (2000). Consumption Externalities and Economic Welfare. *Eastern Economic Journal*, *26*(2), 157–170. Retrieved from https://about.jstor.org/terms

Holst, G. J., Pedersen, C. B., Thygesen, M., Brandt, J., Geels, C., Bønløkke, J. H., & Sigsgaard, T. (2020). Air pollution and family related determinants of asthma onset and persistent wheezing in children: nationwide case-control study. *BMJ*, *370*. https://doi.org/10.1136/BMJ.M2791

Hubbell, B. J. (2006). Implementing QALYs in the Analysis of Air Pollution Regulations. *Environmental & Resource Economics 2006 34:3*, *34*(3), 365–384. https://doi.org/10.1007/S10640-004-7437-1

International Monetary Fund. (2019). World Economic Outlook, Real GDP growth. Retrieved May 17, 2019, from https://www.imf.org/external/datamapper/NGDP_RPCH@WEO/OEMDC/ADVEC/WEOWORLD

James, C., Bernstein, D. I., Cox, J., Ryan, P., Wolfe, C., Jandarov, R., … Reponen, T. (2019). HEPA filtration improves asthma control in children exposed to traffic-related airborne particles. *Indoor Air*. https://doi.org/10.1111/INA.12625

Janke, K. (2014). Air pollution, avoidance behaviour and children's respiratory health: Evidence from England. *Journal of Health Economics*, *38*, 23–42. https://doi.org/10.1016/J.JHEALECO.2014.07.002

Jiao, B., Kim, S., Hagen, J., & Muennig, P. A. (2019). Cost-effectiveness of neighbourhood slow zones in New York City. *Inj Prev*, *25*, 98–103. https://doi.org/10.1136/injuryprev-2017-042499

Jo, C. (2014). Cost-of-illness studies: concepts, scopes, and methods. *Clinical and Molecular Hepatology*, *20*(4), 327–337. https://doi.org/10.3350/cmh.2014.20.4.327

Jones, B., Duncan, K., Elkind, E. N., & Hanson, M. (2017). *The Economic Impacts of California Major Climate Programs on the San Joaquin Valley*. Berkeley, CA. Retrieved from http://laborcenter.berkeley.edu/pdf/2017/economic-impacts-climate-programs-san-joaquin-valley.pdf

Kampa, M., & Castanas, E. (2008). Human health effects of air pollution. *Environmental Pollution*, *151*, 362–367. https://doi.org/10.1016/j.envpol.2007.06.012

Kattan, M., Stearns, S. C., Crain, E. F., Stout, J. W., Gergen, P. J., Evans, R., … Mitchell, H. E. (2005). Cost-effectiveness of a home-based environmental intervention for inner-city children with asthma. *Journal of Allergy and Clinical Immunology*, *116*(5), 1058–1063. https://doi.org/10.1016/J.JACI.2005.07.032

Kelly, F. J., & Fussell, J. C. (2015). Air pollution and public health: emerging hazards and improved understanding of risk. *Environmental Geochemistry and Health*, *37*(4), 631–649. https://doi.org/10.1007/s10653-015-9720-1

Klaassen, G., & Forsund, F. R. (1994). *Economic Instruments for Air Pollution Control*. *Economy and Environment*. Laxenburg, Austria: Kluwer Academic Publishers.

Klarl, T. (2016). Pollution externalities, endogenous health and the speed of convergence in an endogenous growth model. *Journal of Macroeconomics*, *50*, 98–113. https://doi.org/10.1016/J.JMACRO.2016.09.003

Laffont, J. J. (1989). Externalities. In *Allocation, Information and Markets* (pp. 112–116). London: Palgrave Macmillan, London. https://doi.org/10.1007/978-1-349-20215-7_11

Landrigan, P. J., Schechter, C. B., Lipton, J. M., Fahs, M. C., & Schwartz, J. (2002). Environmental pollutants and disease in American children: estimates of morbidity, mortality, and costs for lead poisoning, asthma, cancer, and developmental disabilities. *Environmental Health Perspectives*, *110*(7), 721–728. https://doi.org/10.1289/ehp.02110721

Larg, A., & Moss, J. R. (2011). Cost-of-illness studies: A guide to critical evaluation. *PharmacoEconomics*, *29*(8), 653–671. https://doi.org/10.2165/11588380-000000000-00000

Latza, U., Gerdes, S., & Baur, X. (2009). Effects of nitrogen dioxide on human health: Systematic review of experimental and epidemiological studies conducted between 2002 and 2006. *International Journal of Hygiene and Environmental Health*, *212*(3), 271–287. https://doi.org/10.1016/j.ijheh.2008.06.003

Laurent, O., Pedrono, G., Segala, C., Filleul, L., Havard, S., Deguen, S., … Bard, D. (2008). Air Pollution, Asthma Attacks, and Socioeconomic Deprivation: A Small-Area Case-Crossover Study. *American Journal of Epidemiology*, *168*(1), 58–65. https://doi.org/10.1093/AJE/KWN087

Lessard, L. N., Alcala, E., & Capitman, J. A. (2016). Pollution, Poverty, and Potentially Preventable Childhood Morbidity in Central California. *The Journal of Pediatrics*, *168*, 198–204. https://doi.org/10.1016/J.JPEDS.2015.08.007

Levy, J. I., Carrothers, T. J., Tuomisto, J. T., Hammitt, J. K., & Evans, J. S. (2001). Assessing the Public Health Benefits of Reduced Ozone Concentrations. *Environ Health Perspect*, *109*, 1215–1226. Retrieved from http://ehpnet1.niehs.nih.gov/docs/2001/109p1215-1226levy/abstract.html

Li, D., Wang, J. bing, Zhang, Z. yu, Shen, P., Zheng, P. wen, Jin, M. juan, … Chen, K. (2018). Effects of air pollution on hospital visits for pneumonia in children: a two-year analysis from China. *Environmental Science and Pollution Research*, *25*(10), 10049–10057. https://doi.org/10.1007/S11356-018-1192-2

Liu, W., Du, C., Chu, X., & Wang, Z. (2021). "Inverted quarantine" in the face of environmental change: Initiative defensive behaviors against air pollution in China. *Sustainable Production and Consumption*, *26*, 493–503. https://doi.org/10.1016/J.SPC.2020.12.024

Liu, X., Vedlitz, A., & Shi, L. (2014). Examining the determinants of public environmental concern: Evidence from national public surveys. *Environmental Science and Policy*, *39*, 77–94. https://doi.org/10.1016/J.ENVSCI.2014.02.006

Liu, Y., Zhou, B., Wang, J., & Zhao, B. (2021). Health benefits and cost of using air purifiers to reduce exposure to ambient fine particulate pollution in China. *Journal of Hazardous Materials*, *414*, 125540. https://doi.org/10.1016/J.JHAZMAT.2021.125540

Maclure, M. (1991). The case-crossover design: A method for studying transient effects

on the risk of acute events. *American Journal of Epidemiology*, *133*(2), 144–153. https://doi.org/10.1093/aje/kwx105

Malashock, D. A., Delang, M. N., Becker, J. S., Serre, M. L., West, J. J., Chang, K. L., … Anenberg, S. C. (2022). Estimates of ozone concentrations and attributable mortality in urban, peri-urban and rural areas worldwide in 2019. *Environmental Research Letters*, *17*(5), 054023. https://doi.org/10.1088/1748-9326/AC66F3

Malig, B. J., Pearson, D. L., Chang, Y. B., Broadwin, R., Basu, R., Green, R. S., & Ostro, B. (2016). A time-stratified case-crossover study of ambient ozone exposure and emergency department visits for specific respiratory diagnoses in California (2005-2008). *Environmental Health Perspectives*, *124*(6), 745–753. https://doi.org/10.1289/ehp.1409495

Marshall, A. (1920). The Health and Strength of the Population. In *Principles of Economics, Book 4: The Agents of Production* (8th ed., p. 193). Cambridge, UK: Palgrave Macmillan. Retrieved from https://archive.org/details/economics_4_0802_librivox/principlesofeconomics4_05_marshall.mp3

Martenies, S., & Batterman, S. (2018). Effectiveness of Using Enhanced Filters in Schools and Homes to Reduce Indoor Exposures to PM 2.5 from Outdoor Sources and Subsequent Health Benefits for Children with Asthma. *Environmental Science & Technology*, *52*(18), 10767–10776. https://doi.org/10.1021/ACS.EST.8B02053

McCarthy, G. (2019). The Role of Environmental Economics in U.S. Environmental Policy. In *Review of Environmental Economics and Policy*. https://doi.org/10.1093/reep/rez001

MCDPH. (2019). *Live Well Madera Community Health Improvement Plan*. Madera, CA.

McGuinness, K. L., Hinks, I. R., Westcott, K. E., & Gheewala, S. H. (2020). An integrated assessment of particulate respirators used as personal protection from ambient air pollution in Bangkok, Thailand. *Journal of Global Health Reports*, *4*(e2020082). https://doi.org/10.29392/001C.14598

Mcneil, B. J. (1985). Hospital Response to DRG-Based Prospective Payment. *Medical Decision Making*, *5*(1), 15–21.

Meade, J. E. (1979). *The Theory of Economic Externalities: The Control of Environmental Pollution and Similar Social Costs* (Vol. 2). Brill Archive. Retrieved from https://brill.com/view/title/9985?language=en

Meng, Y.-Y., Rull, R. P., Wilhelm, M., Lombardi, C., Balmes, J., & Ritz, B. (2010). Outdoor air pollution and uncontrolled asthma in the San Joaquin Valley, California. *Journal of Epidemiology & Community Health*, *64*(2), 142–147. https://doi.org/10.1136/jech.2009.083576

Meng, Y. Y., Babey, S. H., Malcolm, E., Brown, E. R., & Chawla, N. (2003). *Asthma in California: Findings from the 2001 California Health Interview Survey*. Los Angeles, CA. Retrieved from https://escholarship.org/uc/item/8v65765d

Mohammadi, T., Sadatsafavi, M., & Carlsten, C. (2021). The economics of precision health: preventing air pollution-induced exacerbation in asthma. *ERJ Open Research*, *7*(1). https://doi.org/10.1183/23120541.00790-2020

Moonie, S. A., Sterling, D. A., Figgs, L., & Castro, M. (2006). Asthma status and severity affects missed school days. *The Journal of School Health*, *76*(1), 18–24.

https://doi.org/10.1111/J.1746-1561.2006.00062.X
Mushkin, S. J. (1958). Toward a definition of health economics. *Public Health Reports*, *73*(9), 785–793. https://doi.org/10.2307/4590242
National Centers for Environmental Information. (2017). *Monthly Wildfires Report for Annual 2016*. San Diego, CA. Retrieved from https://www.ncei.noaa.gov/access/monitoring/monthly-report/fire/201613
Navrud, S. (2001). Valuing health impacts from air pollution in Europe. *Environmental and Resource Economics*, *20*(4), 305–329. https://doi.org/10.1023/A:1013099120078/METRICS
Neumayer, E., Plümper, T., & Barthel, F. (2014). The political economy of natural disaster damage. *Global Environmental Change*, *24*(1), 8–19. https://doi.org/10.1016/j.gloenvcha.2013.03.011
Nilsson, A., Hansla, A., Heiling, J. M., Bergstad, C. J., & Martinsson, J. (2016). Public Acceptability Towards Environmental Policy Measures: Value-Matching Appeals. *Environmental Science and Policy*, *61*, 176–184. https://doi.org/10.1016/j.envsci.2016.04.013
Niu, Y., Chen, R., & Kan, H. (2017). Ambient Air Pollution and Health Impact in China. In *Advances in Experimental Medicine and Biology* (pp. 233–244). Singapore: Springer Nature. https://doi.org/10.1007/978-981-10-5657-4_10
Noe, F. P., & Snow, R. (2010). Hispanic Cultural Influence on Environmental Concern. *Journal of Environmental Education*, *21*(2), 27–34. https://doi.org/10.1080/00958964.1990.9941928
Nurmagambetov, T., Kuwahara, R., & Garbe, P. (2018). The Economic Burden of Asthma in the United States, 2008-2013. *Annals of the American Thoracic Society*, *15*(3), 348–356. https://doi.org/10.1513/ANNALSATS.201703-259OC
OMB. (2018). *2017 Draft Report to Congress on the Benefits and Costs of Federal Regulations and Agency Compliance with the Unfunded Mandates Reform Act* . Washington, DC. Retrieved from https://www.whitehouse.gov/wp-content/uploads/2017/12/draft_2017_cost_benefit_report.pdf
Park, H.-K., Cheng, K.-C., Tetteh, A. O., Hildemann, L. M., & Nadeau, K. C. (2017). Effectiveness of air purifier on health outcomes and indoor particles in homes of children with allergic diseases in Fresno, California: A pilot study. *Journal of Asthma*, *54*(4), 341–346. https://doi.org/10.1080/02770903.2016.1218011
Parkins, J. R., Rollins, C., Anders, S., & Comeau, L. (2018). Predicting intention to adopt solar technology in Canada: The role of knowledge, public engagement, and visibility. *Energy Policy*, *114*, 114–122. https://doi.org/10.1016/J.ENPOL.2017.11.050
Pat Brown Institute. (2014). *The South San Joaquin Valley: The State of the Region*. Los Angeles, CA. Retrieved from www.BeaconEcon.com.
Patankar, A. M., Trivedi, P. L., & Somaiya, K. J. (2011). Monetary burden of health impacts of air pollution in Mumbai, India: Implications for public health policy. *Public Health*, *125*, 157–164. https://doi.org/10.1016/j.puhe.2010.11.009
Peterson, G. C. L., Hogrefe, C., Corrigan, A. E., Neas, L. M., Mathur, R., & Rappold, A. G. (2020). Impact of reductions in emissions from major source sectors on fine particulate matter–related cardiovascular mortality. *Environmental Health*

Perspectives, *128*(1). https://doi.org/10.1289/EHP5692

PPIC. (2018). 2020 Census: Counting the San Joaquin Valley - Public Policy Institute of California. Retrieved May 17, 2019, from https://www.ppic.org/blog/2020-census-counting-the-san-joaquin-valley/

Presidential Science Advisory Committee. (1965). *"Restoring the Quality of Our Environment" Report on Pollution of Air, Soil, and Waters*. Washington DC. Retrieved from https://www.presidency.ucsb.edu/documents/statement-the-president-response-science-advisory-committee-report-pollution-air-soil-and

Rauwald, K. S., & Moore, C. F. (2016). Environmental Attitudes as Predictors of Policy Support across Three Countries. *Http://Dx.Doi.Org/10.1177/001391602237243*, *34*(6), 709–739. https://doi.org/10.1177/001391602237243

Reding, K. W., Young, M. T., Szpiro, A. A., Han, C. J., DeRoo, L. A., Weinberg, C., … Sandler, D. P. (2015). Breast Cancer Risk in Relation to Ambient Air Pollution Exposure at Residences in the Sister Study Cohort. *Cancer Epidemiology, Biomarkers & Prevention : A Publication of the American Association for Cancer Research, Cosponsored by the American Society of Preventive Oncology*, *24*(12), 1907–1909. https://doi.org/10.1158/1055-9965.EPI-15-0787

Romieu, I., Gouveia, N., Cifuentes, L. A., de Leon, A. P., Junger, W., Vera, J., … HEI Health Review Committee. (2012). Multicity study of air pollution and mortality in Latin America (the ESCALA study). *Research Report (Health Effects Institute)*, (171), 5–86. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/23311234

Romley, J. A., Hackbarth, A., & Goldman, D. P. (2012). The Impact of Air Quality on Hospital Spending. *Rand Health Quarterly*, *2*(3), 6. Retrieved from /pmc/articles/PMC4945238/

San Joaquin Valley Air Pollution District. (2019). 2018 PM 2.5 Plan for the San Joaquin Valley. Retrieved April 25, 2019, from https://www.valleyair.org/pmplans/

Savin, I. A., Markov, A. V., Zenkova, M. A., & Sen'kova, A. V. (2022). Asthma and Post-Asthmatic Fibrosis: A Search for New Promising Molecular Markers of Transition from Acute Inflammation to Pulmonary Fibrosis. *Biomedicines*, *10*(5), 1017. https://doi.org/10.3390/BIOMEDICINES10051017/S1

Schmitt, L. H. M. (2016). QALY gain and health care resource impacts of air pollution control: A Markov modelling approach. *Environmental Science and Policy*, *63*, 35–43. https://doi.org/10.1016/j.envsci.2016.05.015

Schoups, G., Hopmans, J. W., Young, C. A., Vrugt, J. A., Wallender, W. W., Tanji, K. K., & Panday, S. (2005). Sustainability of irrigated agriculture in the San Joaquin Valley, California. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(43), 15352–15356. https://doi.org/10.1073/pnas.0507723102

Schultz, P. W., Unipan, J. B., & Gamba, R. J. (2010). Acculturation and Ecological Worldview Among Latino Americans. *Journal of Environmental Education*, *31*(2), 22–27. https://doi.org/10.1080/00958960009598635

Schultz, T. W. (1961). American Economic Association Investment in Human Capital. *American Economic Association*, *51*(5), 1035–1039.

Selin, N. E., Wu, S., Nam, K. M., Reilly, J. M., Paltsev, S., Prinn, R. G., & Webster, M. D. (2009). Global health and economic impacts of future ozone pollution. *Environmental Research Letters*, *4*(4), 044014. https://doi.org/10.1088/1748-

9326/4/4/044014
Sengupta, S. (2020, November 26). Wildfire Smoke Is Poisoning California's Kids. Some Pay a Higher Price. *The New York Times*, pp. A22–A23. Retrieved from https://www.nytimes.com/interactive/2020/11/26/climate/california-smoke-children-health.html
Sheldon, T. L., & Sankaran, C. (2017). The Impact of Indonesian Forest Fires on Singaporean Pollution and Health. *American Economic Review*, *107*(5), 526–529. https://doi.org/10.1257/aer.p20171134
Shibata, H., & Winrich, J. S. (1983). Control of Pollution When the Offended Defend Themselves. *Economica*, *50*(200), 425. https://doi.org/10.2307/2554304
Shindell, D. T. (2002). Separating the influence of halogen and climate changes on ozone recovery in the upper stratosphere. *Journal of Geophysical Research*, *107*(D12), 4144. https://doi.org/10.1029/2001JD000420
Shrier, I., & Steele, R. (2006). Understanding the Relationship Between Risks and Odds Ratios. *Journal of Sport Medicine*, *16*(2), 107–110. Retrieved from https://journals.lww.com/cjsportsmed/fulltext/2006/03000/understanding_the_relationship_between_risks_and.4.aspx#A1-4
Sih, A., Ferrari, M. C. O., & Harris, D. J. (2011). Evolution and behavioural responses to human-induced rapid environmental change. *Evolutionary Applications*, *4*(2), 367–387. https://doi.org/10.1111/J.1752-4571.2010.00166.X
SJV Air Pollution Control District. (2016, June 16). 2016 Plan for the 2008 8-Hour Ozone Standard. Retrieved October 10, 2021, from http://valleyair.org/Air_Quality_Plans/Ozone-Plan-2016.htm
SJV Air Pollution Control District. (2021, October). Ambient Air Quality Standards and Valley Attainment Status. Retrieved October 10, 2021, from https://www.valleyair.org/aqinfo/attainment.htm
SJVAPCD. (2020, July). Air Monitoring Sites in Operation. Retrieved November 28, 2020, from https://valleyair.org/aqinfo/air-monitoring.htm
Social Security Administration. (2017). Fast Facts & Figures About Social Security.
Sockrider, M., & Fussner, L. (2020). What is asthma? *American Journal of Respiratory and Critical Care Medicine*, *202*(9), P25–P26. https://doi.org/10.1164/RCCM.2029P25
Sofia, D., Gioiella, F., Lotrecchiano, N., & Giuliano, A. (2020). Mitigation strategies for reducing air pollution. *Environmental Science and Pollution Research*, *27*, 19226–19235. https://doi.org/10.1007/s11356-020-08647-x
Song, H. J., Blake, K. V., Wilson, D. L., Winterstein, A. G., & Park, H. (2021). Health-related quality of life and health utilities of mild, moderate, and severe asthma: Evidence from the medical expenditure panel survey. *Journal of Asthma and Allergy*, *14*, 929–941. https://doi.org/10.2147/JAA.S316278
Stanford University. (2014). *The History of Utilitarianism*. (E. Zalta, U. Nodelman, C. Allen, & L. R. Anderson, Eds.). Stanford, CA: Center for the Study of Language and Information. Retrieved from https://leibniz.stanford.edu/friends/preview/utilitarianism-history/
Stata V17. (2021, April 21). Stata. College Station, TX, USA: StataCorp. Retrieved from https://www.stata-press.com/data/r17/

Sullivan, P. W., & Ghushchyan, V. (2006). Preference-Based EQ-5D index scores for chronic conditions in the United States. *Medical Decision Making*, *26*(4), 410–420. https://doi.org/10.1177/0272989X06290495

Szasz, A. (2007). *Shopping Our Way to Safety: How We Changed from Protecting the Environment to Protecting Ourselves* (1st ed.). Minneapolis, MN: University of Minnesota Press. Retrieved from https://books.google.com/books?hl=en&lr=&id=guOGS8kv2zgC&oi=fnd&pg=PR7&ots=2gYSClnIC9&sig=jplO2RgRXMPsBKd7t8djMnQ7vbU#v=onepage&q&f=false

Tavallali, P., Gharibi, H., Singhal, M., Schweizer, D., & Cisneros, R. (2020). A multi-pollutant model: a method suitable for studying complex relationships in environmental epidemiology. *Air Quality, Atmosphere and Health*, *13*(6), 645–657. https://doi.org/10.1007/S11869-020-00829-3/FIGURES/6

TCHHSA. (2017). *Community Health Assessment & Community Health Improvement Plan*. Visalia, CA. Retrieved from https://tchhsa.org/eng/index.cfm/community/community-health-assessment-cha-community-health-improvement-plan-chip/

The World Bank. (2016). *The Cost of Air Pollution Strengthening the Economic Case for Action*. Washington, DC. Retrieved from http://documents.worldbank.org/curated/en/781521473177013155/pdf/108141-REVISED-Cost-of-PollutionWebCORRECTEDfile.pdf

Thurston, G. D., Balmes, J. R., Garcia, E., Gilliland, F. D., Rice, M. B., Schikowski, T., … White, C. W. (2020). Outdoor Air Pollution and New-Onset Airway Disease. An Official American Thoracic Society Workshop Report. *Annals of the American Thoracic Society*, *17*(4), 387–398. https://doi.org/10.1513/ANNALSATS.202001-046ST

Tian, Y., Liu, H., Wu, Y., Si, Y., Li, M., Wu, Y., … Hu, Y. (2019). Ambient particulate matter pollution and adult hospital admissions for pneumonia in urban China: A national time series analysis for 2014 through 2017. *PLoS Medicine*, *16*(12). https://doi.org/10.1371/JOURNAL.PMED.1003010

U.K. Parliament. Clean Air Act 1956 (1956). London: Queen's Printer of Acts of Parliament. Retrieved from http://www.legislation.gov.uk/ukpga/Eliz2/4-5/52/enacted

U.S. Bureau of Labor Statistics. (2018, June 26). BLS Data Finder.

UCLA. (2019, September 1). CHIS. Retrieved November 28, 2020, from https://healthpolicy.ucla.edu/chis/about/Pages/about.aspx

UCLA Center for Health Policy Research. (2021). AskCHIS. Retrieved April 25, 2023, from https://ask.chis.ucla.edu/AskCHIS/tools/_layouts/AskChisTool/home.aspx#/results

UN. (2021, November 2). Five dangerous pollutants you are breathing in every day. *United Nations Environment Programme*.

US EPA. (2017). Evolution of the Clean Air Act. Retrieved May 16, 2019, from https://www.epa.gov/clean-air-act-overview/evolution-clean-air-act

US EPA. (2018a). Ground-level Ozone Basics. Retrieved May 17, 2019, from https://www.epa.gov/ground-level-ozone-pollution/ground-level-ozone-

basics#formation
US EPA, O. (2018b). *Nitrogen Dioxide (NO2) Pollution*. Retrieved from https://www.epa.gov/no2-pollution
US EPA, O. (2018c). *Particulate Matter (PM2.5) Trends*. Retrieved from https://www.epa.gov/air-trends/particulate-matter-pm25-trends
US EPA Office. (2018). *Air Quality Guide for Nitrogen Dioxide, EPA-456/F-11-003*. Retrieved from www.enviroflash.info
US Global Change Research Program. (2014). *National Climate Assessment*. Washington, DC. Retrieved from https://nca2014.globalchange.gov/report
Van Der Zee, S. C., Hoek, G., Boezen, M. H., Schouten, J. P., Van Wijnen, J. H., & Brunekreef, B. (2000). Acute effects of air pollution on respiratory health of 50-70 yr old adults. *The European Respiratory Journal*, *15*(4), 700–709. https://doi.org/10.1034/J.1399-3003.2000.15D13.X
Velarde, M. D., Fry, G., & Tveit, M. (2007). Health effects of viewing landscapes – Landscape types in environmental psychology. *Urban Forestry & Urban Greening*, *6*(4), 199–212. https://doi.org/10.1016/J.UFUG.2007.07.001
Veloz, D., Gonzalez, M., Brown, P., Gharibi, H., & Cisneros, R. (2020). Perceptions about air quality of individuals who work outdoors in the San Joaquin Valley, California. *Atmospheric Pollution Research*, *11*(4), 825–830. https://doi.org/10.1016/J.APR.2020.01.010
Von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gøtzsche, P. C., & Vandenbroucke, J. P. (2007). The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: Guidelines for reporting observational studies. *Annals of Internal Medicine*, *147*(8), 573–577. https://doi.org/10.7326/0003-4819-147-8-200710160-00010
Wang, X., Xu, Z., Su, H., Ho, H. C., Song, Y., Zheng, H., … Cheng, J. (2021). Ambient particulate matter (PM1, PM2.5, PM10) and childhood pneumonia: The smaller particle, the greater short-term impact? *Science of The Total Environment*, *772*, 145509. https://doi.org/10.1016/J.SCITOTENV.2021.145509
Warszawski, M. (2020, September 24). Decades of controlled burns save Shaver Lake from Creek Fire. *The Fresno Bee*. Retrieved from https://www.fresnobee.com/opinion/opn-columns-blogs/marek-warszawski/article245842780.html?ac_cid=DM288330&ac_bid=-1976855428
WHO. (2020). *Personal interventions and risk communication on Air Pollution*. Geneva, Switzerland. Retrieved from https://www.who.int/publications/i/item/9789240000278
World Health Organization. (2016). *The economic burden of lung disease*. *European Respiratory Society*.
World Health Organization. (2017). Ambient air pollution: Policy and progress. Retrieved May 17, 2019, from https://www.who.int/airpollution/ambient/policy-governance/en/
Yale School of Forestry & Environmental Studies. (2017). Transportation Replaces Power in U.S. as Top Source of CO2 Emissions - Yale E360. Retrieved May 17, 2019, from https://e360.yale.edu/digest/transportation-replaces-power-in-u-s-as-top-source-of-co2-emissions

Yáñez, A., Cho, S. H., Soriano, J. B., Rosenwasser, L. J., Rodrigo, G. J., Rabe, K. F., … Holgate, S. T. (2014). Asthma in the elderly: What we know and what we have yet to know. *World Allergy Organization Journal*, *7*(1). https://doi.org/10.1186/1939-4551-7-8

Yazdi, S. K., & Khanalizadeh, B. (2017). Air pollution, economic growth and health care expenditure. *Economic Research*, *30*(1), 1181–1190. https://doi.org/10.1080/1331677X.2017.1314823

Zarate, G. Y. (2010). *Overweight and Obesity Factors for Adults in the San Joaquin Valley, California: Data from the Behavioral Risk Factor Surveillance System, 2000-2005*. California State University, Fresno. Retrieved from http://csufresno-dspace.calstate.edu/bitstream/handle/10211.3/118988/GildaZARATE.pdf;sequence=1

Zhang, J., & Yu, K. F. (1998). What's the Relative Risk?: A Method of Correcting the Odds Ratio in Cohort Studies of Common Outcomes. *JAMA*, *280*(19), 1690–1691. https://doi.org/10.1001/JAMA.280.19.1690

Zhang, K. M., Ying, Q., Liang, J., Kleeman, M., Wexler, A., & Kaduwela, A. (2005). Particulate matter modeling in central and northern California. In Journal of Applied Metereorology (Ed.), *cmascenter.org* (pp. 1–5). Chapel Hill, NC: CMAS Center. Retrieved from https://cmascenter.org/conference/2005/abstracts/7_8.pdf

Zhang, M., Song, Y., Cai, X., & Zhou, J. (2008). Economic assessment of the health effects related to particulate matter pollution in 111 Chinese cities by using economic burden of disease analysis. *Journal of Environmental Management*, *88*, 947–954. https://doi.org/10.1016/j.jenvman.2007.04.019

Zhou, Y., Nurmagambetov, T., Mccord, M., & Hsu, W.-H. (2017). Economic Valuation of Selected Illnesses in Environmental Public Health Tracking. *Journal of Public Health Management and Practice*, *23*, S18–S27. https://doi.org/10.1097/phh.0000000000000641

Zhu, B., Pang, R., Chevallier, J., Wei, Y.-M., & Vo, D.-T. (2018). Including intangible costs into the cost-of-illness approach: a method refinement illustrated based on the PM2.5 economic burden in China. *The European Journal of Health Economics*. https://doi.org/10.1007/s10198-018-1012-0

APPENDIX A

CONSENT TO PARTICIPATE IN A RESEARCH STUDY UNIVERSITY OF CALIFORNIA, MERCED

Title of the Study: Impact of COVID-19 on Air Quality and Asthma

Investigators: Paul Brown, PhD, Gilda Zarate-Gonzalez, MPH CLC, Gracy Mantoan MD MSPH, David Veloz PhD, Ricardo Cisneros PhD MPH, Social Sciences, Humanities and the Arts, University of California, Merced. Email: pbrown3@ucmerced.edu and/or gzarate-gonzalez@ucmerced.edu, gmantoan@ucmerced.edu, dveloz@ucmerced.edu, rcisneros@ucmerced.edu.

PURPOSE

You are invited to participate in a research study that aims to understand the impact of COVID-19 on air quality and asthma. Anyone over 18 years of age and is a student attending UC Merced are invited to participate in this study. We anticipate that up to 300 participants will complete this online survey.

PROCEDURES

The study involves completing an anonymous online survey questionnaire. The questionnaire asks about your health status, the factors that have changed since the COVID-19 pandemic, ways that you expect to resume normalcy, and some of the efforts that you will maintain or support. In addition, we will ask your views on the current restrictions. This online survey takes about 25 minutes to complete.

RISKS

There are no risks of physical discomfort from participation in this study. Responding to questions about stress could arouse feelings of discomfort or distress, but these feelings are likely to be temporary and similar to those normally experienced in the course of daily life. You can quit the survey at any time.

BENEFITS

It is possible that you will not benefit directly by participating in this study. However, you may indirectly benefit by becoming more aware of your views about the changes in air quality, respiratory diseases, COVID-19 and impact of the restrictions on your daily life.

CONFIDENTIALITY

Your responses to this research will remain anonymous. You do not need to share your name or any other information that would reveal your identity. All information will be

kept strictly confidential.

COSTS/COMPENSATION

There is no cost to you beyond the time and effort required to complete the online questionnaire. You will be compensated upon survey completion by your panel provider.

RIGHT TO REFUSE OR WITHDRAW

Participation in this study is voluntary. You may refuse to participate in this study. You may change your mind and stop completing the questionnaire at any time. You may choose to not answer any questions on the questionnaire. Should you decide not to continue the survey at any point, you will still receive the credits.

QUESTIONS
If you have any questions about this research project please contact Gilda Zarate-Gonzalez at gzarate-gonzalez@ucmerced.edu.

For questions about your rights while taking part in this study call the Office of Research at IRB 209-228-4613 or write to the Office of Research, 5200 North Lake Rd, UC Merced, Merced, CA 95343. The Office of Research will inform the Institutional Review Board which is a group of people who review the research to protect your rights. If you have any complaints or concerns about this study, you may address them to Ramesh Balasubramaniam, IRB Chair 209-228-
2314, irbchair@ucmerced.edu. **CONSENT**
BY SELECTING "AGREE" BELOW AND PROCEEDING WITH THE SURVEY INDICATES THAT YOU HAVE DECIDED TO VOLUNTEER AS A RESEARCH SUBJECT AND THAT YOU HAVE READ AND UNDERSTOOD THE INFORMATION PROVIDED ABOVE.

- ○ Agree (1)
- ○ Don't Agree (2)

Page Break

Q372 What is the zip code of your primary residence?

_____

End of Block: Consent

Start of Block: Asthma Qualifier

Q293 Have you ever been diagnosed with asthma?

- Yes (1)
- No (2)

Q294 Do you have a child who has ever been diagnosed with asthma?

- Yes (1)
- No (2)

End of Block: Asthma Qualifier

Start of Block: Air Quality

Q209 **COVID-19, Asthma and Air Quality** The COVID-19 pandemic has affected our lives in many ways. The shelter in place measures, in an attempt to stop the spread of the virus, caused people to stay home, lowering the number of transportation vehicles circulating, and stopping some industrial activities that cause air pollution. Scientists are interested on learning how these changes have impacted your life. The following questions will help researchers understand how it has affected the lives of the people who live in the San Joaquin Valley. Your answers are very important, as a member of our community. We will be asking a number of questions relating to how life was before the COVID-19 pandemic began to how it has been afterwards. In doing so, we will pick the date of March 1 to indicate the start of the pandemic. We will be referring to the time before March 1st, 2020 as the "pre-COVID-19 period", and after March 1st as the "COVID-19 period."

Page Break

Q210 To begin, we wanted to ask you some questions about the air quality in the city you are living in. What city were you mainly living in prior to March 1st (the Pre-COVID-19 period)?

_____

Q211 What city are you mainly living in after March 1st (the COVID-19 period)?

_____

Page Break

Q212 In general, aside from any smoke caused by wildfires, what was the air quality like in the city you were living in during the pre-COVID-19 period (before March 1st),?

- Very unhealthy air quality (1)
- Unhealthy (2)
- Unhealthy for sensitive groups (3)
- Moderately healthy (4)
- Good air quality (5)

Q213 In general, aside from any smoke caused by wildfires, what has been the air quality like in your city in the COVID-19 period (after March 1st)?

- Very unhealthy air quality (1)
- Unhealthy (2)
- Unhealthy for sensitive groups (3)
- Moderately healthy (4)
- Good air quality (5)

Page Break

Q176 In the past 2 weeks, what has been the air quality like in your city?

- ○ Very unhealthy air quality (1)
- ○ Unhealthy (2)
- ○ Unhealthy for sensitive groups (3)
- ○ Moderately healthy (4)
- ○ Good air quality (5)

Page Break

Q214 Currently, at what time of day you generally notice air quality issues or air pollution? (Check as many as apply)

- [ ] Morning (1)
- [ ] Afternon (2)
- [ ] Evening (3)
- [ ] All day is bad (4)
- [ ] I don't notice bad air in my city (5)

Q215 In which seasons of the year do you usually notice more air quality issues or air pollution? (Check as many as apply)

- [ ] Spring (1)
- [ ] Summer (2)
- [ ] Fall (3)
- [ ] Winter (4)

Page Break

Q216 How do you check the air quality in your area? (check all that apply)

- ☐ I look outside and see if the mountain range is clear (1)
- ☐ I look outside and see if the valley floor is clear (2)
- ☐ I rely on recommendations from the Valley Air District (3)
- ☐ I see the air quality flags in my kids' school (4)
- ☐ I have my own monitor at home (5)
- ☐ I check the Purple Air website (6)
- ☐ I check the internet (Please tell us where) (7) _____
- ☐ I get text messages from CalFire (8)
- ☐ ⊗I don't check the air quality (9)
- ☐ Other (10) _____

Q217 What do you think a "bad air" day means? (check all that apply)

- ☐ High mold/pollen levels in the air (1)
- ☐ High particle matter counts in the air (2)
- ☐ High ozone levels in the air (3)
- ☐ There is gray or brown haze outside (4)
- ☐ The hole in the ozone layer has made it unhealthy to be outside (5)
- ☐ The air is dirty/polluted (6)
- ☐ Other meaning: (7)

☐ ⊗I don't know what a "bad air" day means (8)

Page Break

Q218 How informed do you feel about air quality in your city/community?

- ○ Not informed at all (1)
- ○ Not very informed (2)
- ○ Somewhat informed (3)
- ○ Very informed (4)
- ○ I don't know (5)

Q219 How would you rate the information that you hear about air quality information in your region?

- ○ Inaccurate and incomplete (1)
- ○ Accurate but incomplete (2)
- ○ Accurate and complete (3)
- ○ I don't know (4)

Q220 What sources of information about the air quality in your city or community do you trust the most? (Check all that apply)

- ☐ Research institutes (1)
- ☐ Universities (2)
- ☐ Local health authorities (3)
- ☐ Citizens' associations or community-based organizations (4)
- ☐ Environmental protection agencies (5)
- ☐ City government and Municipalities (6)

- [ ] Television or Radio (7)
- [ ] Internet (8)

End of Block: Air Quality

Start of Block: Transportation

Q222 **We would now like to ask you some questions about your transportation in the Pre-COVID-19 period and in the COVID-19 period.**
In the Pre-COVID-19 period (before March 1st), approximately how many miles was your normal daily commute one-way?

- ○ Less than 5 miles (1)
- ○ 5-10 miles (2)
- ○ 11-15 miles (3)
- ○ 16-20 miles (4)
- ○ 21-30 miles (5)
- ○ 30+ miles (6)
- ○ I don't regularly commute (7)

Q223 In the Pre-COVID-19 period (before March 1st), approximately how many days did you commute to work?

- ○ 1 (1)
- ○ 2 (2)
- ○ 3 (3)
- ○ 4 (4)
- ○ 5 (5)
- ○ 6 or 7 (6)
- ○ I don't regularly commute (7)

Q224 In the Pre-COVID-19 period, what was your preferred mode of transportation?

- ○ Public transport (e.g. bus, train etc.) (1)
- ○ Private car (your own or car share) (2)
- ○ Cycling (3)
- ○ Walking (4)
- ○ Ride hailing (e.g. taxi, uber etc.) (5)
- ○ Other: (6) _____
- ○ I don't regularly commute (7)

Page Break

Q225 Approximately how many days do you commute to work right now?

- 1 (1)
- 2 (2)
- 3 (3)
- 4 (4)
- 5 (5)
- 6 or 7 (6)
- I don't regularly commute (7)

Q226 Approximately how many miles is your normal daily commute one-way right now?

- Less than 5 miles (1)
- 5-10 miles (2)
- 11-15 miles (3)
- 16-20 miles (4)
- 21-30 miles (5)
- 30+ miles (6)
- I don't regularly commute (7)

Q227 What is your preferred mode of transportation right now?

- Public transport (e.g. bus, train etc.) (1)
- Private car (your own or car share) (2)
- Cycling (3)
- Walking (4)

- ○ Ride hailing (e.g. taxi, uber etc.) (5)
- ○ Other: (6) _____
- ○ I don't regularly commute (7)

Page Break

Q229 Do you currently own an electric or hybrid car?

- Yes (1)
- No (2)

Q231 Since the start of the COVID-19 pandemic, has your interest in buying an electric or hybrid car changed?

- My interest has decreased a lot (1)
- My interest has decreased a little (2)
- My interest has stayed the same (3)
- My interest has increased a little (4)
- My interest has increased a lot (5)
- Not applicable - I have never considered purchasing an electric car (6)

Q232 How much of a concern are each of the factors when you think about purchasing an electric or hybrid car?

	Not at all a concern (1)	A small concern (2)	Somewhat a concern (3)	Very much a concern (4)	Don't know/need more information (5)
Too expensive (4)	○	○	○	○	○
Too complicated to purchase (12)	○	○	○	○	○

Charging stations are not widely available in my city or community (5)	○	○	○	○	○
Charging stations are not widely available when I travel long distances (13)	○	○	○	○	○
Too small for my family/Not spacious enough (7)	○	○	○	○	○
Not safe (8)	○	○	○	○	○
Don’t like the look (9)	○	○	○	○	○
Don’t go fast enough (10)	○	○	○	○	○
Other (11)	○	○	○	○	○

End of Block: Transportation

Start of Block: City

Q416 In which **city** do you currently reside?

End of Block: City

Start of Block: Air Pollution Views

Q234 How effective do you think the following organizations are in helping to improve the quality of air?

	Not at all (1)	A little (2)	Somewhat (3)	Very much (4)	Don't know (5)
The U.S. Government (1)	○	○	○	○	○
The Environmental Protection Agency (EPA) (4)	○	○	○	○	○
The State of California (5)	○	○	○	○	○
The San Joaquin Valley Air District (6)	○	○	○	○	○
County supervisors/City Councils (7)	○	○	○	○	○
Farmers, growers and ranchers (8)	○	○	○	○	○
Grassroot community organizations (9)	○	○	○	○	○
Environmental organizations (10)	○	○	○	○	○
Scientists and Researchers (11)	○	○	○	○	○

Page Break

Q235 In deciding what types of policies to enact to reduce air pollution, how important is it that organizations (such as the EPA, the State, or the Air Control Boards) consider the following factors:

	Not at all important (1)	A little important (2)	Important (3)	Very important (4)	Extremely important (5)
Cost that it will impose on businesses (1)	○	○	○	○	○
Cost to consumers (4)	○	○	○	○	○
Reducing PM2.5 (5)	○	○	○	○	○
Reducing ozone (6)	○	○	○	○	○
Making the air look cleaner (7)	○	○	○	○	○
Having it be locally run as opposed to by the EPA (8)	○	○	○	○	○
The impact it will have on low income communities (9)	○	○	○	○	○
Making sure that people in the Bay Area also have to reduce their pollution (10)	○	○	○	○	○

Getting agriculture to change its practices (11)	○	○	○	○	○
Reduce heating from fireplaces or woodstoves (12)	○	○	○	○	○
Eliminate or reduce large incinerators (13)	○	○	○	○	○
Reduce the amount of pollution from commercial cooking/kitchens (14)	○	○	○	○	○
Reducing pollution from dairies (15)	○	○	○	○	○
Eliminate pesticide drift (16)	○	○	○	○	○

Page Break

Q236 Please express how much do you agree or disagree on the following statements.

	Strongly Disagree (1)	Somewhat Disagree (2)	Neither agree nor disagree (3)	Somewhat Agree (4)	Strongly Agree (5)
"During the COVID-19 period or shelter-in-place, I have sensed/experienced good clean air and I don't want to go back to the air pollution levels we previously had" (1)	○	○	○	○	○
"Cities must take effective measures to protect citizens from air pollution, even if this requires reallocating public space to walking, cycling and public transport" (4)	○	○	○	○	○
"Cities must take effective measures to protect citizens from air pollution, even if it means preventing polluting cars from entering	○	○	○	○	○

the city" (5)					
"I think we need to resume our normal lives soon and must accept that air pollution will rise again" (6)	○	○	○	○	○
"More public space in your nearest town/ city should be reserved for public transport (e.g. by expanding bus lanes)" (7)	○	○	○	○	○
"More public space in your city and nearest towns should be reserved for cycling" (8)	○	○	○	○	○
"More public space should be reserved for pedestrians" (9)	○	○	○	○	○
"More policies should be adopted to stop polluting cars and trucks from entering the city, for example through Zero-Emission Zones" (10)	○	○	○	○	○
"More companies should allow their workers to	○	○	○	○	○

continue working from home or telecommuting ” (11)	
“More cities and counties should work together to create clean, fast and reliable regional transportation systems to connect the Central Valley” (12)	○ ○ ○ ○ ○

End of Block: Air Pollution Views

Start of Block: Health Conditions

Q237 Thank you. We now want to ask you some questions about your health and whether you or any family members have health conditions made worse by air pollution.

Page Break

Q177 **In the Pre-COVID Period**, would you say that your health was

- Excellent (1)
- Very good (2)
- Good (3)
- Fair (4)
- Poor (5)

Q178 Would you say your current health is:

- Excellent (1)
- Very good (2)
- Good (3)
- Fair (4)
- Poor (5)

Page Break

Q238 We'd like to start by asking you about your health in the Pre-COVID-19 period and right now. Please indicate which statements best describe your own health state in the Pre-COVID-19 period (before March 1st).
For each question, choose the statement that best described your health state in the Pre-COVID period (before March 1st):

Q239 Mobility

- I had no problems in walking around (1)
- I had some problems in walking around (2)
- I was confined to bed (3)

Q240 Personal Care

- I had no problems with personal care (1)
- I had some problems washing or dressing myself (2)
- I was unable to wash or dress myself (3)

Q241 Usual Activities

- I had no problems with performing my usual activities (1)
- I had some problems with performing my usual activities (2)
- I was unable to perform my usual activities (3)

Q242 Pain/Discomfort

- I had no pain or discomfort (1)

- ○ I had moderate pain or discomfort (2)
- ○ I had extreme pain or discomfort (3)

Q243 Anxiety/Depression

- ○ I was not anxious or depressed (1)
- ○ I was moderately anxious or depressed (2)
- ○ I was extremely anxious or depressed (3)

Page Break

Q245 We'd like to ask you about your health right now.
Please indicate which statements best describe your own current health state.
For each question, choose the statement that best describes your health state right now.

Q246

Mobility

- I have no problems in walking around (1)
- I have some problems in walking around (2)
- I am confined to bed (3)

Q247 Personal Care

- I have no problems with personal care (1)
- I have some problems washing or dressing myself (2)
- I am unable to wash or dress myself (3)

Q248 Usual Activities

- I have no problems with performing my usual activities (1)
- I have some problems with performing my usual activities (2)
- I have unable to perform my usual activities (3)

Q249 Pain/Discomfort

- I have no pain or discomfort (1)
- I have moderate pain or discomfort (2)
- I have extreme pain or discomfort (3)

Q250 Anxiety/Depression

- I am not anxious or depressed (1)
- I am moderately anxious or depressed (2)
- I am extremely anxious or depressed (3)

Page Break

End of Block: Health Conditions

Start of Block: Smoking

Q259 How often do you currently smoke or use each of the following products?

	Never (1)	Less than once a month (2)	A couple of times a month (3)	At least once a week (4)	Nearly every day (5)
Cigarettes (1)	○	○	○	○	○
Cigars (4)	○	○	○	○	○
Cigarillos (5)	○	○	○	○	○
Hookahs (6)	○	○	○	○	○
Vaping products (7)	○	○	○	○	○
Marijuana (8)	○	○	○	○	○

Page Break

Q260 Have you smoked or used each of the following in the past 30 days?

	Yes (1)	No (2)
Cigarettes (1)	○	○
Cigars (4)	○	○
Cigarillos (5)	○	○
Hookahs (6)	○	○
Vaping products (7)	○	○
Marijuana (8)	○	○

Page Break

Q261 Have you smoked or used each of the following 100 times or more in your life?

	Yes (1)	No (2)
Cigarettes (1)	○	○
Cigars (4)	○	○
Cigarillos (5)	○	○
Hookahs (6)	○	○
Vaping products (7)	○	○
Marijuana (8)	○	○

Page Break

Q262 Does anyone who is living with you smoke or vape regularly?

- ○ Yes (1)
- ○ No (2)

Q179 Have **you** been diagnosed with any of these health conditions that may make you particularly susceptible to air quality and environmental problems? (Check as many as apply)

- ☐ Asthma (1)
- ☐ Chronic Cardiovascular Disease (2)
- ☐ Undergoing Chemotherapy or radiation therapy (3)
- ☐ Immune system suppressed by disease or other causes (4)
- ☐ Allergies (5)
- ☐ Other Chronic Respiratory Disease (6)
- ☐ Chronic Neurological Problems (7)
- ☐ COPD, Chronic Obstructive Pulmonary Disease (8)
- ☐ Other: (9) _____

Q263 How does the outdoor air quality impact your health?

- ○ Serious impact (1)
- ○ Moderate impact (2)
- ○ Minimum impact (3)
- ○ Insignificant impact (4)

○ No impact at all (5)

Page Break

Q180 **Has anyone who is living with you** been diagnosed with any of these health conditions that may make you particularly susceptible to air quality and environmental problems? (Check as many as apply)

- ☐ Asthma (1)
- ☐ Chronic Cardiovascular Disease (2)
- ☐ Undergoing Chemotherapy or radiation therapy (3)
- ☐ Immune system suppressed by disease or other causes (4)
- ☐ Allergies (5)
- ☐ Other Chronic Respiratory Disease (6)
- ☐ Chronic Neurological Problems (7)
- ☐ COPD, Chronic Obstructive Pulmonary Disease (8)
- ☐ Other: (9) _____

Page Break

Q264 How does the outdoor air quality impact the health of people who are living with you?

- Serious impact (1)
- Moderate impact (2)
- Minimum impact (3)
- Insignificant impact (4)
- No impact at all (5)

Page Break

Q266 How often do you feel that poor air quality affects you or people who are living with you in the following ways?

	Never (1)	Rarely (2)	Sometimes (3)	Often (4)	Always (5)
Breathlessness/having more difficulty in breathing (1)	○	○	○	○	○
Doing less outdoor activities (4)	○	○	○	○	○
Doing more to look after my skin (5)	○	○	○	○	○
Doing more to stay healthy (6)	○	○	○	○	○
Feeling depressed (7)	○	○	○	○	○
Irritation to eyes/nose/throat (8)	○	○	○	○	○
Skin problems (9)	○	○	○	○	○
Wanting to move to other less polluted place (10)	○	○	○	○	○
Asthma incidents or attacks (11)	○	○	○	○	○
Poor visibility (12)	○	○	○	○	○
Worrying about the living environment for children (13)	○	○	○	○	○
Please select "Rarely" for this statement (15)	○	○	○	○	○
Other (please specify) (14)	○	○	○	○	○

End of Block: Smoking

Start of Block: COVID-19

Q267 Thank you. We would now like to ask about COVID-19.

Q268 Have you been diagnosed with COVID-19?

- Yes (1)
- No (2)

Q269 Did you require hospitalization for treatment?

- Yes (1)
- No (2)

Page Break

Q271 What level of **health threat** do you think COVID-19 poses to the following:

	Not at all (1)	A minimum threat (2)	A moderate threat (3)	A high threat (4)	A very high threat (5)
Your local community (1)	○	○	○	○	○
Your family and friends (2)	○	○	○	○	○
You personally (3)	○	○	○	○	○

Page Break

Q181 People can have different responses to COVID-19, ranging from having no symptoms to having just flu like symptoms to being serious ill and requiring hospitalization to dying. So please answer this question based on what you know about COVID-19 and how sick you think you would be if you we to get COVID-19. **If you were to contract COVID, what statements do you think would best describe your own health state?**

Q182 Mobility

- I would have no problems in walking around (1)
- I would have some problems in walking around (2)
- I would be confined to bed (3)

Q183 Personal Care

- I would have no problems with personal care (1)
- I would have some problems washing or dressing myself (2)
- I would be unable to wash or dress myself (3)

Q184 Pain/Discomfort

- I would have no pain or discomfort (1)
- I would have moderate pain or discomfort (2)
- I would be in extreme pain or discomfort (3)

Q185 Anxiety/Depression

- ○ I would not be anxious or depressed (1)
- ○ I would be moderately anxious or depressed (2)
- ○ I would be extremely anxious or depressed (3)

Page Break

Q272 What level of **financial threat** do you think COVID-19 poses to the following:

	Not at all (1)	A minimum threat (2)	A moderate threat (3)	A high threat (4)	A very high threat (5)
Your local community (1)	○	○	○	○	○
Your family and friends (2)	○	○	○	○	○
You personally (3)	○	○	○	○	○

Page Break

Q273 How much has COVID-19 impacted you?

	Not true of me at all (1)	A little true of me (2)	Somewhat true of me (3)	True of me (4)	Very true of me (5)
COVID-19 has had a negative financial impact on me. (1)	○	○	○	○	○
I have lost job-related income due to COVID-19 (4)	○	○	○	○	○
I was already seeking employment, and am having more difficulty due to COVID-19 (5)	○	○	○	○	○
I have had a hard time getting needed resources such as food, toilet paper, or other supplies due to COVID-19 (6)	○	○	○	○	○
The COVID-19 Period has had a negative impact on	○	○	○	○	○

my mental health (7)

Page Break

Q274 In the beginning of the COVID-19 Period (March, April, and May), how often did you practiced social distancing (this means: reducing your physical contact with other people in social, work, or school settings by avoiding large groups and staying 3-6 feet away from other people)?

- ○ Never (1)
- ○ Rarely (2)
- ○ Sometimes (3)
- ○ Most of the time (4)
- ○ Always (5)

Page Break

Q275 How often do you practice social distancing right now?

- Never (1)
- Rarely (2)
- Sometimes (3)
- Most of the time (4)
- Always (5)

Page Break

Q276 How much do you think wearing a mask and social distancing protects you from getting COVID-19 from others?

- Not at all (1)
- A little bit (2)
- Somewhat (3)
- A lot (4)
- Fully protects me (5)

Q277 How much do you think wearing a mask and social distancing protects others from getting COVID-19 from you?

- Not at all (1)
- A little bit (2)
- Somewhat (3)
- A lot (4)
- Fully protects others (5)

Page Break

Q285 If the air quality was bad, how likely would you be to wear a face mask or covering during peak hours outside?

- ○ Not at all likely (1)
- ○ A little likely (2)
- ○ Somewhat likely (3)
- ○ Very likely (4)
- ○ I don't know (5)

Q286 If the air quality was bad, how likely would you be to encourage a child or family member to wear a face mask or covering during peak hours outside?

- ○ Not at all likely (1)
- ○ A little likely (2)
- ○ Somewhat likely (3)
- ○ Very likely (4)
- ○ I don't know (5)

Q360 What is your current age in years? (Enter a number)

_____

Q361 What is your sex?

- ○ Male (1)
- ○ Female (2)
- ○ Non-binary (3)

Page Break

Q362 What is the highest level of school, college or vocational training that you have finished?

- ○ Less than 9th grade (1)
- ○ 9-12th grade, no diploma (2)
- ○ High school graduate (or GED/ equivalent) (3)
- ○ Associate's degree or Vocational Training (4)
- ○ Some college (no degree) (5)
- ○ Bachelor's degree (6)
- ○ Graduate or professional degree (7)
- ○ Refuse to answer (8)
- ○ Other: (9) _____

Page Break

Q364 Do you live in an apartment complex?

- Yes (1)
- No (2)

Page Break

Display This Question:
If Do you live in an apartment complex? = No

Q365 Do you rent or own your home?

- Rent/Lease (1)
- Own (2)

Display This Question:
If Do you live in an apartment complex? = No

Q366 Approximately how old is the home you are living in?

- 2000 or newer (1)
- 1978-2000 (2)
- Built before 1978 (3)
- Don't know (4)

Page Break

Q367 How many people currently live in your home or apartment?

- 1 (I live alone) (1)
- 2 (2)
- 3 or 4 (3)
- 4 to 10 (4)
- More than 10 (5)

Page Break

Q368 In general, how often do you use the fireplace or woodstove in your home or apartment?

- ○ Everyday (1)
- ○ 2-3 days per week (2)
- ○ Once a week (3)
- ○ Once per month (4)
- ○ Never / I don't have a fireplace or woodstove (5)

Page Break

Q369 Which of the following best describes your employment status?

- ○ Employed, working 40 or more hours per week (1)
- ○ Employed, working 1-39 hours per week (2)
- ○ Not Employed, looking for work (3)
- ○ Not employed, not looking for work (4)
- ○ Retired (5)
- ○ Disabled, not able to work (6)

Q173 Are you considered an essential worker during the COVID-19 pandemic period?

- ○ Yes (1)
- ○ No (2)
- ○ I don't know (3)

Display This Question:
If Are you considered an essential worker during the COVID-19 pandemic period? = Yes
Or Are you considered an essential worker during the COVID-19 pandemic period? = I don't know

Q174 What type of essential worker are you? (Select all which may apply)

- ☐ Grocery/Pharmacy Staff (1)
- ☐ Food worker (2)
- ☐ Farmworker or agricultural worker (i.e. dairy, packing house, meat processing plant) (3)
- ☐ Police Officer (4)
- ☐ Firefighter (5)

- [ ] Paramedic/EMT (6)
- [ ] Essential government worker (7)
- [ ] Child care provider (8)
- [ ] Hospital personnel (9)
- [ ] Nurse/Nurse Assistant/Licensed Vocational Nurse (10)
- [ ] Physician (MD, OD, DMD, DDS) (11)

Q370 What was your total household income last year, before taxes?

- ○ Less than $10,000 (1)
- ○ $10,000 to $24,999 (2)
- ○ $25,000 to $49,999 (3)
- ○ $50,000 to $74,999 (4)
- ○ $75,000 to $99,999 (5)
- ○ $100,000 or more (6)

Page Break

Q371 How many people, <u>including yourself</u>, does this income support? (If you are paying child support but your child is not living with you, this still counts as someone living on your income. Please enter a number)

_____

Page Break

Q175 How would you describe the area where you live?

- Urban (1)
- Rural (2)
- Frontier or Remote (3)

Page Break

Q373 Are you of Hispanic, Latino/a, or Spanish origin? (One or more categories may be selected.)

- ☐ No, not of Hispanic, Latino/a, or Spanish origin (1)
- ☐ Yes, Mexican, Mexican American, Chicano/a (2)
- ☐ Yes, Puerto Rican (3)
- ☐ Yes, Cuban (4)
- ☐ Yes, another Hispanic, Latino, or Spanish origin (5)

Page Break

Q374 What is your race/ethnic group? (One or more categories may be selected)

- ☐ White (1)
- ☐ Black or African American (2)
- ☐ American Indian or Alaska Native (Please tell us what Tribe or Indigenous Community) (3) _____
- ☐ Asian (4)
- ☐ Hawaiian or Pacific Islander (5)
- ☐ Other (6) _____

Page Break

Q375 How well do you speak English?

- ○ Very well (1)
- ○ Well (2)
- ○ Not well (3)
- ○ Not at all (4)

Q376 What is the mostly spoken language in your family?

- ○ English (1)
- ○ Spanish (2)
- ○ Hmong (3)
- ○ Portuguese (4)
- ○ Native American or Indigenous language. Please tell us which one: (5) _____
- ○ Other: (6) _____

Page Break

Q377 What is your marital status?

- ○ Single/Never married (1)
- ○ Married (2)
- ○ Widowed (3)
- ○ Separated (4)
- ○ Unmarried partner (5)
- ○ Divorced (6)
- ○ Other (7) _____

Page Break

Q378 What type of health insurance do you have?

- ○ Uninsured (1)
- ○ Medicare & Medi-Cal (2)
- ○ Medicare & others (3)
- ○ Medicare only (4)
- ○ Medi-Cal only (5)
- ○ Healthy Families/CHIP (6)
- ○ Employment-based (7)
- ○ Privately purchased (8)
- ○ Other public program (9)

_____

- ○ Don't know (10)

Page Break

Q379 Do you live within 1 mile of a freeway or highway?

- Yes (1)
- No (2)

Page Break

Q380 Of the major political parties list below, which party do you most identify with:

- ○ Democratic Party (1)
- ○ Republican Party (2)
- ○ Libertarian Party (3)
- ○ Green Party (4)
- ○ Constitution Party (5)
- ○ Other party (6)
- ○ Don't know (7)
- ○ I don't support any party (8)

Page Break

Q383 How do you rate your political views?

	Extremely Conservative			Neutral			Extremely Liberal
	1	2	3	4	5	6	7
Political Views ()							

Page Break

Q384 To what level do you consider yourself to be religious or spiritual?

- Not religious/spiritual (1)
- Slightly religious/spiritual (2)
- Moderately religious/spiritual (3)
- Very religious/spiritual (4)
- Don't know (5)

Tables

Table 1. Cost Effectiveness, Cost Utility and Cost Benefit Analyses Literature Review

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
1. Chang, Graff Zivin, Gross, & Neidell, 2016 U.S. Particulate Pollution and the Productivity of Pear Packers	Indoor fluctuations PM2.5 in poorly insulated, well-ventilated setting.	Indoor PM 2.5 Measured by weather and pollution station 2.7 miles away	None	Pear packers in Northern California. 158 unique workers 7,242 worker by day observations	Payroll records 2001, 2002, 2003	Productivity piece-or-hourly system	Estimate the effect of PM2.5 on the marginal product of labor.	An increase in PM2.5 pollution of 10 $\mu g/m^3$ reduces productivity of workers by $0.41 per hour, 6% of average hourly earnings. Suggested potential threshold effect when PM2.5 exceeds 15 $\mu g/m^3$. The negative effect occurs at pollution levels well below current NAAQS.
2. Jiao, Kim, Hagen, &	Neighborhood Slow Zones (NSZs) 20 mph	None specified: by means	CEA	2009-2016 crash data published	From a societal perspective:	QALYs	Markov model, one way	Road casualties fell by

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
Muennig, 2019 U.S. Cost Effectiveness of neighborhood slow zones in NYC	Reduction of traffic crashes and encourage active transportation.	of encouraging active transportation		by NYCDOT for fatal and non-fatal injuries in NYC. Study time period pre intervention and post. Selected a control neighborhood for each NSZ.	construction, maintenance, and reconstruction costs of NSZs, medical costs of fatal and non-fatal traffic injuries, and productivity losses due to traffic injuries. Healthy utility by EQ5D 2016 USD$ Table 1. for sources		sensitivity analyses and Monte Carlo to test error in the model. To calculate ICER: divide changes in costs of NSZs by the additional gains in QALYs 3% discount rate.	8.74% in the case NSZs but increased in the control neighborhoods. Injury costs outweighed intervention costs = net savings of $15 per resident and a gain of 0.002 of QALY over the lifetime of the average NSZ resident. 97.7% chance of NSZ being Cost-effective if $50,000 per QALY

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
								gained threshold was chosen.
3. Griffin, Walker, & Sculpher, 2020 UK Distributional cost effectiveness analysis of West Yorkshire low emissions zone policies	Low emissions zone policies	Reduction of NO2 and PM2.5 Vehicle related emissions	CEA 3 Perspectives Healthcare sector, local authorities and individuals	UK West Yorkshire, highly polluted NHS healthcare data Local area health profile data produced by Public Health England provided the baseline levels of pollution-linked disease in each middle layer super output area	Direct Health Impacts: Healthcare expenses List of emission-reduction strategies with estimated costs in UK $ Direct nonhealth: Opportunity costs Healthy inequality impacts	QALYs Health inequality areas by QALE Expectancy All cause death CHD events Chronic bronchitis Asthma Preterm births Low weight births	Markov model Direct nonhealthy impacts EQ5D-3L Sensitivity analysis	Threshold was a consumption value of at least £16,895 per QALY in order to prefer Strategy 11 over Strategy 6 on the basis of impacts on health and production. Not recommended to have a societal perspective due to multiple stakeholders and budgets.

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
				in the period 2010–2014 Socioeconomic factors to construct "deprived" health inequality geographical areas. Index of Multiple Deprivation (IMD)				
4. Gao et al., 2016 China Improving air pollution control policy in China—A perspective based on	Reduction of emissions from small coal plants policy	Coal emissions	CBA	Energy costs and energy savings (ER and ES)	Formulas to calculate costs from ES (eliminating small coal boilers that produce energy and backward productivity) and from ER to	Benefit: Averted excess deaths prevention and mean number of life years lost due to excess deaths (18 mean avg)	A cost-benefit analysis of the industrial energy-saving and emission-reduction policies. Bottom-up concept	These policies are economically feasible and the estimated benefit-cost ratio is 6.32. Total cost and total benefit are 118.39 and

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
cost–benefit analysis					mitigate different pollutants.	Excess deaths and crop yield as social cost		748.15 billion Yuan The emission-reduction potential of energy-saving policy is greater than that of emission-reduction policy. There is a regional disparity of the benefit-cost ratios of implementing these policies.
5. Janke, 2014 UK Air pollution, avoidance	Air pollution warnings (forecasts, internet, Freephone telephone service, Teletext,	NO2 and O3	CBA "simple"	2003-2007. Children aged 5-19 in 89 local authorities in England. Total 45%	Cost of producing the air pollution forecast is equivalent to a maximum	Asthma and acute respiratory infections. Averted asthma admissions=	Simple method. Reported expenditure for contractor.	Direct effect of an air pollution warning is an 8% in asthma admissions. "Staying indoors

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
behaviour and children's respiratory health: Evidence from England	weather forecasts in newspapers on TV and radio), measure avoidance behaviour			Visits to outdoor attraction (a zoo) by two groups (asthmatics and non-asthmatics)	of 500,000 British pounds for the sample period.	671 @ 699 British Pounds. Predicted increase in admissions if there were no AP warnings-dummy variable 0.	Predicted increase in admissions if there were no AP warnings-dummy variable 0.	imposes a cost on individuals that might exceed the perceived gains" Evidence found of avoidance behavior. For asthmatics the cost of avoidance is low, because sufficient response to air pollution warnings is adjusting the dose of their reliever medicine and making sure they carry their inhaler.

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
6. Liu, Zhou, Wang, & Zhao, 2021 China Health benefits and cost of using air purifiers to reduce exposure to ambient fine particulate pollution in China.	Indoor - portable- air purifiers	PM2.5	CEA Calculated net benefits of using air purifiers as the difference between the monetary health benefits and the associated costs, and the benefit-to-cost ratio from dividing benefit by cost.	2016 10x10 areas using satellite PM2.5 measures for mainland China	Price of air purifier (initial investment) Power of air purifier (electricity use) Price of air purifier filter (cost to replace filters) *Did not consider emissions of excess electricity demand	Attributable or avoidable number of deaths - VSL	1. Exposure assessment model 2. Health risk assessment and 3. Cost effectiveness assessment model – Monte Carlo simulation framework	Deaths attributable to PM2.5 decreased by 30% if indoor PM2.5 concentrations are reduced to under 10 mg/m3 using air purifiers. 4 different scenarios at total annual costs of using purifiers were 82, 175, 438, 798 billion Chinese Yuan. Costs were highest in provinces with largest benefits, also relative costs as the proportion of

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
								per capita disposable income. City with highes per capita annual cost at 1800 RMB or 11.2% of local income, where as city with highest relative cost at 13.7% or 1300 RMB in absolute terms. Costs varied across cities with low, moderate, and high outdoor PM2.5 levels.
7. Mohammadi, Sadatsafavi, & Carlsten, 2021	Asthma-related precision health (anticipatory intervention for asthmatics, guided by	No exposure assessment Prevalence of asthma	CUA	British Columbia data Converted w/CPI into	Cost of asthma exacerbation and hospitalization (ED)	Effectiveness was measured in terms of change in QALY loss.	Costs and QALYs in base case and alternative scenarios	Precision intervention is cost-effective compared with no

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
Canada The economics of precision health: preventing air-pollution induced exacerbation in asthma.	relevant genetic abnormality in the face of acute air pollution)	from literature. Chief concern, increased forest fires in BC		2018 Canadian dollars 3 Different strategies: 1. No preventive intervention 2. Preventive health strategy based on information from genotype testing followed w/treating high-risk patients 3. Rx to all mild asthmatics	from previous studies.		were obtained with probabilistic analysis. Probabilities, Unit Costs and Utilities Monte Carlo simulations and sensitivity analyses (sensitive to prevalence of genetic abnormalities in asthma. TreeAge to build decision	intervention ICER of CAD $49,555 per QALY. Incorporation of genomic testing to stratify risk of asthmatics to pollution-driven exacerbations, and then tailoring a preventive intervention accordingly may be cost effective relative to untailored methods. Comparing no intervention with targeted therapy

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
							making scenarios.	shows that using a preventive intervention only for the ones with genetic abnormality is expected to cost more than no intervention ($150.5 versus $42) but it causes QALY gain (decrease in QALY loss from 0.0024 to 0.00021). The incremental cost-effectiveness ratio (ICER) was $49 555 per QALY. At a

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
								willingness-to-pay threshold of $50 000 per QALY, the personalized intervention is considered cost-effective. Projected that 27 093 extra pollution-induced exacerbations can be avoided in 1 year by using additional medication as a preventive intervention
8. Levy, Carrothers, Tuomisto, Hammitt, & Evans, 2001	None – hypothetical reduction (arbitrary)	O3	Benefit-cost	Hypothetical case study in Houston, Texas	Literature driven WTP	Premature mortality, chronic asthma, respiratory hospital	Estimated average length of life lost in O3 related deaths	Central estimate 1 mg/m3 decrease in annual average

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
U.S. Assessing the Public Health Benefits of Reduced Ozone Concentrations.						admissions, and minor restricted activity days Given a projected at-risk population of 345 million	(constant value per YLL assumptions individuals with COPD) ~10 YLL per death given age distribution of deaths for COPD in the U.S.	ozone concentrations would have an annual benefit of $10 per individual. 90% is related to premature mortality.
9. McGuinness, Hinks, Westcott, & Gheewala, 2020 Thailand An Integrated Assessment of particulate	Officially certified respirators	PM2.5	Cost	Bangkok, Thailand	Cost of respirator (by phone, online, retail, pharmacy) Longevity of respirator for end-cost score.	No health outcomes.	Cost scores Scenarios for effectivity.	In haze periods the average cost of reusable respirators was 8 and 9 times higher than disposable respirators. Integrated scores suggest

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
respirators used as personal protection from ambient air pollution in Bangkok, Thailand.								model DR1 respirator is the optimal choice (.97 dollars per respirator) for short term. For long term RR2 is the optimal choice at $12.96 per respirator.
10. Hubbell, 2006 U.S. Implementing QALYs in the Analysis of Air Pollution Regulations	Regulations of Heavy Duty Engine/Diesel Fuel Premature mortality Chronic bronchitis	PM2.5	CEA or CUA "referred as"	Reanalysis of ACS cohort study of mortality and long-term exposure to fine particles, applied to adults aged 30 and over. Life expectancy	Cost of the HDE rule $4.2 billion	QALY weight of 0.95 because the general population is likely to be on avg at somewhat less than perfect health. Bronchitis RR of	WTP for avoided incidences of chronic bronchitis are valued at $331,000 in 1999$ 3% discount rate	QALY analysis of mortality risks gained from reductions in PM mortality Discounted 88,000 Undiscounted 116,000 by 2030. Highest gains at ages 55

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
				from CDC at different ages. Concentration response function for chronic bronchitis from a cohort of 7th day Adventist nonsmokers w/adults 27 and older. Prevalence rates from CDC.		1.0086 for the HDE reduction in PM2.5 of 0.65 mg/m3. Incidence estimate of 3.78 cases per 1,000. Bronchitis is assumed to have the same age-specific life expectancy as the general population no loss of life. QALY weight of 0.69.		and over until 85+. QALYs gained from reductions in chronic bronchitis is 34,000. In a CUA total cost per discounted QALY is $35,710 *HDE also resulted in $3.8 billion in other health and environmental benefits, or net costs of $0.4 billion thus net cost per discounted

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
								QALY is then $3400
11. Fisk & Chan, 2017 U.S. Health benefits and costs of filtration interventions that reduce indoor exposure to PM2.5 during wildfires	HVAC system fans operation or portable air cleaners (two brands) CADR= Clear Air Delivery Rate	PM2.5 from wildfires	CBA "as stated" Health benefits – Cost of interventions	Southern California exposed population to wildfire smoke in 2003 (Simulation)	Interventions costs: portable air cleaner, HVAC incremental energy cost, HVAC incremental filter cost, Portable filter equipment cost	Health-related economic benefits ($million) All respiratory diseases, Sum of four outcomes, Mortality, and All respiratory plus mortality	Used reference parameters from literature for values of respiratory admissions and premature death ($) Energy use and housing units. Estimated reductions in hospital admissions and premature deaths were calculated using the population mean for	Interventions in all homes the economic benefits from avoided respiratory hospitalizations during the wildfire period range from $1 million to $5.5. From reduced mortality from $75m to $416m. Operating portable air cleaners is lowest than energy costs for continuous HVAC fans $2.3 vs $16 per house.

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
							each intervention.	Intervention cost is up to $4.4 trillion. Interventions only in elderly housing, economic benefits are similar in magnitude and the intervention costs decrease 80%. Mortality-related benefits are not sufficient to pay for portable air cleaner purchases when the intervention is for all homes but are exceeded

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
								by the cost of their operation.
13. Martenies & Batterman, 2018 U.S. Effectiveness of Using Enhanced Filters in Schools and Homes to Reduce Indoor Exposures to PM2.5 from Outdoor Sources and Subsequent Health Benefits for Children	High efficiency filters in homes and schools.	PM2.5	CBA CEA	136,000 children ages 6 to 18 years old. 11,999 have asthma (11.3%) Attending 290 schools in Detroit, Michigan and nearby cities. 2011-2015 Hospital data from Census ACS and Michigan Inpatient Database,	Cost of drop-in filters (MERV 5, 8, 12, and 14) for unit ventilators (UV) providing ventilation and filtration in classrooms. Drop-in filters for homes with forced-air systems. Three-compartment model for free-	Incidence of asthma-related hospitalizations, ED visits, and respiratory symptoms days estimated using HIA methods. Concentration responses were from EPA's epidemiological studies for PM2.5. No effect threshold.	Monte Carlo analysis for all application types (1,000). Ambient air pollution concentrations use 24hr measurements from 12 Detroit area monitoring sites every 3rd day. Sensitivity analyses to evaluate	Schools show greater reductions in indoor/outdoor ratios from using MERV 5 to 8 (46%), 12 (80%), and 14 (83%). This reduction is higher than in homes. In homes the I/O ratios see a reduction of 34%, 54% and 56%. Air purifiers reduce them by 84% in bedrooms and 88% in

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
with Asthma.				ED visits from Medicaid data at zip code level and county level and are assumed rates for all children. Respiratory symptom day from an unpublished cohort in Detroit. Assumption: children live and go to school in the same zip code.	standing air cleaners (bedroom, living room, and remainder of the house model) Time weighted averages for exposure in each location. For stand-alone air purifiers assumed to run continuously. Increased electricity.	Attributable cases are converted to DALYs and monetized in 2010 USD$	usage from 0 to 100%	living rooms. The 3rd air cleaner showed a modest I/O ratio reduction. In total, PM2.5 exposures cause an estimated 110 DALYs and $6 million in monetized impacts per year. Replacing filters with 8, 12 or 14 MERV filters in schools reduce asthma burden up to 14% annually

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
								(or up to 30% of the school year) and is this benefit was monetized at $0.5 – 0.9 million in avoided health impacts. Schools that are near road DALYs are reduced by 10-17%. At home, filters avoid 12 to 18 DALYs per year representing $0.7 – 1 million per year ($63-93 per child with asthma per

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
								year). MERV 8, 12, 14 reduce asthma burden by 11% to 17%, not a significant difference from 12 to 14. Assuming 20 students in each classroom and 2 with asthma, the marginal cost is $2 – 3 per students per year or $20-$32 per student per asthma per year. This is below the benefits of asthma

Author, Publication, Year, Country	Intervention/Policy	Air Pollutant	CEA, CBA, CUA	Time Frame, Sample Size & Target Group	Cost Measures	Outcomes Measures	Scope of Analysis	Results
								exacerbations. At home filters costs exceed ($1.4-$1.6 million per year for homes with forced air systems and $800,000 per year for homes using air cleaners) the monetized benefit of avoided asthma impacts from resulting lower exposures

Table 11. Cost of Illness Analyses Literature Review

Author, Publication, Year, Country	Attributable Diseases	Air Pollution Component	Perspective, Prevalence or Incidence	Time Frame, Sample Size & Target Group	Cost as Reported (Year)	Direct Costs Included Items	Indirect Costs Included Items	Method
1. D. Zmirou, 1999 France Health Effects Costs of Particulate Air Pollution	Asthma, cold, sore throat, sinusitis, laryngitis, tracheitis, bronchitis, isolated dyspnea or cough, acute respiratory failure or other conditions. Attributable Risk from Meta-Analysis-Dose Response	PM 10 Measurements from air-quality monitors. Daily averages of air pollution.	Society Prevalence	3 days in December 1994 508 families 1265 subjects 395 Physicians 13 hospitals Children and Adults 3 Metro areas Lyon Grenoble Chambery	For a population of 1 million: 79-135 million French francs. Annual extrapolation. OTC Meds: 44% Wage losses 38% Education losses 27% Hospital expenditures 5%	Medical care, drugs, labs, x-rays, use of other healthcare workers. Daily hospital and clinics for respiratory conditions.	Absenteeism Prescribed work leave for average daily wage losses and productivity.	Cross-sectional study. HCA Monte Carlo simulation Uncertainties management
2. El-Fadel & Massoud, 2000 Lebanon Particulate matter in urban areas: health-based	Pneumonia, COPD and ED visits	PM 10 10 $\mu g/m^3$ reduction	Societal Mortality & Morbidity	Census 1996 13,440 Households Lebanon (urban)	Total range $2,700,000 - $126,000,000 (USD) COPD, Pneumonia	Hospital ED visits and admissions	Productivity loss years of 20 and 5 for two age groups 40-59 and 60-69. Multiplied average	HCA 1) Total # of admissions of each health endpoint obtained by multiplying the total # of hospital

Author, Publication, Year, Country	Attributable Diseases	Air Pollution Component	Perspective, Prevalence or Incidence	Time Frame, Sample Size & Target Group	Cost as Reported (Year)	Direct Costs Included Items	Indirect Costs Included Items	Method
economic assessment					and ED Visits $140,000 - $32,000,000 (USD) Lebanese cases at 1990 USD value Hospital Admission COPD $1,944 p/c Pneumonia $1,896 p/c All respiratory $1,464 p/c Respiratory illness or symptom $26,000 p/c Acute bronchitis $5 Acute asthma $3 Acute respiratory		productivity years by the average income. Restricted activity days/person Work loss days at $8 per case Mild restricted activity days $4.	admissions with the % of health endpoint hospital admissions. 2) Multiplying (1) by the % decrease in health endpoint hospital admissions due to intervention.

Author, Publication, Year, Country	Attributable Diseases	Air Pollution Component	Perspective, Prevalence or Incidence	Time Frame, Sample Size & Target Group	Cost as Reported (Year)	Direct Costs Included Items	Indirect Costs Included Items	Method
					symptoms $2 URS $2 LRS $1			
3. Zhang, Song, Cai, & Zhou, 2008 China Economic assessment of the health effects relates to PM pollution in 111 Chinese cities by using economic burden of disease analysis	Acute and chronic bronchitis, asthma, increased outpatient visits and hospital admissions. Mortality	PM 10 Conditions from the annual report of SEPAC. Average level of ambient PM concentrations for the year 2004.	Societal Morbidity & Mortality (Premature death) Macro-economic approach to estimate health impacts on national economy, WTP approach.	CY 2004 111 Cities in China Residents in cities producing 70% of China's GDP	US $29, 178,700 (18634.4 – 37923.2) With threshold PM10 at National standard (40 mg/m^3 Table 3. breakdown per condition	Respiratory, cardiovascular Hospital admissions IM and Peds outpatient visits	Loss of wages. Restricted activity days were not included because they could not be valued quantitatively. Potential underestimation of the results.	HCA WTP Mortality, bronchitis and asthma (Literature) COI for hospital admissions and outpatient visits. Exposure function
4. Patankar, Trivedi, & Somaiya, 2011 India Monetary burden of health impacts	Symptoms: cough, phlegm, breathlessness, wheezing and cold. Diseases: bronchitis, asthma,	PM10 NO_2 SO_2 NH_3 Monthly averages for time frame	Societal Morbidity Incidence (Discount not stated)	February 2003 – April 2004 1,800 Mumbai city residents for cross-	USD $113.08 million for PM10 USD $218.10 million for NO_2	Cost of treatment: hospitalization, medicines, equipment, consultation charges of doctors.	Productivity loss: Lost wages for restricted or total inactivity days due to illness.	Cross-sectional study for health impacts. Logistic regression controlling for age, gender, smoking, distance to work, occupation, width

Author, Publication, Year, Country	Attributable Diseases	Air Pollution Component	Perspective, Prevalence or Incidence	Time Frame, Sample Size & Target Group	Cost as Reported (Year)	Direct Costs Included Items	Indirect Costs Included Items	Method
of air pollution in Mumbai, India: Implications for public health policy	URTI, cardiac, other chest illnesses, allergic rhinitis and COPD.			sectional survey 150 households to estimate monetary costs of health impacts (five areas) People who live within 1 km of air quality monitoring stations (six areas) Medical practitioners		Gov't expenditure (evidence of decrease), personal expenses for healthcare		of road adjacent to residence, presence of polluting industry near residence, hours spent in kitchen, quality of kitchen ventilation and cooking fuel type. COI (Cost of Tx and productivity) for monetary burden of impacts. Inflation 9% per annum for healthcare and 5% for wages based on CPI.
5. Brandt et al., 2017 Southern, California USA	Coronary Heart Disease	PM 2.5 NRAP	Societal for VSL Individual for Hospitalizations	At risk: 45 yo adults and older	2014 USD 2018 NRAP Measures Road proximity:	Hospitalizations (mean cost) Medical costs- 1 year following discharge:	Lost wages minus short-term disability Complete restricted	VOSL from USEPA Assumptions 2008-2035 age distribution, mortality and

Author, Publication, Year, Country	Attributable Diseases	Air Pollution Component	Perspective, Prevalence or Incidence	Time Frame, Sample Size & Target Group	Cost as Reported (Year)	Direct Costs Included Items	Indirect Costs Included Items	Method
Costs of Coronary heart disease and mortality associated with near-roadway air pollution			Mortality & Morbidity Incidence (Discount not stated)		USM$ 3,791 Elemental Carbon USM$ 6,083 Traffic density USM$11,461 PM2.5 USM$16,751 2035 NRAP Measures Road proximity: USM$ 10,579 Elemental Carbon USM$ 7,935 Traffic density USM$ 22,040 PM2.5 USM$ 25,567	Outpatient Tx, medical office visits and pharmaceuticals.	activity and minor restricted activity.	hospitalization rates. Opportunity Cost of time lost to illness: CHD Hospitalizations for 45-64 and 65+

Author, Publication, Year, Country	Attributable Diseases	Air Pollution Component	Perspective, Prevalence or Incidence	Time Frame, Sample Size & Target Group	Cost as Reported (Year)	Direct Costs Included Items	Indirect Costs Included Items	Method
6. Bachmann & van der Kamp, 2017 France Expressing air pollution-induced health-related externalities in physical terms with the help of DALYs	Asthma, bronchitis, Cardiovascular, cough, lower respiratory symptoms	PM 2.5 PM 10 O_3 Winter & △Summer variations	Societal Mortality & Morbidity Incidence (Discount rate 0%)	2030 with current conditions. Nice, French Provence Alpes Cote d'Azur. Nice Grid Project (Power Plant) service area residents.	PM 2.5 related health impacts: 3.482 – 276.43 DALY/k tonne Morbidity share 0.07% PM 10 related health impacts: 0.021 – 1.963 DALY/k tonne Morbidity share 0% Ozone related health impacts: -0.470 – 1.785 DALY/k tonne	Non-monetised Hospital admissions length of stay.	Restricted activity day Work loss day	YLL, YOLL Disability weights. Regional life expectancy. Supply-demand related health impacts. DALY= YLL + YLD Years of life lost (premature mortality) Years of healthy life lost due to disability for non-fatal health outcomes

Author, Publication, Year, Country	Attributable Diseases	Air Pollution Component	Perspective, Prevalence or Incidence	Time Frame, Sample Size & Target Group	Cost as Reported (Year)	Direct Costs Included Items	Indirect Costs Included Items	Method
					Morbidity share 2.71%			
7. Brandt et al., 2014 LA County, USA Cost of near-roadway and regional air pollution-attributable childhood asthma in LA County.	Asthma in children Related outcomes: bronchitis	NRP O_3 NO_2	Societal Morbidity Prevalence No discount	CY 2007 Children 0-17 yo Los Angeles County 17.8% population living neat major roadways (75m)	2010 USD $441 million for O_3 $202 million for NO_2 Cost of routine asthma care $3,000 yearly for each child $1,500 per bronchitis case	Amount charged for hospital admissions, ED visits, doctor visits, rescue/controller medications, antibiotics (Bronchitis)	School absences Caregivers' lost wages, traveling, waiting and receiving care	Reviewed ORs for health effects and direct/indirect estimates. Scenarios of decreasing exposures per air quality plan. Avoided double counting by evaluating pollutants separately. WTP study in CA with families with children with asthma.
8. Zhou, Nurmagambetov, Mccord, & Hsu, 2017 USA	Asthma, carbon monoxide poisoning, lead poisoning	Wildfire exposure (Richardson et al.)	WTP Individual COI 3rd Party Societal	1996 – 2014 Literature review U.S. States, CDC:	Asthma Annual total direct COI $800 - $3,300	Hospitalizations, ED visits, Primary care doctor visit, medical devices, medical tests	Loss in income School absence	HCA COI and WTP estimates comparison.

Author, Publication, Year, Country	Attributable Diseases	Air Pollution Component	Perspective, Prevalence or Incidence	Time Frame, Sample Size & Target Group	Cost as Reported (Year)	Direct Costs Included Items	Indirect Costs Included Items	Method
Economic valuation of selected illnesses in environmental public health tracking				Mississippi, Arizona, Michigan, Wyoming and California	Indirect costs $90 to $1,700 WTP $580 to $4,200 per year (to eliminate asthma symptoms)	and medications	Travel time for medical care	WTP estimated using contingent valuation survey.
9. Niu, Chen, & Kan, 2017 China Air pollution, disease burden, and health economic loss in China	Excess deaths, premature mortality, bronchitis and asthma	PM 2.5	WTP Individual COI Societal	Literature review China	Welfare loss $126.6 billion - $1,589.8 billion Labor output lost $12.5 billion - $44.6 billion	Hospital care, home health care, medicines, doctors and nurses visits	Forgone labor output	GBD HCA WTP VOSL
10. Zhu, Pang, Chevallier, Wei, & Vo, 2018 China	Asthma, acute and chronic bronchitis.	PM 2.5	Societal Mortality and Morbidity Prevalence	2014 76 cities in China (North and South)	2013 prices 382.30 billion ~ USD$55.01 billion (2014 Yuan	Per capita expenses and average days spent in the hospital, outpatient visits, adjusted	Labor income loss in future work.	Exposure-response function to estimate health effects of air pollution. % Change in the incidence rate of

Author, Publication, Year, Country	Attributable Diseases	Air Pollution Component	Perspective, Prevalence or Incidence	Time Frame, Sample Size & Target Group	Cost as Reported (Year)	Direct Costs Included Items	Indirect Costs Included Items	Method
Including intangible cost into the cost-of-illness approach: a method refinement illustrated based on the PM 2.5 economic burden in China				Urban residents	exchange rate)	by the per capita disposable income for each city. Internal medicine and pediatrics.		premature death or disease caused per 1 $\mu g/m^3$ fluctuation of PM 2.5 in the concentration level. VSL and income elasticity coefficient (1) Benefit transfer approach to adjust the costs of outpatient visits, asthma attack and acute bronchitis by the per capita disposable income for various cities. Sensitivity analysis with extreme conditions to manage pollution level variation uncertainties
11. Guo, Cheng, Chen, Zhou, & Wang, 2010	Long term mortality, acute and chronic bronchitis,	PM10 Transport related, tail-pipe and road dust)	Societal Mortality and Morbidity	2004-2008 Beijing ~16.95	Mean 2004-2008 USD$272 million	Hospital admission costs, ED visits, fees for service,	Lost wages during days spent in hospital	Direct cost approach (bottom-up approach)

Author, Publication, Year, Country	Attributable Diseases	Air Pollution Component	Perspective, Prevalence or Incidence	Time Frame, Sample Size & Target Group	Cost as Reported (Year)	Direct Costs Included Items	Indirect Costs Included Items	Method
China Estimation of economic costs of particulate air pollution from road transport in China	asthma. Cardiovascular and respiratory hospital admissions.		Prevalence	million residents In 2008, the Olympics imposed vehicle control measures.	USD$297 million USD$310 million USD$323 million USD$298 million	outpatient visits	Restricted activity days	WTP (contingent valuation method) unless health endpoints (morbidity) could not been valued in existing literature. COI when no WTP is available. Mortality assessed with VOSL. Conversion to 2004-2008. Exposure-response coefficients. Monte Carlo simulations to estimate uncertainties.
12. Hall, Brajer, & Lurmann, 2008 San Joaquin Valley Counties, CA USA	Asthma, acute and chronic bronchitis and non-asthma respiratory symptoms	PM 2.5 (annual average) O_3 27 stations, daily PM2.5 for 14.	Societal Mortality and Morbidity Prevalence	2002-2004 SJV Counties ~3.34 million residents in 2004	Ozone attributed $32.64 million per year PM2.5 attributed	Emergency room visits, hospital admissions.	Minor restricted activity days School absences Work loss days	Exposure assessment using concentration response. Sensitivity test to estimate adult mortality.

Author, Publication, Year, Country	Attributable Diseases	Air Pollution Component	Perspective, Prevalence or Incidence	Time Frame, Sample Size & Target Group	Cost as Reported (Year)	Direct Costs Included Items	Indirect Costs Included Items	Method
Measuring the gains from improved air quality in the San Joaquin Valley	Premature mortality	Hourly concentrations of Ozone for each day.			$3,206 million per year ($1,000 p/pp/y)			VSL for premature mortality Economic values from literature, including hospital admissions and symptoms