Analysis of Race/Ethnicity in Social Determinants of Health and Climate Change Vulnerability

Final Report

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1. Background and Introduction:

1.1. Impacts of Climate Change on Population Health

There is well-documented evidence of the impact of climate change and variability on population health globally, across the United States, and within California. As a result of climate change, not only are baseline temperatures trending upwards, potentially putting billions of people at risk of exposure to dangerous heat (Vecellio et al., 2023), but existing patterns of extreme weather are becoming exacerbated, leading to previously unprecedented extreme events around the world (Ebi et al., 2021). Globally, climate change is expected – and has already begun – to increase the frequency, intensity, and/or duration of extreme precipitation events, droughts and dust storms, extreme heat events, tropical cyclones, and wildfires, all of which have knock-on effects for human health, both direct and indirect (Ebi et al., 2021).

In California, two of the most impactful climate change-related phenomena for population health are extreme heat and air pollution (Shonkoff et al., 2011). Air pollution associated with wildfire smoke in particular is a growing threat to the health of Californians (Do et al., 2024). The western US, including California, has seen a dramatic increase in wildfire activity in recent years due to climate change (Abatzoglou and Williams, 2016). This increased fire activity brings elevated levels of wildfire smoke-associated PM2.5 pollution, which is detrimental to human health – even more so than PM2.5 from other pollution sources (Reid et al., 2016; Aguilera et al., 2021). Impacts of wildfire smoke on multiple health outcomes across the life course have been reported.

Extreme heat events are also increasing in frequency, intensity, and duration in California, leading to increases in morbidity and mortality (Shonkoff et al., 2011; Gershunov and Guirguis, 2012). One study estimates that extreme heat hospitalizes ~7,000 Californians every summer (Vaidyanathan et al., 2019). Extreme heat can lead to a variety of negative health outcomes, from dehydration to heat stroke, but can also cause harm by exacerbating existing health conditions, impacting the cardiovascular, respiratory, renal, and other body systems (Basu, 2009; Bobb et al., 2014). Heat can also negatively impact pregnancy and birth outcomes, as well as mental health (Ilango et al., 2020; Thompson et al., 2018).

1.2. Interaction with Social Determinants of Health

Climate change, including the effects of extreme heat and wildfires, impacts everyone. Yet, it's crucial to acknowledge and address the fact that some communities are systematically more exposed, more affected, and less resilient to these impacts. Climate change thus constitutes a critical environmental justice issue.

There are various factors that may influence which populations, communities, or individuals are more vulnerable to the health impacts of climate hazards. These non-medical factors are called social determinants of health (SDOH) (Marmot and Wilkinson, 2006). According to the US Department of Health and Human Services, SDOH are "the conditions in the environments where people are born, live, learn, work, play, worship, and age that affect a wide range of health, functioning, and quality-of-life outcomes and risks" (health.gov, n.d.). In contrast with biological factors that may determine health outcomes, SDOH include social factors such as race, gender, income, education, food security, housing, access to healthcare, and social inclusion (WHO, n.d.). These different factors affect the health outcomes of individuals and populations and contribute to health disparities as they are not distributed evenly within and between populations (health.gov, n.d.).

Climate change can be seen as a context in which SDOH play out. Climate hazards, such as extreme heat, interact with SDOH, contributing to and further exacerbating health inequities. For example, in an extreme heat event, access to adequately cool shelter can affect those who are exposed to non-optimal temperatures. Those who do not have access to shelter will face the brunt of the heat and its associated health impacts. Further still, those who have the means to access shelter with additional adaptive features such as air conditioning are likely to fare the best.

1.3. Health Outcomes among Communities of Color

Race and ethnicity (referred to as race/ethnicity in the rest of the text) are social determinants of health that are particularly important to understand in the United States. In the US, due to various structural and historical reasons including the racist practice of redlining, in which people of color were systematically excluded from accessing mortgages, communities of color –especially Black and Latino communities– continue to be more vulnerable to environmental and climate health issues compared to their White counterparts (Gutschow et al., 2021; Berberian et al., 2022; Deivanayagam et al., 2023).

Studies of the health impacts of extreme weather events have already demonstrated these discrepancies. Focusing on extreme heat, studies have shown that neighborhoods with higher concentrations of people of color are hotter on average than predominantly white neighborhoods, typically a result of land surface differences such as a lack of tree canopy cover (Deivanayagam et al., 2023). This puts these communities at a heightened risk for the health impacts that come with extreme heat exposure. In the US, the risk of dying from extreme heat has been found to be higher for Black, Latino, and Native American individuals than for Whites and Asians – and the risks are even higher for non-citizens (Basu and Ostro, 2008; Berberian et al., 2022; Khatana et al., 2022).

Heat morbidity is also higher for communities of color. Asthma and heart attacks due to heat exposure are more common in Black and Hispanic people compared to Whites (Deivanayagam et al., 2023). Additionally, Black individuals are at higher risk of heat-associated cardiovascular, renal, and respiratory diseases than Whites (Berberian et al., 2022). Extreme heat has been shown to influence birth outcomes and maternal health – which intersects with the inequitable burden of extreme heat health impacts on people of color: for instance, during a heat wave, Black women are at a higher risk of preterm birth compared to White women (Deivanayagam et al., 2023). Race/ethnicity can also intersect with other SDOH, such as one’s occupation (Gronlund, 2014). For example, Hispanic men are overrepresented in many outdoor industries, such as construction and agriculture, which have an elevated risk of heat-related illness and mortality (Berberian et al., 2022).

When it comes to wildfire-related health impacts, fewer studies have been conducted that assess race as an effect modifier (Reid et al., 2023). But some studies have found evidence that communities of color are disproportionately impacted. For instance, among those over the age of 65, Liu et al. (2017) found that the risk of respiratory hospital admissions due to wildfire smoke was significantly higher for Black than for White subpopulations. Reviewing the literature, Berberian et al. (2022) found that, in summary, people of color, specifically Black and Native American populations, are at a higher risk of cardiovascular and respiratory impacts from wildfire smoke compared to Whites.

Communities of color, Black communities in particular, and especially children, have disproportionately high asthma rates compared to predominantly White communities – partially a result of historical redlining, which has resulted in communities of color being located nearer to sources of air pollution (Gutschow et al., 2021; Fuller et al., 2022). Wildfire smoke has been demonstrated to exacerbate respiratory diseases including asthma (Reid et al., 2016; Ebi et al., 2021). Given the already uneven burden of asthma on communities of color, these same communities would therefore most likely face disproportionate morbidity during a wildfire smoke pollution event.

In addition to considering wildfire and extreme heat events and their impacts on population health separately, we can also investigate how these events compound or reinforce one another when they occur at the same time. Recent studies suggest that co-occurring extreme heat and wildfire smoke has synergistic effects on cardiorespiratory health, resulting in a combined effect that is larger than the sum of extreme heat and wildfire health impacts independently (Chen et al., 2024). As might be expected, these synergistic health effects are stronger in communities that have higher proportions of racial/ethnic minorities (Chen et al., 2024).

1.4. Systematic Differences in Exposure, Susceptibility, and Adaptive Capacity

Climate change will only amplify the already existing inequities in which populations are exposed to and vulnerable to the effects of extreme heat, wildfire smoke, and other environmental hazards – unless climate policies adopt themes of racial equity and climate justice proactively (Shonkoff et al., 2011). To create a more equitable society where populations are equally resilient to climate change it is essential to understand the systematic differences between populations and deconstruct the systems that produce environmental injustice.

Communities of color are often said to face a type of "double jeopardy" when it comes to environmental and climate stressors (Institute of Medicine, 1999). Not only are many communities of color at an elevated risk of environmental or climate hazard exposures, but they are facing this on top of existing socioeconomic challenges, disenfranchisement, and health disparities, making these populations more susceptible to the health impacts of these exposures (Institute of Medicine, 1999; Morello-Frosch and Shenassa, 2006).

Certain populations may be vulnerable to climate impacts due to differences in either exposure to climate hazards or susceptibility to these hazards. Both are important to address in order to achieve climate justice goals. Differential exposure describes situations in which the environmental or climate hazard itself is unevenly distributed, with certain communities more exposed than others. For instance, discriminatory housing policy (i.e., the systematically racist practice of redlining) has created a landscape in many American cities in which predominantly Black neighborhoods are hotter on average than predominantly White neighborhoods. During a heat wave, Black populations in these cities are exposed to more extreme heat than White communities are, exacerbating health discrepancies.

Differential susceptibility (or vulnerability) describes the effects of a stressor being uneven between populations even when the exposure is equal due to underlying differences in resiliency or SDOH. Let's say a wildfire produces a smoke plume that evenly covers a town, exposing all communities equally to hazardous air pollution. Even still, certain communities may face worse health impacts due to differential susceptibility – for instance, communities of color where exposure to air pollution from industrial sources has already elevated the prevalence of respiratory diseases such as asthma. It's also important to realize that communities can experience differential exposure and differential susceptibility at the same time.

Though the current landscape in California, the US, and around the globe is one in which systems have produced and reinforced inequalities in who faces the brunt of climate health impacts, policies that adopt a climate and racial justice approach have the ability to reverse or lessen these uneven burdens.

1.5. Purpose of the Scoping Review

The purpose of this white paper is to synthesize existing literature related to the eight topical areas analyzed in the 2022 Scoping Plan's Public Health Appendix (Appendix G) using a racial and ethnic lens to describe disproportionate risk and impacts for population groups and communities. The eight topical areas have been identified following the Resolution 20-13 (Health Evaluation of Air Quality and Climate Regulations and Programs) and the recommendation to "*explore and develop new methods for evaluating health impacts in disadvantaged communities that account for increased vulnerability and exposure to sources of pollution that impact communities*." The eight topical areas include: heat impacts, children's health and development, economic security, food security, mobility and physical activity, urban greening, wildfires and smoke impacts, and housing affordability.

The specific objectives of this white paper are the following:

1) Conduct a scoping review to identify published scientific papers to describe how climate change may worsen racial and ethnic inequities in various health outcomes.

2) Summarize available databases and tools, and online resources that could be used for a future comprehensive assessment of the differential health impacts across racial and ethnic

groups. We will identify the best state, regional or local databases of information to help provide information on health disparities in relation to race and ethnicity and social determinants of health to inform CARB's climate and health analysis. We will describe and compare information on race and ethnicity in currently available tools exploring health and equity conditions for the state or in different regions and at more local levels in California and provide recommendations for CARB's use of this information.

2. Methods

2.1. Scope of Review

There are numerous direct and indirect impacts of climate change on human health and these impacts are not equitably distributed across population groups. Many already vulnerable groups, including communities of color, have greater exposure and less resiliency to climate change effects, which compounds health risks. The purpose of this white paper is to build upon the public health analysis (Appendix G) of eight Co-Benefit areas of focus conducted as part of the CARB 2022 Scoping Plan. The original analysis identified expected health effects of "no action" and "action" scenarios under the Scoping Plan. The current review aims to evaluate specific impacts of climate change on racial and ethnic groups in California within the eight health co-benefit areas, pre-defined as the CARB 2022 Scoping Plan. The information gathered from this white paper will allow CARB to better identify opportunities in California to reduce racial and ethnic health inequities through eight co-benefit areas to ensure CARB's policies benefit those most vulnerable to climate change and air pollution.

2.2. Eligibility Criteria

The main objective was to identify major health impacts on racial and ethnic groups in California, USA related to CARB's eight co-benefit areas. We included quantitative, empirical articles that evaluated health impacts related to heat, wildfires and smoke, mobility and physical activity, urban greening, children's health and development, affordable housing, economic security, and food security. Inclusion criteria were as follows:

1) Original research papers,
2) Published on or after the year 2000,
3) Published in English,
4) Included health impacts related to the eight co-benefit areas,
5) Study conducted in California or had data from which California records could be extracted,
6) Included race/ethnicity analysis.

Details about excluded studies at each step are described below. We excluded systematic or scoping review papers. Studies conducted in the U.S. but lacking specific results related to California were excluded as were studies that adjusted models for race/ethnicity but did not report results across racial/ethnic categories or conduct specific moderation analyses.

2.3. Keywords and Data Extraction

To identify original research studies, we used a comprehensive search strategy differentiated by each co-benefit area of interest. We searched the following online databases from January 1, 2000: Web of Science, PubMed, and Google Scholar. There were eight different search queries used, one for each co-benefit area for interest. However, all queries had in common the search terms related to California and to race/ethnicity, as shown in Appendix 1.0. These terms were then combined with the more specific search terms in Appendix 1.1-1.8 for each focus area. Some papers covered multiple co-benefit topics, for example assessing wildfire smoke and child development. These studies were counted separately for each co-benefit area.

From the results for each query, the papers were then manually screened to make sure they met all inclusion criteria. Two authors (SL and KC) conducted independent reviews of titles and abstracts. Full texts were reviewed for those articles that passed the first-round screening. All selections were discussed with the study PI for final inclusion or exclusion. Data were extracted from the studies into a spreadsheet and consensus on inclusion was achieved at regular project meetings. A comprehensive list of data sources for each co-benefit area for the included exposures, outcomes and race/ethnicity data is provided in Section 3.10.

2.4. Development of Conceptual Model

See the conceptual model in Appendix 4.

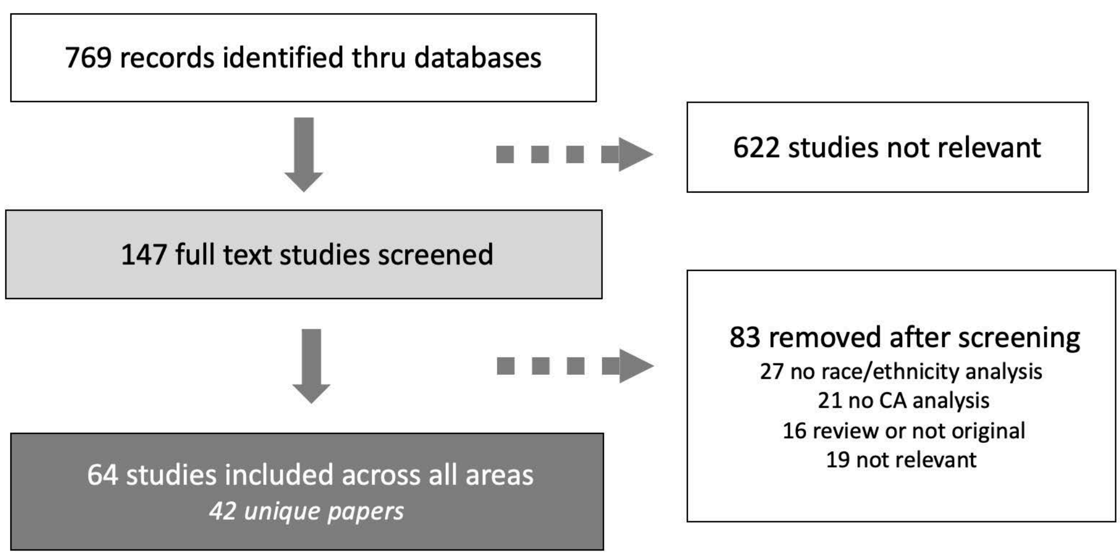
This conceptual model was developed through an iterative process between the co-authors until a consensus has been found.

3. Results

3.1. Summary of Studies

Figure 1 shows the flow of articles in the scoping review. A total of 769 articles were identified across the 8 co-benefit area searches. Of these returned results, 622 were excluded based on a review of the title and abstract. Full texts for 147 articles were screened and 83 were excluded based on the following criteria: did not pertain to the 8 co-benefit areas (n=19), did not include an analysis by race/ethnicity (n=27), did not include data from CA (n=21), 16 were either review articles or not original research, and 6 did not include a relevant analysis with many articles excluded for more than one reason. A total of forty-two (42) unique articles were included in the review. Twenty-two papers pertained to multiple co-benefit areas thus the total number of papers across all focus areas was sixty-four (64).

Figure 1. Flow diagram of overall study selection



Papers pertaining to some aspect of birth or children's health were the most common co-benefit area studied (n=20), followed by heat (17), wildfires and smoke (14), and mobility and physical activity (7). Fewer studies were found for the remaining co-benefit areas of interest, mostly due to a lack of a specific race/ethnicity analysis. We tried to be as inclusive as possible given this limitation, in some cases including studies that were conducted solely in populations of color or that addressed race/ethnicity in some aspect.

Table 1. Characteristics of included studies

A. Papers included for all co-benefit areas

Health co-benefit area	Count (n=64)	%
Heat Impacts	17	36
Wildfires and smoke	13	30
Mobility and physical activity	7	23
Urban greening	4	9
Children's health and development	20	43
Affordable housing	3	6
Food security	0	0
Economic security	0	0

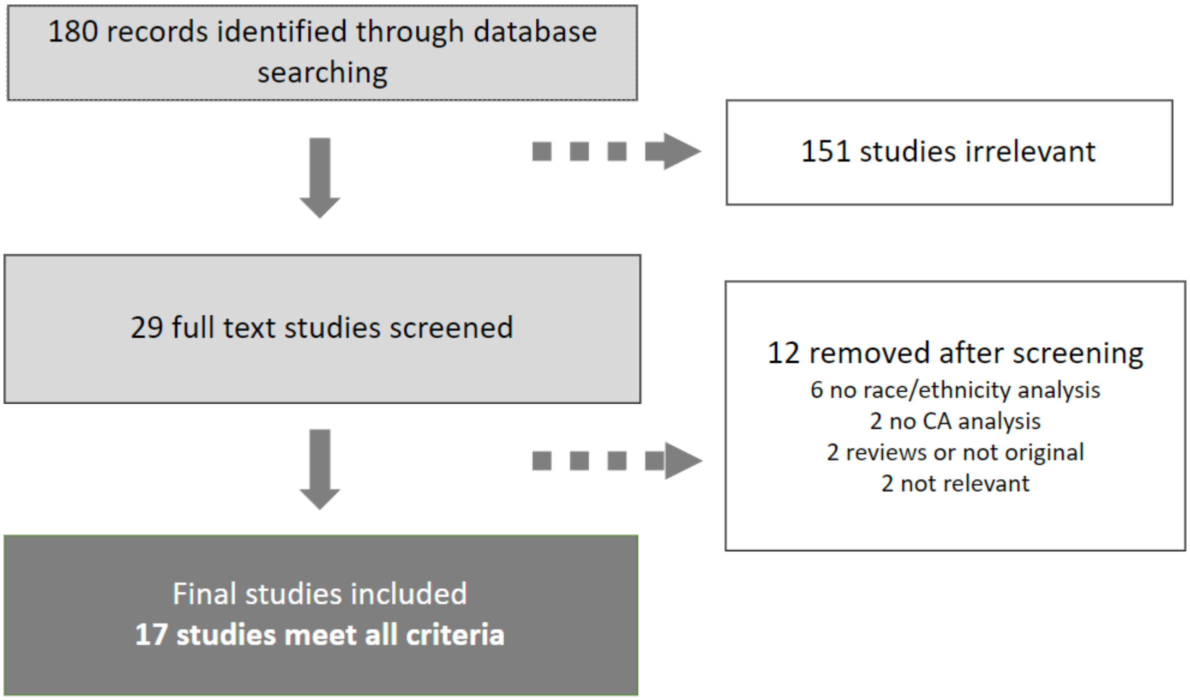
B. Unique Papers (without duplicates)

Year of publication	Count (n=42)	%
2000-2011	4	9.5
2012-2024	38	90.5
Racial/ethnic group		
Non-Hispanic Black/African American	38	90.5
Non-Hispanic Asian/Pacific Islander	32	76.2
Non-Hispanic White	36	85.7
Hispanic/Latinx	39	92.9
Native American	14	33.3
Study location in CA		
Entire State	26	61.9
Northern CA	6	14.3
Central CA	1	2.4
Southern CA	5	11.9
Other/Multiple Regions	4	9.5

3.2. Heat Impacts

Excessive heat has known negative health implications and extreme heat events are expected to become more frequent with continued global warming. Seventeen (17) articles studied the impacts of heat in California across racial and ethnic groups.

Figure 2. Heat study selection



3.2.1. Exposure

Dialesandro et al. evaluated inequalities in heat exposure by race/ethnicity and income in urban regions at greater risk from heat throughout the southwestern United States (Dialesandro et al., 2021). Land Surface Temperature (LST) was calculated from top -of-atmosphere radiance and surface reflectance using Google Earth Engine's Landsat 8 Operational Land Imager (OLI) Tier 1 imagery. LST was calculated for 20 metropolitan regions in southwest regions of the U.S. at the block group level and comparisons were made between the top and bottom decile groups based on racial/ethnic groups. Demographic data at the block group were from 2013-2017, 5-year American Community Survey (ACS), and included percent Black, Asian, and Latinx as well as median household income, among other variables. CA had the largest thermal exposure inequities compared to all other regions, likely due to differences in geography and vegetation. Neighborhoods with the highest Latinx population were more than 2 ^{o}C warmer than those neighborhoods with the lowest Latinx population when examining average and extreme heat days. While still greater than other regions, nighttime temperature inequities were closer to 1 ^{o}C. CA's neighborhoods with the greatest proportion of Black residents also had heat disparities, though the differences were not as large as for Latinx communities. Nighttime disparities were still higher than other non-CA regions, but less than average day or extreme heat day inequities.

3.2.2. Mortality

Two studies assessed impacts of heat exposure on mortality outcomes in CA. Basu and Ostro conducted a study to understand vulnerability to heat across population subgroups in nine CA counties that account for a majority of the state's population (Basu & Ostro, 2008). Average daily apparent temperature (heat index) was obtained from the National Climatic Data Center (NCDC) during the study period from May 1999 to September 2003 (*NOAA National Centers for Environmental Information. Climate Data Online*, n.d.). Daily mortality data and demographic information were from death certificates obtained from the CA Department of Health (CDPH), Health Data and Statistics Branch. Air pollutants were not considered as prior research from the authors had not shown them to be significant confounders or moderators. In general, there was a significant association between apparent temperature and mortality from all combined cardiovascular diseases. While there was an increased risk of mortality from heat in all racial/ethnic groups, the change was highest for the Black population, followed by White and a smaller, non-significant increased risk among the Hispanic group.

A study by Joe et al. evaluated the impact of a 2006 CA heat wave on excess deaths and mortality (Joe et al., 2016). The heat wave period included a 12-day heat wave and a 6-day lag period, in order to capture delayed impacts. Heat wave days were compared to reference days from the same summer. Death records were from the CDPH which provided demographic data and ICD-10 codes for all causes of death. In general, the authors found an excess of 582 deaths during the heat wave period, the majority of which occurred at home (66%). The greatest total mortality risk was among the Hispanic population who had a significantly greater relative risk compared to the White subgroup. The Black subgroup had the next highest risk of mortality, after Hispanics, with Asian/Pacific Islanders having the lowest risk. However, this pattern varied when looking at deaths that occurred at home specifically. The greatest mortality risk for at-home deaths was among Asian/Pacific Islanders, with Hispanic and White populations having similar relative risk. This change could be due to a greater proportion of Hispanic adults having outdoor/agriculture jobs that could increase their exposure during a heat wave. While the scope of this review was on peer-reviewed literature, it is worth mentioning a report published by the CDPH that quantified the excess mortality during a heat wave taking place in September 2022 (see report here: https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/Climate-Health-Equity/CDPH-2022-Heat-Wave-Excess-Mortality-Report.pdf)

3.2.3. Pregnancy and Birth Outcomes

Six of the heat studies included in this review examined adverse pregnancy and birth-related outcomes. Prior reviews, not exclusive to CA, have found positive associations between heat exposure during pregnancy and increased risk of stillbirth, low birth weight, and preterm birth (Bekkar et al., 2020; Syed et al., 2022). While the review by Bekkar et al. reported consistently worse pre-term birth outcomes for Black mothers, Syed et al. pointed out that many studies lack specific analyses across racial or ethnic groups.

For the current review, two studies evaluated the relationship between apparent temperature (heat and humidity) and preterm birth outcomes in CA from 1999-2006 and 1995-2009 (Basu et al., 2010, 2017). Data sources for temperature and humidity included the California Irrigation Management Information System (CIMIS) (*California Irrigation Management Information System, California Department of Water Resources*, n.d.) and the National Center for Environmental Information (NCEI) (*National Centers for Environmental Information, National Oceanic and Atmospheric Administration (NOAA)*, n.d.) for the CA warm season from May through September. Birth outcome and race/ethnicity data were captured from Kaiser Permanente Northern California's (KPNC) Electronic Health Records (EHR) and CA's Office of Vital Records birth certificate data. Preterm deliveries were those occurring before 37 weeks and excluded induced premature deliveries due to pregnancy complications. The studies included stratified analyses by maternal race/ethnicity group including: non-Hispanic white, non-Hispanic black, Hispanic, and non-Hispanic Asian (Basu et al., 2017). In both studies, a higher risk of preterm birth was observed during the warm season, compared to the cold season. One study found associations between increased temperature and preterm birth were highest for Black (24.60%) and Hispanic mothers (17.25%), compared to roughly 7% of births to White or Asian mothers (Basu et al., 2017). This population was insured, so access to healthcare may not explain differences in risk. The second study found elevated risk for all racial/ethnic groups, with Black mothers again having the highest risk, followed by Asian and Hispanic mothers. White mothers had the lowest risk.

A third study assessed the relationship between both heat events and wildfire smoke exposure with 85,806 preterm births in California (Ha et al., 2024). Preterm deliveries (from 20 to 37 weeks) from May to October of 2015 to 2019 were similarly obtained from the CDPH's Vital Records housed within the Center for Health Statistics and Information and included birth parent race/ethnicity. Both daily temperature and apparent temperature were used to define heat events. Meteorological data at the ZIP code level were calculated by interpolating GridMET (Gridded Surface Meteorological Data for Ecological Applications and Modelling) estimates to ZIP code centroids (Abatzoglou, 2013). Heat days were those exceeding the 90th, 95th, or 98th percentile of each ZIP code's annual temperature. Heatwaves were defined as ranging from two to four consecutive heat days. Heat days were positively associated with preterm births, with a 7% increase in odds within 2 days of a heat event. The odds of preterm birth increased to 19% among those concurrently exposed to smoke-related $PM_{2.5}$. There were no differences in associations across racial or ethnic categories.

Jiao et al. studied the relationship between heat exposure and premature rupture of membranes (PROM), which is a common condition in which the amniotic sac breaks early. PROM usually induces labor within 24 hours. The study was a retrospective analysis including 190,767 pregnant women with electronic health record (EHR) data from Kaiser Permanente Southern California (KPSC) during the warm season from 2008 to 2018.The study created 12 heatwave definitions based on daily maximum heat index and heatwave duration using Gridded Surface Meteorological (gridMET) data and the U.S. National Weather Service Heat Index algorithm. Pregnant women were categorized into exposed/unexposed groups for each heatwave definition. PROM and two PROM subtypes, (TPROM and PPROM), were diagnosed via obstetric exam. Race and ethnicity data were extracted from the EHRs. In general, there was a greater heatwave exposure among women who experienced PROM, compared to those who did not. They reported a 9-14% increase in adjusted risk of PROM for heatwave definitions 1-7. Results for more intense heatwaves (with higher temperature thresholds such as 99th percentiles) were less precise given the small sample size due to lower frequency. There were no significant differences by race/ethnicity in risk of PROM. However, the authors reported that Hispanic and non-Hispanic White mothers had greater positive associations between PROM and heatwave categories than other groups. This study did find a greater risk of PROM for those women exposed to higher PM2.5 levels during pregnancy.

Several studies assessed relationships between heat and other adverse birth outcomes. Basu, Sarovar and Malig studied 8,510 stillbirths during the warm season in CA from 1999 to 2009 (Basu et al., 2016). Temperature and humidity data were from CIMIS (*California Irrigation Management Information System, California Department of Water Resources*, n.d.), US Environmental Protection Agency (EPA) (*AQS Data Mart, United State Environmental Protection Agency*, n.d.), and National Climatic Data Center (NCDC) (*NOAA National Centers for Environmental Information. Climate Data Online*, n.d.). The authors additionally evaluated confounding by air pollutants using CARB data (*Air Quality and Emissions Data, California Air Resources Board*, n.d.). Information on stillbirths and maternal race/ethnicity were obtained from CDPH (*Data and Statistical Reports, California Department of Public Health*, n.d.). Stillbirths were included if they occurred during the warm season and there was a meteorological monitor within 10km of the mothers' residential zip code. Results were stratified by demographic factors, including maternal race/ethnicity. Overall, they found a roughly 10% increase in stillbirth risk with every 10°F increase in cumulative average temperature. Hispanic mothers had a significant increase in stillbirth. Asian mothers had lower risk compared to other racial and ethnic groups.

In a separate study, Basu et al. examined associations between apparent temperature and infant deaths during CA's warm season from 1999 to 2011 (Basu et al., 2015). Data to calculate mean apparent daily temperature, the exposure of interest, was from CIMIS, US EPA and the NCDC, as previously described. Only those cases from mothers living within 20km of a meteorologic monitor within their same climate zone were included in the analysis. Death certificates from CDPH provided data for all-cause mortality, and deaths from respiratory, circulatory, congenital malformations, abnormal gestation duration, and sudden infant death syndrome (SIDS), as well as infant race/ethnicity. In general, mortality risk from all causes, except SIDS, was elevated with positive change in apparent temperature. There were insufficient cases to do all subgroup analyses, and most results were imprecise, so results should be considered with caution. The greatest increase in risk was for respiratory or circulatory causes of death. The analysis revealed differences by race and ethnicity. Black infants had the greatest excess risk for all-cause mortality, gestation duration, and congenital malformations with increased apparent temperature, compared to other racial/ethnic groups. Increased apparent temperature was associated with increased risk from respiratory causes of death among White infants. There was a decrease in risk from gestation duration and an increased risk from congenital malformation with elevated apparent temperature, among Asian infants. The results did not show confounding or effect modification by exposure to the air pollutants studied.

Jhun et al. studied associations between ambient temperature and SIDS, the third leading cause of overall infant mortality (Jhun et al., 2017). Infant mortality data (deaths of infants less than 1 year) were collected for 210 US cities between 1972 and 2006 from the National Center for Health Statistics (NCHS). International Classification of Diseases (ICD) codes were used to identify SIDS cases. The National Oceanic and Atmospheric Administration (NOAA) airport weather stations provided daily, average, 24-hour outdoor air and dew-point temperatures from the airport closest to each city. Cities were stratified into clusters based on temperature and humidity characteristics with CA cities falling into 2 different climate clusters. Associations between temperature and SIDS were estimated for each season. Overall, a 10°F increase in temperature was associated with an increased risk of SIDS in the summer and a decreased risk in the winter. There was a greater SIDS risk for Black infants in the summer, compared to White infants (18.5% excess risk vs 3.6%, respectively). There were too few SIDS cases to observe associations among Asian/Pacific Islander or Native American groups. The study did not present racial/ethnic analyses for CA cities only. While this study includes CA cities and presents overall heat and SIDS results by climate cluster, the race/ethnicity analyses were not specific to CA.

3.2.4. Hospitalizations and Emergency Room Visits

Five papers included in this review examined the effects of heat on emergency room (ER) visits or hospitalizations. Basu et al. used a case-crossover design to assess the relationship between average apparent temperature and California ER visits (Basu et al., 2012) during the warm seasons from 2005 to 2008. Data to calculate mean apparent temperature were from CIMIS and the US EPA, as previously described. Temperature data were assigned from the closest monitor located within 10km of each ER case. Outpatient and inpatient hospital visits were identified from two data sources: the California Emergency Department Data and the California Hospital Patient Discharge Data. Discharge cases were limited to those hospitalizations that originated with an ER visit. Specific diagnoses and race/ethnicity data were collected from these datasets. Associations between heat and risk of ischemic heart disease, ischemic stroke, renal failure, and intestinal infections were greater in the Hispanic subgroup, compared to other race/ethnicities. The Black population had a decreased risk of dysrhythmia, compared to other racial/ethnic groups. The Asian population had stronger positive associations between heat and diabetes and dehydration, however heat was negatively associated with hypertension. No differences by race/ethnicity were observed for general respiratory and cardiovascular visits.

Knowlton et al. examined the impact of the 2006 CA heat wave on hospitalizations and ER visits to understand the impact across racial/ethnic groups (Knowlton et al., 2009). The authors defined the heat wave period as an 18-day window from mid-July to August 1, 2006, to capture events at the heat wave's onset and those occurring in the days after highest temperatures. Heat wave days were compared to an 18-day reference period during the same summer. Patient discharge data were provided by the CA Office of Statewide Health Planning and Development (now called California Department of Health Care Access and Information) (*Calif. Dep. Heal. Care Access Inf.*, n.d.) and ER visit records. The authors reported significantly increased rates of ER visits for all racial and ethnic groups, with the exception of Native American/Alaska Native and API groups. Rates were highest for Hispanic/Latino groups and unknown/unreported race/ethnicities. No increase in hospitalization rates were observed across racial/ethnic groups. Results were similar when looking specifically at ER visits for internal causes (excluding injuries and poisoning). There were largely elevated rates of ER visits for heat related illnesses in all racial/ethnic groups, again minus Native American/Alaska Native, with rate ratios ranging from 5.3 (Black) to 11.4 (API). Among Hispanic/Latino participants, rates of ED visits for acute myocardial infarction and ED visits and hospitalizations for cardiovascular diseases were increased. They found an increased rate of hospitalization for respiratory illnesses among the API group and ED visits for diabetes among Whites. There were no increases in rates of either among the African American population.

One paper investigated the impacts of heat on mental health-related ER visits in all 16 California climate zones (Basu, Gavin, et al., 2018). Data to calculate mean, minimum, and maximum apparent temperature from December 2004 through December 2013 were obtained from the EPA Air Quality System Data Mart (*AQS Data Mart, United State Environmental Protection Agency*, n.d.), CIMIS (*California Irrigation Management Information System, California Department of Water Resources*, n.d.), and NOAA (*National Centers for Environmental Information, National Oceanic and Atmospheric Administration (NOAA)*, n.d.). Daily ER visit, mental health diagnoses, and race/ethnicity data were abstracted from the CA Office of Statewide Health Planning and Development. Associations for individual climate zones and overall estimates were calculated. They found a 10ºF increase in apparent temperature was associated with significant increase in all mental health outcomes among White and Hispanic groups. During the warm season, White patients had significantly greater risk of all mental health visits, as well as those from all subcategories, including psychosis, neurotic disorders, self-injury/suicide, and inflicted injury/homicide. Hispanic populations had similar results with the exception of psychosis, where no association was observed. The Black subgroup had increased risk for suicide and homicide and not the other mental health outcomes. There were not enough cases for psychosis and neurotic visits among Asian patients to complete analyses, but no significant associations were found for self-harm or homicide in the warm season. In general, Hispanic patients had the greatest increases in risk compared to other groups.

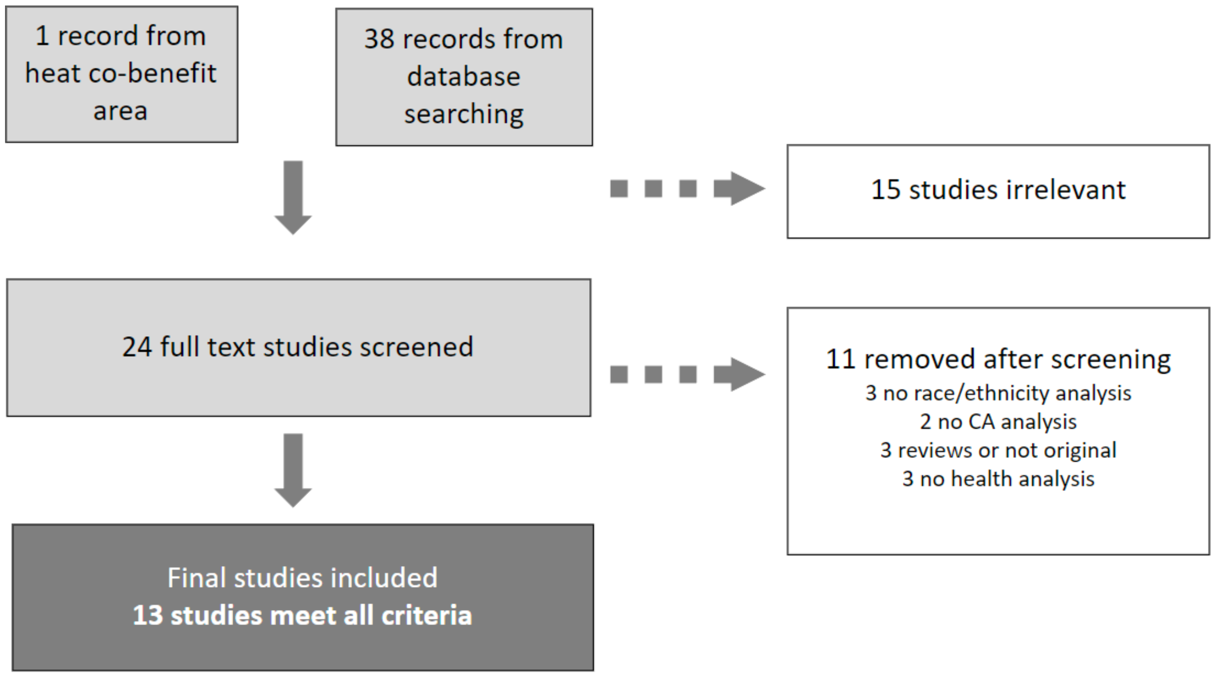
One study used a case-crossover design to assess the relationship between heat and morbidity related to drug use (Chang et al., 2023). Daily apparent temperature was calculated from temperature and humidity data obtained from Daymet Version 4 (Thornton, M.M., R. Shrestha, Y. Wei, P.E. Thornton, S. Kao, 2020), a system of automated surface meteorology stations across the US. Records of ER visits from 2005 to 2019, including race/ethnicity data, were acquired from the CA office of Statewide Health and Planning Department. ER visits included those discharged from the ER as well as those admitted to the hospital. ER visits related to amphetamine, cocaine, and opioid use and overdose were determined from ICD codes. Hispanic and White patients, in general, had increased odds of ER visits for amphetamine and opioid use and overdose on hot days. The White population had greater odds of cocaine overdose as well. Associations between heat and amphetamine use or overdose were significantly less among Black, compared to Hispanic, patients.

Finally, Malig et al. studied the relationship between temperature and hospitalizations related to liver, kidney, and urinary system morbidity from 1999 to 2009 in CA (Malig et al., 2019). Two data products were used to get complete temperature and humidity data for the study period. Temperature data were acquired from a model-based dataset from Maurer et al. (Maurer et al., 2002). The dataset uses meteorological data from NCEI first-order Automated Surface Observing System and the Cooperative observer (COOP) Summary of the Day (*Automated Surface/Weather Observing Systems (ASOS/AWOS), National Centers for Environmental Information, NOAA*, n.d.; *U.S. Daily Surface Data (COOP Daily/Summary of Day), National Centers for Environmental Information, NOAA*, n.d.). Relative humidity data were from the National Centers for Environmental Prediction (NCEP) North American Regional Reanalysis (Mesinger et al., 2006). Unscheduled admissions to acute care facilities in CA and race/ethnicity data were obtained from the Office of Statewide Health Planning and Development Patient Discharge Data. Both Non-Hispanic White and Hispanic groups had increased hospitalizations for the outcomes under study with a 10ºF increase in warm season temperatures. However, larger associations for hospitalizations for biliary tract disease, urinary tract infections (UTI), and septicemia were observed in Hispanic, versus Non-Hispanic White, patients.

3.3. Wildfires and Smoke Impacts

Wildfires produce fine particulate matter that has significant negative effects on morbidity and mortality throughout the U.S. Thirteen (13) studies assessed the impact of wildfires and smoke across racial and ethnic groups in CA.

Figure 3. Wildfire study selection



3.3.1. Exposure and Vulnerability

A study by Masri et al. aimed to understand how wildfire activity and impacts varied by socioeconomic factors across the state of CA (Masri et al., 2021). They used data from the California Fire and Resource Assessment Program (FRAP) (*Fire and Resource Assessment Program (FRAP), California Department of Forestry and Fire Protection*, n.d.) and National Interagency Fire Center (NIFC) (*National Interagency Fire Center*, n.d.) to calculate areas burned by wildfires from 2000 to 2020. Race/ethnicity were from 5-year American Community Service (ACS) data for all CA census tracts and included Hispanic, African American, Asian, Native American and immigrant non-native resident categories. They found rural areas had greater wildfire impacts over the study period and these areas tended to have a greater proportion of White and Native American populations. On average, more frequent wildfires and larger burn areas occurred in census tracts with a greater proportion of Native American residents. Conversely, there was a negative correlation between the percent of other minority groups, Black, Asian, Hispanic, or immigrant residents, with wildfire frequency and wildfire burn area. These groups tended to live in more urban areas, however the relationship was true for both urban and rural census tracts. Other socioeconomic factors, which tend to be highly correlated with race/ethnicity, indicated disadvantaged communities suffered worse consequences of wildfires so results should be interpreted with caution.

One study assessed exposure to $PM_{2.5}$ during the 2020 wildfires in the San Francisco Bay and Los Angeles County areas (Kramer et al., 2023). The authors utilized indoor and outdoor $PM_{2.5}$ data from the PurpleAir sensor network within a 30km radius of active fires in the study regions, which included some of the largest fires that season (*PurpleAir*, n.d.). The exposure data were interpolated to census tracts to understand exposure across demographic factors and environmental vulnerability. The CA Office of Environmental Health Hazard Assessment's (OEHHA) CalEnviroScreen 4.0 tool provided demographic data including the percentage of the population identified as White, African American, Hispanic, Asian American, Pacific Islander, or other (*CalEnviroScreen 4.0, California Office of Environmental Health Hazard Assessment, n.d.).* The largest and most consistent positive correlations between the wildfire period and PM2.5 levels were for areas with a higher percent Hispanic population in the LA County area. Areas with a greater proportion of African Americans were also associated with greater PM2.5 levels, while the percent non-Hispanic White was negatively correlated with particulate matter.

A study by Masri, Jin, and Wu sought to understand what communities are most impacted by the compound risk presented by both elevated temperatures and $PM_{2.5}$ concentrations across the state of California and what percentage of these compound risk days are due to nearby wildfires (Masri et al., 2021). The authors used gridMET temperature data from the University of California, Merced's Climatology Lab which utilizes Parameter-Elevation Regressions on Independent Slopes Model (PRISM) and North American Land Data Assimilation System Phase 2 data to calculate a census tract level estimate of daily maximum temperature (*GridMET, Climatology Lab, UC Merced*, n.d.). $PM_{2.5}$ data were from PurpleAir sensors from 2018 through 2020 (*PurpleAir*, n.d.). Data on area burned by wildfires in CA were from the California Fire and Resource Assessment Program (FRAP) and the National Interagency Fire Center (NIFC). Race and ethnicity data were from ACS 5-year estimates from 2018. In general, wildfires were strongly correlated to elevated PM2.5 and compound risk days. In multivariate models, percent Hispanic and African American residents was negatively associated with compound risk days per year, whereas several economic variables were related, like poverty rate, unemployment, and households without computers.

3.3.2. Pregnancy and Birth Outcomes

One study assessed the relationship between wildfire smoke exposure and over 3 million birth outcomes in CA between 2006 and 2012 (Heft-Neal et al., 2022). NOAA's HMS Fire and Smoke Product was used to gather smoke plume boundary data which was combined with surface $PM_{2.5}$ concentration estimates from machine learning algorithms (*Daily and Annual PM2.5 Concentrations for the Contiguous United States, 1-Km Grids, v1 (2000 – 2016), Socioeconomic Data and Applications Center (SEDAC)*, n.d.; Hu et al., 2017; Park et al., 2020; Reid et al., 2021). These algorithms utilize inputs from multiple sources including satellite and ground monitor observations, and chemical transport model predications. Birth outcomes and mother's race/ethnicity were determined from CA Department of Health birth certificates and preterm birth was determined based on gestational age. Births and smoke exposures were assigned to the mother's residential zip code. In terms of exposure, the authors found differences in total $PM_{2.5}$ and wildfire smoke exposures by race/ethnicity. Black, Hispanic and Asian mothers who lived in below-median income zip codes had higher *total* $PM_{2.5}$ exposure compared to White mothers of similar income. However, White mothers living in low-income areas had much greater *smoke-specific* $PM_{2.5}$ exposure, compared to Black or Asian mothers in low-income areas. Overall, every additional day of wildfire smoke exposure was associated with an increased risk of preterm birth, with greater risks for higher intensity smoke days, with no differences across racial/ethnic groups. While not significantly different from other racial/ethnic groups, the absolute change in preterm birth risk was higher than other groups for Black mothers.

One study, described in Section 3.2.2, assessed the relationship between heat and wildfire smoke events with 85,806 preterm births in California (Ha et al., 2024). Preterm deliveries (from 20 to 37 weeks) from May to October of 2015 to 2019 were obtained from the California Department of Public Health Vital Records and included birth parent race/ethnicity. Daily $PM_{2.5}$ concentrations from wildfire smoke were estimated following previously published methods (Childs et al., 2022). Smoke days were from satellite-based plume identification linked to $PM_{2.5}$ data from US Environmental Protection Agency (EPA) monitoring stations. Machine learning models estimated smoke-related $PM_{2.5}$ concentrations for each ZIP code (Childs et al., 2022). A wildfire day was defined as any day with greater than zero wildfire smoke $PM_{2.5}$ concentration. Additionally, days exceeding the 95th and 98th percentile of smoke $PM_{2.5}$ across the state were classified as smoke days. Overall, there were positive associations between smoke days and wildfire $PM_{2.5}$ concentration, as a continuous variable, and preterm birth. Effects were strongest within four days of smoke exposure. Associations between continuous $PM_{2.5}$ concentrations and preterm birth were stronger among non-White mothers, including Black, Hispanic, Asian and American Indian groups. No differences across racial/ethnic groups were observed for categorical classification of days with >98th percentile statewide smoke distribution.

3.3.3. Emergency Department and Clinic Visits

Multiple studies have assessed the relationship between wildfire smoke pollution and emergency department (ED) or hospital visits. Liu et al. investigated associations of smoke wave days (days with high pollution from wildfires) and respiratory hospital admissions among older adults in 561 counties across the western US between 2004 and 2009 (Liu et al., 2017). Counties were aggregated into four regions, including one for California. $PM_{2.5}$ was estimated at the county-level using Global Fire Emissions Database (Van Der Werf et al., 2010) and the GEOS-Chem (version v9-01-03) global chemical transport model (*GEOS-Chem (Version v9-01-03)*, n.d.). Monitoring data from the EPA were used to calibrate estimates to be specific to wildfire sources (*Environmental Protection Agency Pre-Generated Data Files. Daily Summary Data:PM2.5 FRM/FEM Mass (88101) 2004-2009*, 2010). The sample was comprised of Medicare enrollees in the states under study, allowing for capture of self-reported race/ethnicity data (Black, White, or other). They found that CA had the highest number of annual smoke wave days (~4 per year) compared to other regions and 99% of the California sample were exposed to at least one smoke wave. The racial/ethnic analyses were conducted across the full sample and thus not specific to CA. However, they reported a greater proportion of Black and other, non-White racial/ethnic groups experienced at least 1 smoke wave day compared to White enrollees. Black older adults were found to have a greater risk of hospital admissions for respiratory issues with smoke exposure, compared to White older adults.

Heaney et al. investigated the relationship between smoke-specific $PM_{2.5}$ and cardiorespiratory hospital visits during the wildfire seasons of 2004 to 2009 in CA (Heaney et al., 2022). Daily wildfire $PM_{2.5}$ data were generated using meteorological data from the Goddard Earth Observing System (GEOS-5) and the Global Fire Emissions Database using the GEOS-Chem (v9-01-03) chemical transport model framework (*GEOS-Chem (Version v9-01-03)*, n.d.; *Goddard Earth Observing System (GEOS-5)*, n.d.). The CA Office of Statewide Health and Development provided daily, county-level records of hospital visits during the study period, which included race and ethnicity data. Health outcomes of interest included all respiratory and cardiovascular diseases as well as selected disease subgroups. Hospital visits and wildfire pollutant data were matched at the county level. Analyses revealed smoke event days were positively associated with hospitalizations for all respiratory visits among both non-Hispanic White and Hispanic individuals. Smoke event days were associated with acute respiratory infection hospitalizations among Hispanics and COPD hospitalizations among White individuals. For cardiovascular outcomes, positive associations between smoke days and all cardiovascular disease and ischemic heart disease were observed among White individuals. Black and White patients additionally had an increased risk of heart failure hospitalizations on smoke event days. Notably, heat modified the relationship between smoke events and cardiovascular outcomes, with worse outcomes on days with both elevated $PM_{2.5}$ and heat.

A study by Thilakaratne et al. similarly examined disparities in cardiorespiratory ED and hospital visits associated with $PM_{2.5}$ and wildfire smoke in CA from 2008 to 2016 (Thilakaratne et al., 2023). Daily, average $PM_{2.5}$ concentrations for wildfire smoke and non-smoke affected days were obtained from a previously developed model (Alexeeff et al., 2015; Di et al., 2019). Smoke days were derived from National Oceanic and Atmospheric Administration Hazard Mapping System (HMS) Fire and Smoke product (*Hazard Mapping System Fire and Smoke Product, Office of Satellite and Product Operations, NOAA*, n.d.). ED visits, hospital admissions, and race/ethnicity data from January 1, 2008, through December 2016 were captured from the CA Department of Health Care Access and Information (HCAI). Overall $PM_{2.5}$ exposure was associated with an increased risk of asthma and respiratory ED visits and hospitalizations among all groups, but the greatest increase in risk was observed among Asian and “other” race/ethnicity (which included multiracial individuals). No differences in the risk of cardiovascular visits were found by race/ethnicity. With regard to smoke-related $PM_{2.5}$, Black and Native American individuals had the highest morbidity burden.

A study by Reid et al. examined differential impacts of wildfire air pollution on respiratory heath across racial/ethnic groups. Data were included for all zip codes with more than 100 people that were impacted by the wildfires in Northern CA from June 20 to July 31st, 2008. Machine learning models (Reid et al., 2015; Watson et al., 2019) were used to estimate 24-hour $PM_{2.5}$ and ozone for each zip code. Daily ED visits and hospitalizations were obtained from CDPH Environmental Health Investigations Branch for respiratory outcomes including asthma, COPD, pneumonia, acute bronchitis and acute respiratory infections. The heat index was calculated using temperature and humidity data from the Rapid Update Cycle model (replaced by the Rapid Refresh (RAP) (*Rapid Refresh/Rapid Update Cycle, National Centers for Environmental Information, NOAA*, n.d.), as a covariate. Racial composition at the zip code level was determined from the 2000 Census as an effect modifier. The American Indian, Alaska Native, Native Hawaiian, and other Pacific Islander populations were too small for inclusion. The study found the percentage White population was positively associated with $PM_{2.5}$ levels. Ozone concentrations during the wildfire period were also higher in zip codes with more White and Hispanic residents, compared to Black or Asian individuals. This is somewhat contrasting with prior studies. While they did not find clear heterogeneity in the relationship between wildfire-period $PM_{2.5}$ nor O_3 and respiratory hospitalizations or ED visits by race or ethnicity, the proportion of Hispanic or Latino residents was most consistently associated with asthma hospitalizations.

A study by Chen et al. investigated the relationship between smoke events during the CA wildfire seasons (June to December, 2016-2019) and ED visits for cardiovascular, diabetes, respiratory, and mental health outcomes (Chen et al., 2023). Daily mean total and wildfire specific $PM_{2.5}$ concentrations at the zip code tabulation area (ZCTA) were obtained using machine learned algorithms incorporating land use, satellite and meteorological data and aggregated into CA air basins (regions with similar air quality characteristics). Smoke events for air basins were identified from Hazard Mapping System data that identified wildfire $PM_{2.5}$ levels equal to or greater than the 98th percentile (Schroeder et al., 2008). ED visits and race/ethnicity were determined from CA Department of Health Care Access and Information's Emergency Department Data and Patient Discharge Data (*Calif. Dep. Heal. Care Access Inf.*, n.d.). Smoke events were associated with a significantly increased risk of diabetes-related ED visits among Hispanic, compared to White patients. While imprecise, Black and API groups also had an elevated risk of diabetes ED visits. API patients had a lower risk of anxiety-related ED visits, compared to the White sample. Black patients tended to have a greater change in risk for acute myocardial infarction and dysrhythmia visits, compared to other race/ethnicity groups, though differences were not statistically significant.

One study analyzed associations between particulate matter of less than 10 microns (PM_{10}) from wildfire smoke and clinic visits for numerous health conditions specifically among a Native American population living on the Hoopa Valley Indian Reservation (Lee et al., 2009). Wildfires bordering the northern-CA reservation in the late summer of 1999 led to increased exposure to smoke pollutants. PM_{10} data were from a monitor on the reservation that collects hourly observations. Data on asthma, circulatory-only illness, respiratory-only illness, headache, diabetes, and coronary artery disease visits during the fire were obtained from the medical clinic on the reservation. Visits during a 12-week fire period were compared to visits made during the corresponding dates in the prior year. The authors found PM_{10} level significantly predicted visits for headache, asthma, and coronary artery disease.

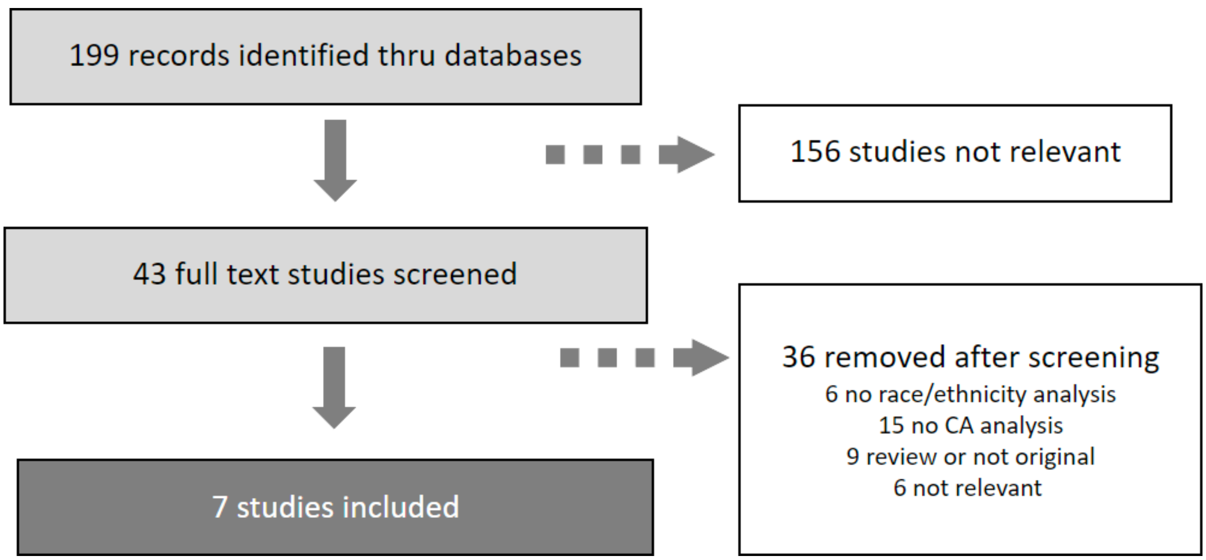
3.3.4. Mental Health Outcomes

One article studied whether wildfire-related thoughts modified the relationship between three risk factors for poor adjustment to trauma (gender, race/ethnicity and disaster impact) and mental and physical outcomes (Scher & Ellwanger, 2009). The study sample consisted of 200 university students who were impacted by wildfires in Southern California in 2003 that burned on and around California State University, San Bernadino. Students provided demographic information and answered survey items about the fire's impact on their lives, cognitions after the fire, and anxiety symptoms, depressive symptoms, and physical symptoms/ medical visits immediately after the fire and again 6-months later. The Fire Impact Questionnaire was developed by the author for the study. The Posttraumatic Cognitions Inventory was used to assess students' thoughts after experiencing the fire trauma (Foa et al., 1999). They found that, compared to minority students, Non-Hispanic White participants had greater anxiety symptoms when negative cognitions related to the fire were high. Similarly for physical symptoms, White students reported more physical symptoms with high negative fire-related cognitions, compared to minority students.

3.4. Mobility and Physical Activity

We included 7 studies related to various aspects of physical activity or mobility and climate change.

Figure 4. Mobility and physical activity study selection



3.4.1. Parks

Winter et al. studied urban park usage and ozone exposure in the City of Los Angeles, CA during August and September of 2015 (Winter et al., 2019). Observations were collected on 24 days in two economically advantaged and two disadvantaged communities for both coastal and inland areas. Ethnicity (Latino, Black, Asian, White, Other), age, and physical activity (sedentary, walking, vigorous) were assessed through direct observation by study team members using SOPARC protocols (Mckenzie et al., 2006). Ozone was concurrently captured by field observers through passive monitoring badges worn during data collection periods. The ozone dose measure was determined by combining the average hourly ozone level (in parts per billion (ppb)) multiplied by metabolic expenditures (METS). Physical activity classifications were assigned METS according to established approaches (Ainsworth et al., 2000). Latino park users were the primary racial/ethnic group observed in the parks in disadvantaged neighborhoods, while White park users were the majority in affluent neighborhoods. They found Latino park users had greater ozone exposure, compared to all other racial or ethnic groups and ozone dose exposure was overall higher in parks in disadvantaged communities, especially those that were inland. Latino park users also engaged in more sedentary activity, compared to other racial groups, with Asian park visitors being the most active.

3.4.2. Transitioning to Zero Emissions Vehicles (ZEVs) and e-Bikes

Transportation contributes more than 40% of GHG emissions in the state of CA. Transitioning to ZEVs and e-bikes is expected to mitigate emissions contributing to climate change and also generate health co-benefits by reducing exposure to air pollution, especially in disadvantaged communities.

A study used ZEV purchasing data from 2015 to 2020 in CA to analyze adoption trends in both disadvantaged and non-disadvantaged communities, as defined by the CalEnviroScreen criteria, and to project future changes in 2035 (*CalEnviroScreen 4.0, California Office of Environmental Health Hazard Assessment*, n.d.; Yu et al., 2023). Disadvantaged communities are those facing the most risk from various pollution sources and also tend to have a greater proportion of racial and ethnic minority groups. The authors used the Southern California Association of Government's (SCAG) activity-based travel demand model to predict electric-vehicle miles travelled (eVMT) at the roadway level in Los Angeles County. ZEV ownership was determined through vehicle registration data from the CARB Fleet Database (*Fleet Database, California Air Resources Board*, n.d.). Future ZEV adoption in 2035 was estimated using the EMFAC2021 v1.0.2 growth model, using ZEV ownership data from 2015 and 2020 (*EMIssion FACtor (EMFAC), California Air Resources Board*, n.d.). ZEV ownership and eVMT in Los Angeles County were analyzed at the census tract level by racial/ethnic group. They additionally estimated census tract $PM_{2.5}$ and nitrogen oxides (NOx) concentrations related to eVMT using the EPA's R-LINE V1.2 model (Snyder et al., 2013). Hourly surface level meteorological data were obtained from the NCEI in the Integrated Surface Dataset (*Surface Meteorological Data, National Centers for Environmental Information (NCEI)*, n.d.) and upper air data from the National Oceanic and Atmospheric Administration Radiosonde Database (*NOAA/ESRL Radiosonde Database, National Oceanic and Atmospheric Administration*, n.d.) near the Los Angeles International Airport. They found both White and Asian American/Pacific Islander populations had higher ZEV ownership and eVMT share, relative to their population proportion. At 26% of the total population, White individuals owned 45% of ZEVs and had more than 30% of total eVMT. The opposite was true for Hispanic groups whose ZEV ownership share (26%) was almost half of its population share (48% of population). However, eVMT among the Hispanic population was almost equal to the population proportion, perhaps because of greater driving distances. African Americans also had lower eVMT and ZEV ownership relative to their population proportion. These patterns were similar in both disadvantaged and non-disadvantaged communities, indicating differences in purchasing behaviors. At baseline, concentrations of traffic-related air pollutants were twice as high in disadvantaged communities. With expansion of ZEVs through 2035, disparities between disadvantaged and advantaged communities in traffic-related $PM_{2.5}$ and NOx were projected to remain, though the gap in pollution exposure between communities would decrease. Given that ZEVs travel through disadvantaged communities, even if disparities persisted in ownership, these communities would benefit from greater ZEV usage overall. However, the authors warned that medium and heavy-duty trucks are more prevalent in disadvantaged communities and responsible for traffic-related pollution, which could limit any future reduction in disparities.

Another recent study by Hennessy and Syal similarly evaluated equity in the transition to electric vehicles in CA (Hennessy & Syal, 2023). They evaluated the distribution of battery electric vehicles (BEVs), as they are most promising for climate mitigation, usage of state electric vehicle incentives, and how these relate to redlined neighborhoods. Department of Motor Vehicle (DMV) data on light-duty vehicle registrations by fuel type from 2010 to 2020 were obtained from the Center for Sustainable Energy (*Zero Emission Vehicle and Infrastructure Statistics - Collection, California Energy Commission*, n.d.). Rebates given between the same period for hybrid and electric vehicles were from the Clean Vehicle Rebate Project (CVRP) (*California Air Resources Board Clean Vehicle Rebate Project, Rebate Statistics, Center for Sustainable Energy*, n.d.). Both datasets were matched to ZIP code level demographics from the American Community Survey 5-year estimates for 2019 (US Census Bureau, n.d.). The University of Richmond's Mapping Inequality project provided historical redlining maps (*Mapping Inequality: Redlining in New Deal America, University of Richmond*, n.d.) The analyses compared ZIP codes classified by the racial and ethnic majority population and presented the proportion of light duty vehicles that were BEVs. Overall, BEV adoption was less than 3% for all racial/ethnic groups and penetration, as well as disparities by race/ethnicity, were generally higher in high-income ZIP codes. Regardless of income, Asian-majority ZIP codes had the highest penetration of BEVs and Latino populations the lowest. Adoption of BEVs over time grew the most in high-income Asian and White-majority ZIP codes, though high-income Black ZIP codes also showed increases. Predominantly Latino ZIP codes show the slowest growth. Similarly, disparities in BEV rebate distribution were greatest in high income ZIP codes, with Asian-majority, followed by White-majority ZIP codes, having the most rebates per capita. BEV penetration and rebate usage were three and five times greater in areas that had been classified as "Best" versus "Hazardous" in historical redlining maps. In general, there were fewer differences in BEV rebates or penetration observed across racial and ethnic groups in low-income ZIP codes, indicating income is likely universally restrictive of BEV purchasing. In higher-income areas, certain racial and ethnic groups appear to be benefitting from rebates and participating in the BEV transition than others. As reported previously, this inequitable adoption has implications for air quality in these communities.

Another study similarly evaluated the impact of three Northern California e-bike rebate programs on travel behaviors, transportation-related GHG emissions, and program participation across demographic factors (Johnson et al., 2023). The programs differed in their incentive structure, providing after purchase rebates or point of sale discounts, and the value of the incentive payment. There were also eligibility requirements for participation based on residency in a certain geographic area, age, and income status. Demographic information and travel behavior was collected from participant surveys. Overall, they found the program resulted in more regular bike use and the replacement of car trips with e-bikes, though biking frequency declined over time. They estimated a reduction of 12-44kg of CO_2 per participant. Racial and ethnic analyses were limited to understanding who participated in and benefited from the program, compared to surrounding regional demographics. Rebate program participants were predominantly White (ranging from 65% - 92% of participants), followed by Asian (8% to 21%). The proportion of White rebate participants was greater than the White population in surrounding areas, from Census estimates (*Census Bureau Data Tables, U.S. Census Bureau*, n.d.). In one program only, Hispanic adults were overrepresented in the rebate program, relative to the surrounding community. The sample was also more highly educated, older, and had more male representation than the study area population. This disparity persisted even in the programs that limited participation to low-income populations, indicating that other measures are needed to ensure equitable participation and benefit.

3.4.3. Transportation Planning

One study built on an existing health impact assessment tool to assess impacts of transportation plan alternatives (Wu et al., 2019). The Integrated Transport and Health Impacts Model (ITHIM) has been widely used to model potential health impacts from increased active transportation scenarios (Maizlish et al., 2013), however had not previously included analyses across demographic strata. The authors utilized a simulated travel behavior dataset from SACSIM15, an activity-based travel demand model developed by the Sacramento Area Council of Governments (SACOG) (*Travel Demand Model, SACOG*, n.d.). They estimated current travel behavior as well as three alternative travel behavior scenarios and the resulting changes in health outcomes due to physical activity and traffic injuries. Travel behaviors were estimated for the alternative scenarios with increasing levels of transit service, bus lines, bike and pedestrian investments, housing/employment density, and decreased spending on roadways. Data inputs included health, physical activity, transportation, and traffic-related injuries from a variety of sources. All-cause mortality across racial groups was calculated using data from the CDPH vital statistics dataset (*Vital Records Data and Statistics, California Department of Public Health*, n.d.). The health burden from physical activity, traffic injuries, mortality and disability-adjusted life years (DALYs) was obtained from the Global Burden of Disease (GBD) database (*Global Burden of Disease, Institute for Health Metrics and Evaluation (IHME)*, n.d.). The California Health Interview Survey (CHIS) was used to capture non-transportation related physical activity (UCLA Center for Health Policy Research, n.d.) and transportation-related physical activity was estimated using the SACSIM model. Data on traffic injuries were captured from the Statewide Integrated Traffic System (SWITRS) (California Highway Patrol, 2013), which was geocoded using the Transport Injury Mapping System (TIMS) (*Transportation Injury Mapping System (TIMS), UC Berkeley*, n.d.). Compared to the base year, conditions under the adopted

2016 Regional Transportation Plan were estimated to result in fewer deaths due to physical inactivity in both White and minority groups. However, this benefit was offset in the near term by an increase in traffic injuries due to more active travel. Over time, as models estimated more people would begin to use active travel modes and to drive less, the risk of traffic deaths decreased. Differences in health benefits were observed when comparing the three alternative transportation planning scenarios. Communities of color were estimated to have a greater reduction in death risk, largely due to a larger increase in physical activity from active travel, compared to the White population. They also reported low-income groups would experience greater reductions in risk of death due, again, to larger increases in active travel among these groups, compared to higher income populations.

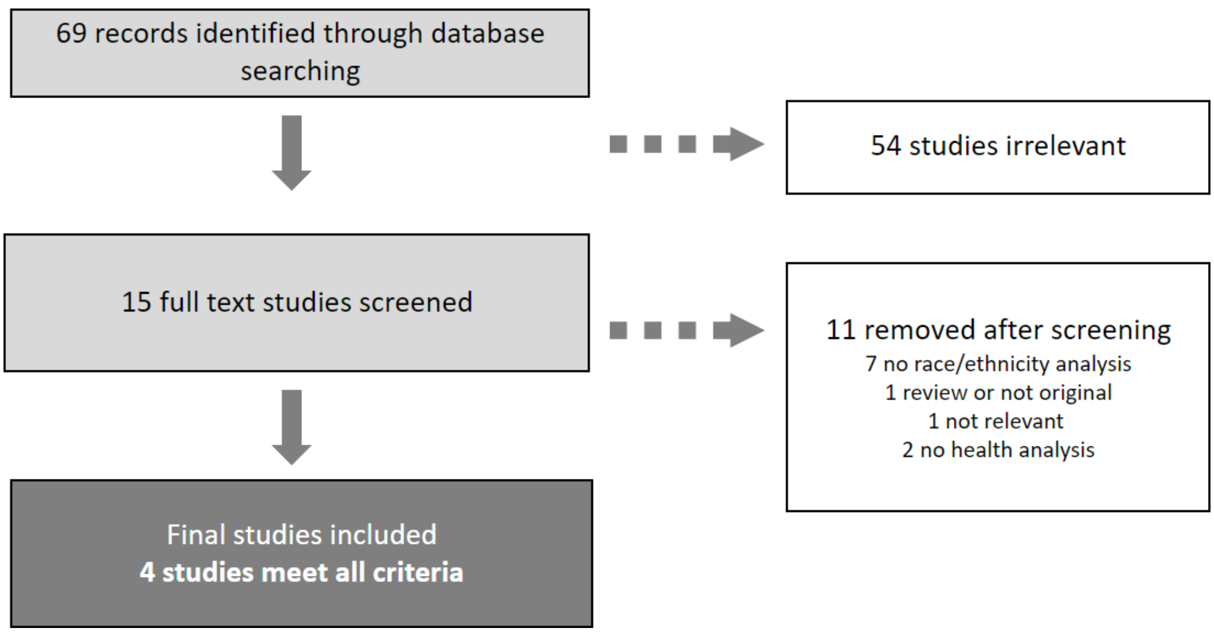
One study aimed to quantify potential bias in air pollution exposure estimates that only consider static air pollution concentrations near someone's home. Instead, they estimated personal exposure by incorporating simulated mobility data along with $PM_{2.5}$ monitoring data in Los Angeles County, CA (Lu, 2021). Individual weekday daily activity, travel behaviors, and race/ethnicity for every person living in six Southern CA counties were modeled using the activity-based model (ABM) developed by the Southern California Association of Governments (SCAG) (Bhat et al., 2013). These data were validated using American Community Survey (ACS) and Census data to ensure the ABM was accurately predicting trip purpose and population characteristics. Hourly ground-level $PM_{2.5}$ concentrations were estimated with a model using PurpleAir sensor data and a random forest algorithm developed for LA County (Lu et al., 2021; *PurpleAir*, n.d.). A dynamic exposure measure was created by linking someone's daily movement to corresponding hourly $PM_{2.5}$ concentrations in those locations. Overall, they found that the static relative risk estimates would be underestimated by 13%, when individual mobility is not considered. They found minority racial or ethnic workers tended to live in more highly polluted areas, compared to White populations, and be exposed to greater $PM_{2.5}$ levels overall. However, using a static measure likely *over*estimates their $PM_{2.5}$ exposure among a working population that travels outside their residential area. The converse was true for White residents who lived in less polluted areas and worked in more polluted areas. Thus, the static measure *under*estimated their overall exposure. The difference in $PM_{2.5}$ exposure between White and minority groups would likely decrease if dynamic exposure measures were to be used, providing a better exposure estimates for planning purposes.

A study by Patterson and Harley examined change in neighborhood demographics and air pollution exposure related to a freeway rerouting in West Oakland, CA (Patterson & Harley, 2019). West Oakland, despite being a redlined neighborhood, was one in which African Americans were succeeded in buying homes. A freeway that had bisected the West Oakland neighborhood was destroyed in an earthquake in 1989 and community members successfully advocated for the freeway to be rerouted, and the existing route converted to a landscaped boulevard, called the Mandela Parkway. The paper assessed two scenarios; one which the freeway was rebuilt in its existing location (rejected) and the rerouting of the freeway around the neighborhood (selected). Traffic count data, including vehicle counters and manual truck counts, were from the West Oakland Truck Survey in 2008 and used to model hourly traffic volumes (*Bay Area Air Quality Management District. West Oakland Truck Survey.*, n.d.). Roadway link-specific counts for annual average daily traffic and truck counts for the rerouted freeway were from the California Department of Transportation. These were converted into hourly estimates using previously described methods (McDonald et al., 2014). The EMFAC model was used to calculate vehicle emissions from traffic volumes. The RLINE model predicted near-roadway air pollutant concentrations within 250m of the Mandela Parkway and freeway reroute using meteorological data from the National Weather Service modeled in AERMET (Cimorelli et al., 2005). West Oakland demographic information over time, including race/ethnicity, median household income, education and poverty levels, were from 1990 and 2010 Census and the 2006 to 2010 ACS and linked to 2010 census tract shapes (Manson, S.; Schroeder, J.; Riper, D.V.; Ruggles, n.d.). Demographic estimates for the area surrounding the Mandela Parkway were calculated and compared to the greater West Oakland neighborhood to assess the impact on the boulevard on gentrification. Results indicated the decision to reroute the freeway resulted in large reductions in nitrous oxide and black carbon emissions in central West Oakland, an area which prior to the new parkway was 93% people of color. The Mandela Parkway that replaced the freeway was linked to far lower emissions due to lower traffic volume and fewer heavy trucks. Median home values along the Mandela Parkway were initially lower compared to all of West Oakland. After the greenway was built, however, this reversed and home values along the Parkway were significantly higher compared to West Oakland. Over this same period, there was a significantly greater reduction in the Black population and residents living in poverty in the area surrounding the Mandela Parkway, compared to West Oakland as well as an increase median household income. In sum, the rerouting succeeded in reducing traffic-related emissions in the West Oakland center, compared to if the freeway had been rebuilt in the previous alignment. However, the improvement from the Mandela Parkway may also have contributed to displacement of the historical Black community and an increase in property values.

3.5. Urban Greening

Four (4) studies assessed associations of greenspace exposure with birth outcomes and various behavioral and academic outcomes among children and adolescents.

Figure 5. Urban greening study selection



A study by Gailey examined whether an increase in residential greenspace exposure was associated with positive birth outcomes (Gailey, 2023). The study sample included mothers who had a minimum of two births and did not relocate during the period between 2005 and 2015 in order to reduce potential bias from residential self-selection (i.e. that concept that healthier mothers selectively move to greener neighborhoods). Comparing longitudinal relationships between greenspace and birth outcomes between siblings was also designed to control for unmeasured characteristics that could bias analyses. Information on births, infant and maternal health and race/ethnicity were from the CDPH Birth Cohort Files. The outcomes of interest were infant birth weight and small-for-gestational age (SGA). Census tract level greenspace data (NOAA Climate Data Record NDVI) were linked to maternal residential address at the time of birth. Results indicate that a greater proportion of non-Hispanic White mothers lived in areas with high levels of greenspace, compared to Black mothers. Conversely, a greater proportion of Black mothers (38%) lived in areas with the least greenspace, compared to 17% of White mothers. The study found that increased residential greenspace was associated with higher birthweight (a positive outcome) only among Black infants. No associations between greenspace and birthweight were observed among Hispanic, Asian, or White mothers and there were no significant associations with SGA. This differential effect may be due to Black mothers facing greater health risks, like stress and environmental pollution exposure, which may be reduced by exposure to greenspace.

One prospective study examined aggressive behaviors of nearly 1,300 Southern California twins and triplets between the ages of 9 to 18 who were part of the Risk Factors for Antisocial Behavior (RFAB) study (Younan et al., 2016). Residential information was collected and geocoded throughout the study and residential greenspace was determined using Normalized Difference Vegetation Index (NDVI) data from the Global Agriculture Monitoring Project (Center for Global Agricultural Monitoring Research, n.d.). The data were normalized to values between 0 (very sparse) to 1 (dense vegetation). They averaged NDVI values in buffers ranging from 250 to 1000 meters around each participants' residence to compute neighborhood greenspace measures and calculated both short and long-term exposures. Parents completed the Aggressive Behavior subscale of the Child Behavior Checklist (CBCL/6-18) as a measure of adolescents' aggressive behavior in the 6-month period preceding the assessment (Achenbach, n.d.). In general, a reduction in aggressive behavior was found in relation to both short and long-term exposure to greenspace using a 1,000m residential buffer. While White participants were more likely to live in areas with greater vegetation compared to Hispanic, African American, or multiple race individuals, they did not find any differences in the relationship between greenspace and aggressive behaviors by racial/ethnic categories.

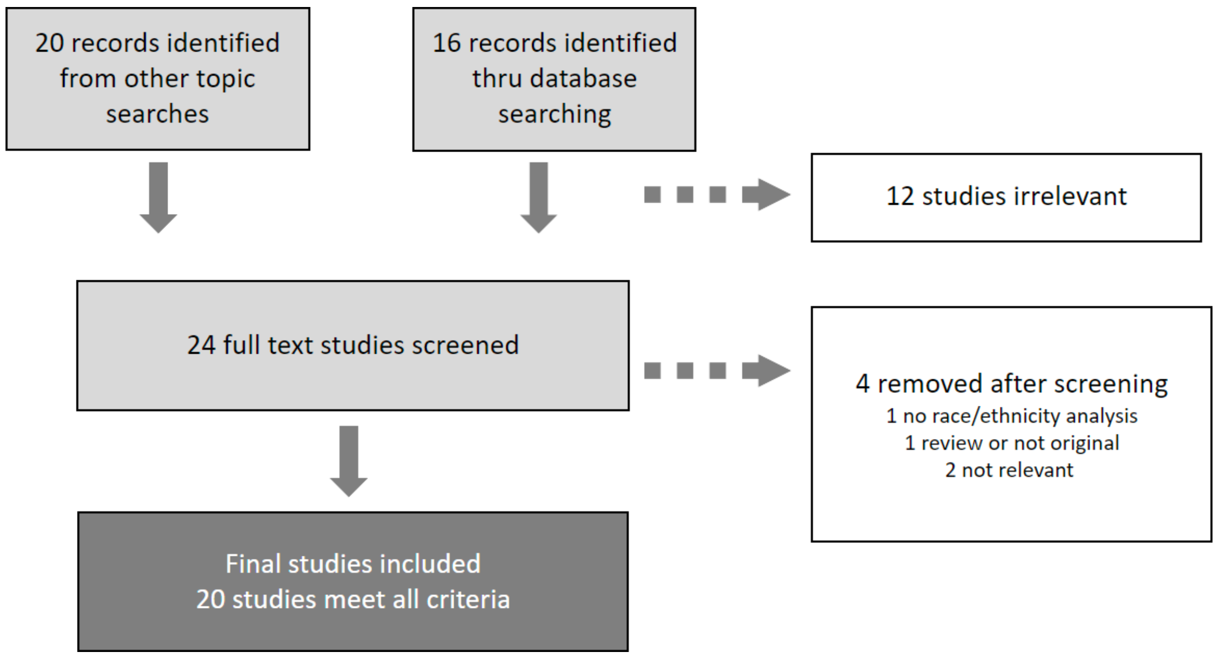
Another study examined correlations between vegetation surrounding schools and standardized test scores in a large sample of elementary schools in 2012 (Tallis et al., 2018). NDVI data were obtained using 1 meter resolution aerial photos from the US Department of Agriculture National Agriculture Imagery Program (NAIP). They used several different buffer sizes around the schools ranging from 10m to 1000m and created additional variables to capture greenness from agricultural fields and greenery on/around school campuses. The period from April to July 2012 was selected to capture standardized testing dates in the state of CA. Student achievement was assessed a combined score on California's standardized testing (STAR) data, in science, English and mathematics (California Department of Education, n.d.). STAR data for 495 selected schools provided information on the schools as well as race/ethnicity information. From these data, they created a variable capturing ethnic diversity as well as the proportion of non-White or non-Asian students for each school. Overall, they found positive associations between tree and shrub coverage within 750m and 1000m and fifth grade standardized testing scores in urban schools only. However, the largest impact was observed between the percentage of minority race/ethnicity students was the most impactful factor on test scores, with significant reductions in test scores as minority representation increases.

A study by Rahai, Wells, and Evans examined greenspace as a potential moderator of associations between literacy programs and test scores in a sample of minority elementary school students (Rahai et al., 2023). The sample was drawn from students who participated in a statewide literacy improvement program in CA between 2012 and 2020. The outcome of interest was improvement in reading scores, assessed by the Rigby PM Ultra Benchmark test taken at program enrollment and exit time points. The exposure of interest was the number of reading tutoring sessions students received. The authors calculated the percentage of greenspace both within the school boundary and in a 25m buffer around the school. Data on school parcels were obtained from tax parcel data by the California School Campus Database (*California School Campus Database*, n.d.). Greenspace coverage was determined from land classification data from Earthdefine LLC (*Earthdefine LLC*, n.d.). Students' race/ethnicity was from parent-reported data. They did not analyze effects across race/ethnicity categories; however, the sample was comprised of mainly Hispanic (70%), Black (14%) and Asian (7%) students, with White students making up only 5% of the population. They found greater improvements in reading associated with literacy interventions in schools with more greenspace.

3.6. Children's Health and Development

Twenty (20) studies examined the impacts of climate change on children's health and development. Most of the studies pertained to heat and wildfire smoke exposures and were reviewed under the previous two sections. As such, the data sources will not be described again as they are included in Sections 3.2 and 3.3 and the compilation data source table in Section 3.10. New studies included impacts of urban greening on child-related outcomes and are described in full. It should be noted that all studies lacked race/ethnicity-specific analyses within age groups.

Figure 6. Children's health study selection



3.6.1. Heat Exposure

Ten studies assessed relationships between heat exposure and birth and child outcomes. One study examined relationships between apparent temperature and nearly 60,000 preterm births across 16 counties in CA from 1999 to 2006 (Basu et al., 2010). Risk was increased in all racial/ethnic groups, with the greatest percent change observed among Black, then Asian, Hispanic, and White mothers. The difference in percent change in risk between Black and White mothers, however, was not significant. Similarly, a study of associations between temperature and full-term low birth weight found Black mothers, followed by White mothers, had the greatest increased odds of low birth weight outcomes (Basu, Rau, et al., 2018). Odds among Asian and Hispanic mothers were also elevated, though not statistically significant. Jiao et al. found an increased risk of premature rupture of membranes (PROM), which is associated with increased mortality and morbidity in infants, with late pregnancy heatwave exposure in a large cohort of pregnant women in Southern CA (Jiao et al., 2023). Hispanic and non-Hispanic White mothers had positive associations between PROM and multiple heatwave definitions, while African American and Asian mothers did not. However, the differences across racial/ethnic categories were imprecise.

Knowlton et al. examined differences by age group in ED visits and hospitalizations during the 2006 CA heat wave (Knowlton et al., 2009). They analyzed rate ratios and excess morbidity during the heat wave period, compared to reference periods in the same summer. Children four years of age and younger had the greatest increase in overall ED visit rates, compared to other age groups. There was no difference in overall hospitalizations. Looking at specific causes, children under 4 had significant increased risk of ED visits for heat-related illness and electrolyte imbalance. There were no effects or insufficient data for ED visits for acute renal failure or nephritis and hospitalizations (any cause). Analyses across racial/ethnic groups in children were not conducted. Basu et al. found age modified the effect of heat on ED visits (Basu et al., 2012). A 10ºF change in same-day apparent temperature was negatively associated with respiratory and dehydration-related ED visits in children under 18 years of age. However, children 0-4 and 5-18 were at greater risk of intestinal infection visits. Another study found that the risk of mental health related ED visits related to increased temperature was greatest in those aged 6 to 19, compared to older age groups (Basu, Gavin, et al., 2018). Risk was increased in all age groups, however 6-19 year olds also had the highest associations for self-inflicted injury/suicide and neurotic disorders. White and Hispanic individuals had the greatest increase in risk, but specific analyses by age were not conducted.

Four studies assessed heat and child mortality outcomes. Basu and Ostro aimed to identify population groups at risk of high temperature by assessing non-accidental deaths from 1999 to 2003 (Basu & Ostro, 2008). By age group, they found greater risk of death across all age groups, but mortality risk was greatest in infants (< 1 year of age) and children under the age of 5. No increased mortality risk was observed in 5-17 year olds. Risk was elevated in all racial/ethnic groups with Black and White individuals having the largest increase. Basu, Sarovar and Malig assessed associations between warm season apparent temperature and risk of stillbirth (Basu et al., 2016). Risk was increased in all racial/ethnic groups but was only significant among Hispanic mothers. The lowest risk was observed in Asian mothers, still a 7.4% change in stillbirth risk. Unlike low birth weight outcomes, risk was greater for young and less educated mothers. Another study found Black infants had a greater risk of Sudden Infant Death Syndrome (SIDS) with outdoor ambient temperature during summer months (Jhun et al., 2017). A 10ºF increase in temperature was associated with an 18.5% increase in excess SIDS risk in Black babies, compared to a 3.5% increase in White babies. There were not enough data to study risk in other racial/ethnic groups. The risk was also greater in older infants (3-11 months), compared to 0-2 months. One study assessed the relationship between warm season temperatures and infant mortality, across multiple causes over a 13-year period (Basu et al., 2015). Again, Black infants had the highest risk from heat exposure, with a 13% excess risk of all-cause mortality.

3.6.2. Wildfire Smoke Exposure

Five studies examined the health impacts of wildfires and smoke on children's health, with many focusing on cardiorespiratory outcomes. As with heat-related studies, analyses included stratification by age but did not assess differential effects within age groups. Multiple studies reported negative health impacts of wildfire related $PM_{2.5}$ in children. Thilakaratne et al. found increased $PM_{2.5}$ was associated with significantly elevated risk of asthma or respiratory ED visits in children aged 0 to 4 (Thilakaratne et al., 2023). Similarly, 5–18-year-olds had significantly elevated risk of asthma ED visits and hospitalizations and respiratory ED visits. Smoke-day $PM_{2.5}$ was related to higher ED visit and hospitalization rates in children, though these rates were lower than for the oldest age groups (65+). Heaney et al. found differential effects by age in relationships between $PM_{2.5}$ from wildfire smoke during the 2004 to 2009 wildfire seasons and cardiorespiratory hospitalizations (Heaney et al., 2022). Smoke event days were associated with increased hospitalizations in all age groups, but the effect was largest among those aged 5 and under, followed by those 6 to 18 years of age. Hospitalizations for acute respiratory infections were significantly increased in those under 5, whereas no effect was observed for older age groups. Associations between smoke events and cardiovascular hospitalizations were not observed for children 18 and younger. Another study found wildfire specific $PM_{2.5}$ was associated with increased risk of ED visits for asthma and pneumonia among 0 to 17 year olds, though risks were elevated for all age groups (Chen et al., 2023). Children, however, had a decreased risk for mental-health related ED visits, compared to those 18 and over.

One study found every additional day of wildfire smoke exposure in pregnant mothers was associated with an increased risk of preterm birth, particularly when the smoke days were high intensity or occurred later in the pregnancy (Heft-Neal et al., 2022). They estimated wildfire smoke accounted for nearly 4% of preterm births during the study period, which greatly increases risk of serious health problems as those children develop.

Winter et al. studied urban park usage and ozone exposure in neighborhoods in the City of Los Angeles, CA during August and September of 2015 (Winter et al., 2019). They found teens and children had significantly greater ozone exposure compared to adults or older adults.

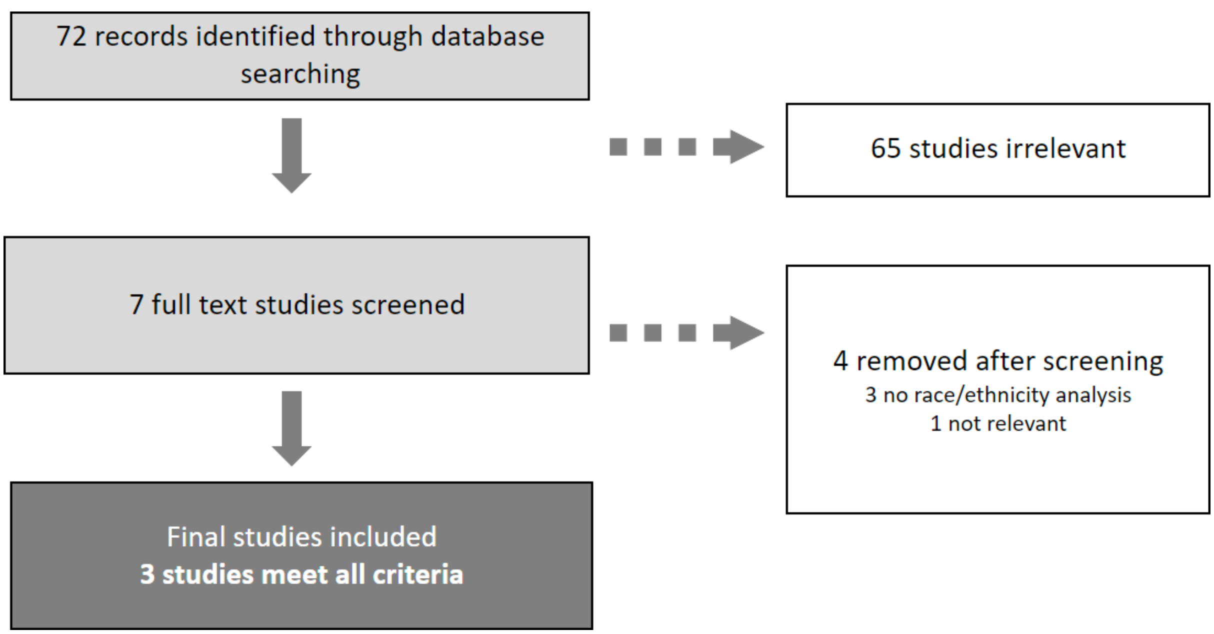
3.6.3. Greenspace Exposure

Three studies assessed associations of greenspace exposure with various outcomes among children and adolescents, as described in section 3.5. One found that, in general, aggressive behaviors were reduced in relation to both short and long-term exposure to greenspace though no differences were found by race/ethnicity (Younan et al., 2016). Another study examined the associations between vegetation surrounding schools and standardized test scores in a large sample of elementary schools in 2012 (Tallis et al., 2018). Overall, positive associations were found between tree and shrub coverage surrounding schools and fifth grade standardized testing scores in urban schools. However, the percentage of minority race/ethnicity students was the most impactful factor on test scores, with significant reductions in test scores as minority representation increases. The third study examined greenspace as a potential moderator of associations between literacy programs and test scores in a sample of minority elementary school students (Rahai et al., 2023). They did not analyze effects across race/ethnicity categories; however, the sample was comprised of mainly Hispanic (70%), Black (14%) and Asian (7%) students, with White students making up only 5% of the population. They found greater improvements in reading associated with literacy interventions in schools with more greenspace.

3.7. Housing Affordability

Three studies evaluated historical housing practices, like redlining, or housing cost burden and health impacts.

Figure 7. Housing affordability study selection



3.7.1. Redlining and Health

During the depression era in the U.S., the Home Owners' Loan Corporation (HOLC) was formed to prevent foreclosures on home mortgages. HOLC created "security maps" that categorized neighborhoods in U.S. cities based on the perceived mortgage lending risk into four categories; Best, Still Desirable, Definitely Declining, and Hazardous (color-coded as red on maps). These classifications were based on factors including housing conditions, employment status and the racial and ethnic composition of neighborhoods. Neighborhoods with the Hazardous rating, tended to be those with high Black and minority populations and the practice led to long-lasting segregation in urban areas and the inability of minority groups to build equity through home ownership.

A study by Nardone et al. examined asthma burden in historically redlined neighborhoods. Census tracts were from the eight CA cities that were included in the HOLC redlining maps (*Mapping Inequality: Redlining in New Deal America, University of Richmond*, n.d.). Census tract level demographics, air pollution and asthma ED visits were from CalEnviroScreen 3.0 (CES3.0) (*CalEnviroScreen 3.0, California Office of Environmental Health Hazard Assessment*, n.d.). Nearly 40% of the census tracts from included cities had HOLC risk scores and were included in the analysis. Results showed a greater proportion of non-Hispanic Black and Hispanic populations in tracts with worse risk scores. Poverty rates, diesel exhaust and $PM_{2.5}$ concentrations were also much higher in tracts rated as Hazardous. Rates of asthma-related ED visits were higher in redlined census tracts, compared to those with the best rating.

Another study assessed relationships between redlining categories and severe maternal morbidity (SMM) in CA births over a 20-year period from 1997 to 2017 (Gao et al., 2023). Data on live births, discharge records (including any diagnostic or procedural ICD codes), and race/ethnicity were obtained from HCAI (*Calif. Dep. Heal. Care Access Inf.*, n.d.). Residential address of the birthing parent was linked to the birth files and neighborhood level variables. The analysis was limited to non-White self-reported racial groups. SMM was determined using the Centers for Disease Control and Prevention's (CDC) SMM Index, which includes 21 indicators of life-saving procedures or potentially deadly conditions (*Severe Maternal Morbidity, Centers for Disease Control and Prevention*, n.d.). HOLC grades were linked spatially to census tracts of the birth parents. Hispanic birthing parents had the highest proportion living in historically Hazardous/redlined census tracts. For Black and Hispanic birthing parents, living in neighborhoods with the worst risk rating was associated with an increased risk of SMM, compared to birth mothers of the same race or ethnicity living in neighborhoods with HOLC ratings of "Best" or "Still Desirable".

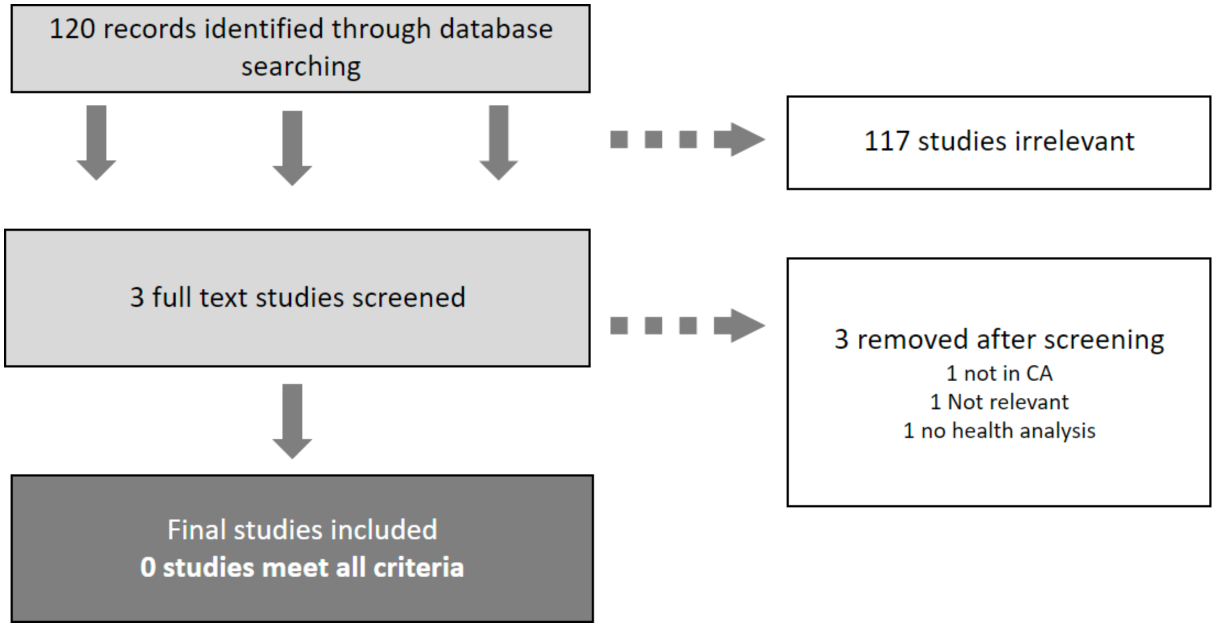
3.7.2. Housing Burden and Wildfire Pollution

A previously described study by Kramer et al. (Section 3.3.1) assessed indoor and outdoor $PM_{2.5}$ concentrations from ten CA wildfires in 2020 in the metropolitan areas of San Francisco Bay and Los Angeles (Kramer et al., 2023). Demographic variables, including race and ethnicity and housing burden, were from the CalEnviroScreen 4.0 dataset (*CalEnviroScreen 4.0, California Office of Environmental Health Hazard Assessment*, n.d.). Housing burden refers to low-income households that are additionally burdened by high housing costs as a proportion of household income. Results in the Los Angeles area showed housing burden was significantly and positively correlated with wildfire $PM_{2.5}$. Areas with a greater proportion of Hispanic and African American residents were correlated with higher wildfire $PM_{2.5}$ concentrations whereas the percentage of White residents was negatively correlated with wildfire $PM_{2.5}$ pollution.

3.8. Food Security

There were no studies in California that met the scoping review criteria.

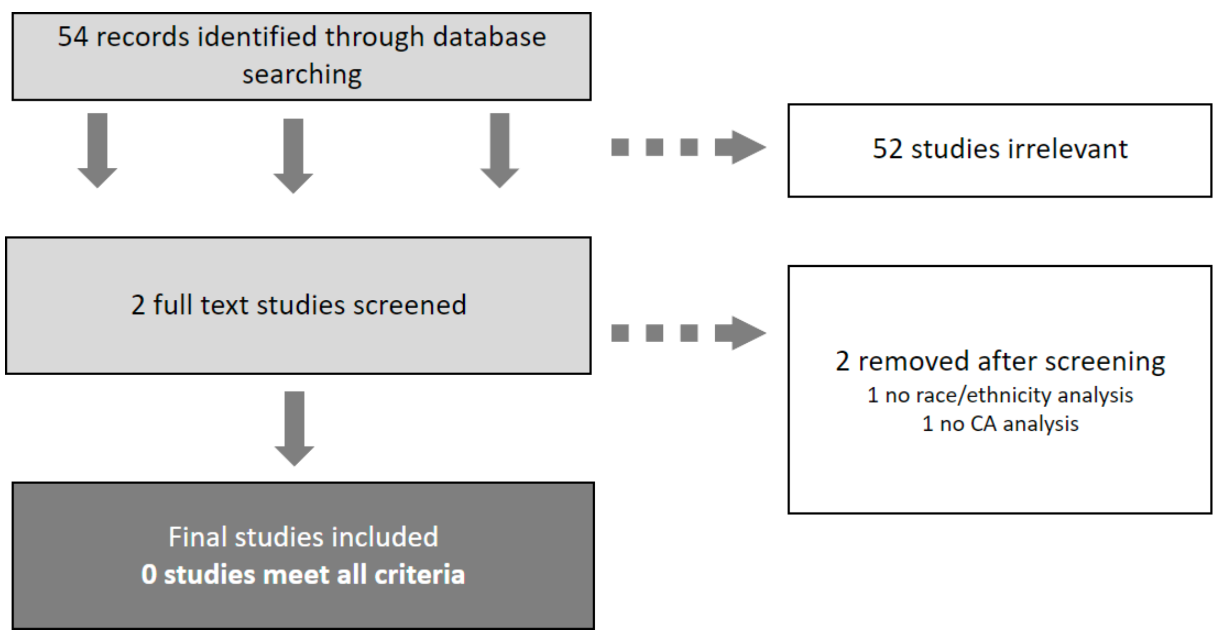
Figure 8. Food security study selection



3.9. Economic Security

There were no studies in California that met the scoping review criteria.

Figure 8. Economic security study selection



3.10. Summary of Available Databases, Tools, and Online Resources

We have compiled a list of all data sources utilized in the included studies. The identification of race and ethnicity was primarily through hospital or health records at the individual level, or Census data for aggregated analyses. The table provides a description of the data source and which papers used the data referenced. The paper numbers correspond to those found in Appendix 2.

PLEASE SEE APPENDIX 3.0

4. Summary and Recommendations for Future Research

4.1. Heat Impacts

The heat studies generally provide evidence of disparities in exposure to, and impact of, heat by race and ethnicity. Communities with the greatest proportion of Latinx and Black residents were shown to be significantly warmer compared to communities with the lowest percentage of these groups (Dialesandro et al., 2021). Black and Hispanic populations have greater risk of mortality from heat exposure (Basu & Ostro, 2008; Joe et al., 2016) and communities of color disproportionately suffer worse birth outcomes with high temperatures. One study found the strongest associations between heat and preterm birth among Black and Asian mothers (Basu et al., 2010), while another showed Black and Hispanic mothers had greater risk (Basu et al., 2017). Hispanic mothers were also found to have a significantly higher risk of stillbirth, compared to other racial/ethnic groups (Basu et al., 2016) and Black infants were at greater risk of death and low birth weight with heat exposure (Basu et al., 2015; Basu, Rau, et al., 2018; Jhun et al., 2017). Conversely, Ha et al. found heat exposures increased the odds of preterm birth for all mothers but did not find differences in the risk by race or ethnicity (Ha et al., 2024). Similarly, there were no disparities observed in a study of PROM risk with heat exposure (Jiao et al., 2023).
A review of ED visits and hospitalizations in CA associated with heat showed a relatively consistent greater burden of morbidity among Hispanics. Multiple studies found increased temperature was associated with a greater risk of ED visits for multiple morbidities in Hispanic, compared to White, populations (Basu et al., 2012; Malig et al., 2019). Hispanic and White groups were found to have significantly elevated risk of mental health and drug overdose outcomes with elevated heat exposure (Basu, Gavin, et al., 2018; Chang et al., 2023). A 2006 CA heatwave was associated with significantly increased rates of ER visits for all racial and ethnic groups, with the exception of Native American/Alaska Native and API groups (Knowlton et al., 2009), which can be explained by the very small sample sizes for these groups. In addition, they found that rates were highest for Hispanic/Latinos and those with unknown/unreported race/ethnicities. Similar to the findings of Basu et al., the Hispanic group had elevated ED visit and hospitalization rates for cardiovascular diseases.

There are still several subgroups of the population for which evidence regarding heat-impacts is lacking. A recent study conducted in San Diego showed that individuals experiencing homelessness were more vulnerable to extreme heat as compared to individuals not experiencing homelessness (Schwarz et al. 2022). It would be important to extend such study to rest of California and analyze which subgroups are particularly vulnerable. Evidence regarding the effect of extreme heat on substance use disorders across diverse populations is emerging in California (Chang et al. 2023) but it would be interesting to explore which subgroups of the population are particularly at risk and what types of preventive actions can be implemented. In addition, further evidence about specific susceptibility to heat-related impacts for some subgroups is still lacking including: undocumented migrants (especially in the context of occupational settings), people with existing multiple-comorbidities or people who use durable medical equipment (particularly in the context of compounded power outages) for example.

4.2. Wildfires and Smoke Impacts

The review identified multiple disparities in health outcomes associated with wildfire and smoke exposure, though which racial or ethnic group was most at risk differed across studies. Wildfire frequency and burn area were both found to be higher in Native American and White communities, whereas exposure risk was lower for other minority groups (Masri et al., 2021). While minority mothers were found in one study to have greater *total* $PM_{2.5}$ exposures, compared to similar White populations, Heft- Neal et al. reported White mothers living in low-income areas had much greater *smoke-specific* $PM_{2.5}$ exposure, compared to Black or Asian mothers in low-income areas (Heft-Neal et al., 2022). This is likely due to White and Native American populations living in more rural areas that are more susceptible to wildfires. Hispanic and African American groups neighborhoods had decreased exposure to compound risk days, i.e. days with both heat and wildfire smoke exposure (Masri et al., 2022). By contrast, Black and Hispanic neighborhoods were positively associated with $PM_{2.5}$ exposures during wildfires impacting the Los Angeles region, whereas there was a negative relationship for neighborhoods with a greater White population (Kramer et al., 2023).

Black and Native American populations generally had elevated risk of respiratory and cardiovascular-related health outcomes associated with PM (Heaney et al., 2022; Lee et al., 2009; Liu et al., 2017; Thilakaratne et al., 2023). Black, Hispanic, Asian, and Native American populations show stronger associations between wildfire-smoke days and increased odds of preterm birth outcomes when compared to White participants (Ha et al., 2024). Asian and Pacific Island populations had more heterogenous relationships with wildfire smoke. Ha et al. found preterm birth outcomes were worse in Asian and Pacific Island populations, compared to White mothers. One study reported the greatest increase in risk of respiratory ED visits and hospitalizations were among the Asian population (Ha et al., 2024; Thilakaratne et al., 2023). Another study found Asian individuals to be at lower risk of anxiety-related ED visits (Chen et al., 2023).

Some studies did not find evidence of disparate risk, or that communities of color had less risk compared to White populations. Heft-Neal reported every additional day of wildfire smoke exposure was associated with an increased risk of preterm birth, with no differences across racial/ethnic groups. Reid et al. found ozone concentrations during the wildfire period were higher in zip codes with more White and Hispanic residents, compared to Black or Asian individuals. They also did not find clear heterogeneity in the relationship between wildfire-period $PM_{2.5}$ nor O_3 and respiratory hospitalizations or ED visits by race or ethnicity (Reid et al., 2021).

Overall, there is still a lack of evidence about the long-term effects wildfire smoke PM2.5 on various health issues. A recent national study (Ma et al. 2024) identified a positive association between long-term exposure to wildland smoke PM2.5 and nonaccidental, cardiovascular, ischemic heart disease, digestive, endocrine, diabetes, mental, and chronic kidney disease mortality rates. They did not find evidence of differential effects across race/ethnic groups. It would be interesting to further investigate these long-term impacts and if some differential effects appear across socio-demographic subgroups in California.

4.3. Mobility, Physical Activity, and EV Usage

The relationship between climate change and physical activity is complex and multidirectional. Increased heat or air pollution from wildfires can impact physical activity behaviors and, conversely, active forms of mobility (like walking or biking) can impact climate warming emissions. Physical activity may also moderate relationships between climate exposures and health outcomes. Many of the studies on these topics have been conducted outside of CA or did not include a race/ethnicity analysis, however the review provides insights on disparities in multiple mobility related areas.

Two studies evaluated inequities in CA’s transition to electric vehicles. One found disparities in the adoption of ZEVs with non-White and non- Asian groups owning fewer ZEVs relative to their population size, regardless of whether they lived in disadvantaged communities (Yu et al., 2023). Minority populations had greater traffic related pollution exposure and, while the adoption of ZEVs could reduce differences in exposure between minority and non-minority populations, the authors postulate any reduction would likely be limited without further restricting truck traffic in disadvantaged communities. Another study assessed EV adoption in relation to historical redlining practices. They found that EV adoption and use of EV rebates grew the most in White and Asian neighborhoods and the least in the Latino population. Communities that had been redlined had far less EV penetration compared to historically advantageous communities. They found fewer disparities in ZEV ownership in low-income communities, indicating that EV adoption is more universally limited by household income (Hennessy & Syal, 2023). Similarly, a study found that e-bike rebate program participants were predominantly White and Asian, whose representation in the rebate program was higher relative to their population (Johnson et al., 2023). A modeling study estimated effects of several transportation planning scenarios on health inequities. They found racial and ethnic minority populations would likely experience a greater benefit under scenarios that supported more active transportation, mainly due to a larger increase in physical activity from active travel modes, compared to the White population (Wu et al., 2019). A study evaluating static versus dynamic air pollution exposure modeling methods found minority racial or ethnic workers tended to live in more highly polluted areas, compared to White populations, and be exposed to greater $PM_{2.5}$ levels overall (Lu, 2021). Results indicated that using static measures (as is currently common practice) likely *over*estimates minority group $PM_{2.5}$ exposure among a working population that travels outside their residential area. The converse was true for White residents who lived in less polluted areas and worked in more polluted areas. Dynamic exposure measures may help to reduce potential measurement bias for multiple environmental and built environment exposures such as air pollution, noise or walkability indexes. Finally, a study of parks in Los Angeles, CA found that Latino park users were exposed to greater levels of ozone, compared to all other racial/ethnic groups (Winter et al., 2019). In general, the studies provide evidence that careful planning is needed to reduce air pollution exposure among minority groups and ensure that disparities are not worsened by unintended consequences of transportation planning and policies to transition to climate friendly travel modes.

It is possible that active transportation and EV promotion/programs targeting minority groups could reduce disparities. However, no evidence regarding the equity implications of such benefits is available at the moment. Studies are needed to assess impacts of climate sensitive exposures on physical activity, including impacts across racial/ethnic groups. While some early literature exists outside of CA, it would be important to conduct such assessments in California.

4.4. Urban Greening

Prior research on the moderating effects of greenspace on health disparities has been mixed. Only four studies met our inclusion criteria for this review, with only one study assessing health outcomes. That study found disparities in exposure to greenspace with a greater proportion of Black mothers tending to live in areas with the lowest levels of greenspace compared to White mothers (Gailey, 2023). Increased residential greenspace was positively associated with birthweight only among Black infants, with null findings in other racial/ethnic groups. Further study is warranted to determine whether greening interventions in Black neighborhoods may mitigate risk factors faced by pregnant Black mothers that could reduce inequities in birth outcomes. Younan et al. similarly found that White participants lived in areas with more green vegetation compared to other racial and ethnic groups (Younan et al., 2016). However, they did not find any relationship between greenspace exposure and aggressive behaviors among youth. Two studies evaluated the impact of greenspace on academic outcomes, though neither specifically addressed differences across racial groups. In a study sample comprised of mainly minority students, greater literacy improvements were observed for students in schools with more greenspace (Rahai et al., 2023). The other (Tallis et al. 2016) found greenspace to be positively correlated with standardized testing scores, though the effect size associated with minority representation in the school was larger. Further testing is warranted to determine whether test score improvements correlated with greenery are modified by race or ethnicity.

4.5. Children's Health and Development

There were many studies that assessed the impact of climate sensitive exposures, mainly heat and wildfire, on children's health, however none of the studies evaluated whether effects were heterogeneous across racial and ethnic groups. We have included them here to provide evidence of potential impacts on children's health, though future studies should further investigate effect modification by race/ethnicity.

Heat was found to elevate risk of adverse birth outcomes in all racial and ethnic groups, though generally Black and Hispanic mothers had the most elevated risk (Basu et al., 2010; Gao et al., 2023; Jiao et al., 2023). Children under four were also at greater risk, relative to other age groups, for ED visits for certain morbidities (Basu et al., 2012; Basu, Gavin, et al., 2018; Basu & Ostro, 2008). Negative mental health outcomes were linked to heat in those between the ages of 6 to 10, compared to older age groups (Basu, Gavin, et al., 2018). Babies born to Hispanic mothers exposed to heat were at greater risk of stillbirth and Black infants were found to have elevated risk of SIDS and infant mortality (Basu et al., 2016; Jhun et al., 2017).

Multiple studies reported negative health impacts of wildfire related $PM_{2.5}$ in children though none stratified by race/ethnicity within age groups. Children under the age of five generally experienced the largest increase in risk of ED visits or hospitalizations associated wildfire smoke (Heaney et al., 2022; Thilakaratne et al., 2023). Unlike with heat exposure, those under 18 had fewer mental health related visits related to wildfire smoke exposure (Chen et al., 2023). Teens and children were also found to have greater ozone exposure, compared to older park users, likely because they were more active in a recreational space (Winter et al., 2019).

Three studies found greenspace exposure impacted behavioral and academic testing outcomes among children, though analyses by race/ethnicity were limited. Race/ethnicity did not appear to moderate the relationship between greenspace and decreased aggression in adolescents (Younan et al., 2016).

It is also important to mention that while we focused on environmental determinants of children's health and development that are directly sensitive to climate change and variability as well as in relation to adaptation strategies (e.g. green spaces), other environmental determinants may have an indirect impact on such outcomes. For example, traffic related air pollution has well documented impacts on children health (Stenson et a. 2021; Khreis et al. 2017) and reducing traffic emissions can have co-benefits on greenhouse gas (GHG) emissions. We did not consider such indirect impacts in this work, but in future work, it would be interesting to explore the potential co-benefits of reducing GHG emissions from traffic sources on children health outcomes.

4.6. Housing Affordability

Three studies provide evidence of disparate impacts of climate change related to housing practices, demonstrating that the harms of redlining practices persist today. Historically redlined census tracts still house a greater proportion of Black and Hispanic residents who have worse air pollution and higher rates of asthma-related ED visits (Nardone et al., 2020). In a population on non-White mothers, Black and Hispanic mothers living in redlined neighborhoods had greater risk of morbidity outcomes during childbirth, compared to mothers living in neighborhoods with historically desirable ratings (Gao et al., 2023). A study by Kramer et al. showed that minority neighborhoods and those burdened by high housing costs relative to income had greater exposure to wildfire pollution (Kramer et al., 2023). Some research gaps can be acknowledged which can potentially inform future research efforts. Some recent unconditional cash transfer experiments in the US have led families to make opportunity moves to better quality neighborhoods (Das et al. 2024). It would be interesting to explore how such residential changes led to an increase in resilience to climate hazards such as extreme heat or wildfire smoke for example, or via an increase to environmental amenities such as green spaces or public transportation. In parallel, it would be important to study how gentrification may influence the changes in climate-related vulnerability across neighborhoods in California. Neighborhood gentrification refers to process through which "the demographic, real estate, and business characteristics of a place transition towards a more educated, wealthy and whiter population, able to afford new or renovated expensive homes while also fomenting new cultural and consumption practices" (Cole et al. 2024). Such changes can be associated with population mobility towards hotter, drier areas and more exposed to wildfire risk and would be critical to describe.

5. Conclusions

In this white paper, we synthesized existing literature related to the eight a priori selected topical areas using a racial and ethnic lens to describe disproportionate risk and impacts for population groups and communities in California. We conducted a scoping review for each of these eight topical areas and summarized available databases and tools, and online resources that could be used for a future comprehensive assessment of the differential health impacts across racial and ethnic groups. We summarized the findings in the previous section and here we would like to emphasize the areas that would require more evidence and research in the upcoming years. We also indicate key data sources that could be used in these areas.

Heat Impacts:

- Extending studies to specific vulnerable populations, such as undocumented migrants, individuals with multiple comorbidities, and those reliant on medical equipment during power outages.
    - Data on power outages can be obtained on https://poweroutage.us/ for example and can be linked with extreme heat events. When using cohorts, it is also possible to rely on comorbidity indexes such as the Charlson Comorbidity (https://www.ncbi.nlm.nih.gov/books/NBK587905/ and https://www.sciencedirect.com/topics/medicine-and-dentistry/charlson-comorbidity-index) or the Elixhauser indexes (https://www.sciencedirect.com/topics/medicine-and-dentistry/elixhauser-comorbidity-index#:~:text=The%20Elixhauser%20Comorbidity%20Index%20quantifies%20a%20patient%E2%80%99s%20comorbidity,comorbidity%20with%20death%2C%20to%20produce%20a%20summary%20index) to explore differential vulnerability to extreme heat.
- Exploring the effects of extreme heat on substance use disorders across diverse populations.
    - There are several ICD codes that can be used to explore the effects of heat on substance use disorders such as in Parks et al. (2023).
- Broadening research on heat vulnerability among homeless individuals beyond localized studies. Information regarding unhoused status can be found in some electronic health records such as in the UC Health Data Warehouse (UCHDW) (available from https://blink.ucsd.edu/technology/helpdesk/queries/warehouse/overview.html.)

Wildfires and Smoke Impacts

- Investigating long-term health effects of wildfire smoke PM2.5 on multiple chronic diseases across different socio-demographic subgroups.
    - There are different available data sources regarding wildfire smoke PM2.5 in California from Aguilera et al. 2023 for example (see: https://github.com/benmarhnia-lab/Wildfire_PM25_California_ZIP_and_census_tract)
- Examining whether multiple structural racism metrics (e.g. Political representation, criminal legal system, economic opportunity, and housing) modify the health impacts of wildfire smoke exposure in California.
    - There are various metrics that can be found on existing platforms such as CalEnviroScreen 4.0 (https://oehha.ca.gov/calenviroscreen) or the Healthy Place Index (https://www.healthyplacesindex.org/)
- Studying combined risks of heat and wildfire smoke exposure as well as other ambient air pollutants such as NO2 or O3 across different racial/ethnic groups.
    - Data on air pollutants can also be found on CalEnviroScreen 4.0.

Mobility, Physical Activity, and EV Usage:

- Assessing strategies to promote EV adoption in minority communities and evaluating equity implications of transportation policies.
  - Data on zero emission vehicles sales for example can be found on the California Energy Commission website (https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics-collection/new-zev)
- Improving air pollution exposure modeling by incorporating dynamic measures to better understand disparities for minority workers.
  - Methods to develop dynamic measures from existing GPS data have been proposed by Jankowska et al. 2023.
- Conducting studies in California to evaluate how climate-sensitive exposures affect physical activity across racial/ethnic groups.
  - Data on physical activity at the population level can be obtained via measuring population mobility for example using data from U.S. Bureau of Transportation Statistics as used in Schwarz et al. 2023. Then, existing cohorts such as the California Teachers study also collects individual information on physical activity that can be linked to multiple environmental exposures.

Urban Greening:

- Investigating whether greening interventions in underserved neighborhoods can mitigate health disparities, particularly among Black populations.
  - Several tools can be used to capture greening and changes over time such as Normalized Difference Vegetation Index (NDVI) (https://developers.google.com/earth-engine/tutorials/tutorial_api_06), Land surface Temperature (https://developers.google.com/earth-engine/datasets/catalog/MODIS_061_MOD11A1) or tree canopy (https://policies.healthyplacesindex.org/neighborhood/tree-canopy/about). These variables are available via platforms such as Healthy Place Index or Google Earth Engine.
- Further exploring the relationship between greenspace exposure and academic performance, with a focus on race/ethnicity as a moderating factor.

Children's Health and Development:

- Examine how climate-sensitive exposures affect children's health outcomes across racial/ethnic groups.
  - Time-fixed and ecological measures of birth and children health outcomes are available on CalEnviroScreen 4.0.
- Study the co-benefits of reducing greenhouse gas emissions (e.g., from traffic) on children's health outcomes and equity.

Housing Affordability:

- Explore how historical housing practices (e.g., redlining) exacerbate climate-related vulnerabilities and assess strategies to address these inequities.
    - Data on redlining using the Home Owner's Loan Corporation (HOLC) can be found on the following website: https://dsl.richmond.edu/panorama/redlining/
- Assess the role of housing factors in modulating the risk of climate-sensitive exposures and related inequities such as housing insecurity (proportion of unhoused individuals and overcrowding in homes), filtration characteristics, square footage or presence of Heating, Ventilation, and Air Conditioning (HVAC) system.
    - There are different housing factors at the neighborhood level that can be found in the American Community Survey: https://www.census.gov/programs-surveys/acs/.

Food and Economic Insecurity:

We were not able to identify any studies focusing on food or economic insecurity in relation to health impacts related to climate-sensitive exposures in California. Yet, other studies, outside of California have been conducted and can be used to motivate future studies in California. For example, a study by Berkowitz et al. 2017, used different metrics for food insecurity in the US that can be linked to climate sensitive exposures. Individuals were categorized as food insecure using a validated 10-item USDA questionnaire with a 30-day reference period, based on National Health Interview Survey (NHIS) 2011 data, to examine the relationship between food insecurity and health (Berkowitz et al., 2017). Regarding economic insecurity, several indicators to capture poverty level have been proposed. For example, a recent review by Bezgrebelna et al. 2024, summarized evidence in Canada and identified several indicators of poverty (i.e., housing precarity and homelessness, difficulty meeting health needs, food insecurity, low income, and low educational attainment) that can be used for future studies in California.

Variables capturing such dimensions have been proposed in the literature (Ashby et al. 2016; Walker-Pow et al. 2024) and can be easily combined with environmental and health data. All the tools from Ashby et al. (2016), including Radimer/Cornell, Cornell Child Food Security Measure, Community Childhood Hunger Identification Project (CCHIP) tool, Hager two-item screen, Girard four-point tool, Kuyper past food insecurity, Household Food Insecurity Access Scaled (HFIAS), and Townsend Food Behavior Checklist, assessed the dimension of food access. In the systematic review, Walker-Pow et al. (2024) identified various aspects of financial concerns including insecurity, difficulty, distress, hardship, toxicity, worry, crisis, problems, as well as poverty, and economic problems, which were often linked to worsened physical and psychological well-being in terminally ill patients. It is very plausible that such variables may modulate the risks associated with multiple climate-sensitive exposures such as extreme heat or wildfire smoke. Therefore, investigating the role of food or economic insecurity in relation to health impacts to extreme heat or wildfire smokes as well as other climate-sensitive exposures appears to be an important research priority for the upcoming years in California.

In conclusion, these research directions highlight the need for targeted studies to address gaps in understanding the intersection of climate change impacts, health outcomes, and social inequities across race/ethnic groups. By focusing on these areas, researchers can contribute to developing more effective and equitable strategies for mitigating the health impacts of climate change across diverse populations in California.

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7. Appendix

7.1. Appendix 1.0 Terms Applied to All Searches

NB: Searches were conducted in an iterative way, and additional search terms were added as additional databases were explored.

General Search Terms	Search terms
PubMed	(race OR ethnicity OR ethn* OR Black OR African-American OR African American OR Hispanic OR White OR Caucasian OR Asian OR API OR Native OR Indigenous OR minorit* OR disparit*) AND California[Title/Abstract] or CA[Title/Abstract]
Google Scholar	(race OR ethnicity OR ethn* OR Black OR African-American OR African American OR Hispanic OR White OR Caucasian OR Asian OR API OR Native OR Indigenous OR minorit* OR disparit*) AND California
Web of Science	TS=(race OR ethnicity OR ethn* OR Black OR African-American OR African American OR Hispanic OR White OR Caucasian OR Asian OR API OR Native OR Indigenous OR minorit* OR disparit*) AND (TI=California OR AB=California)

7.1.1. Appendix 1.1 Search Terms Applied to Heat Impacts

Heat Impacts	Search terms

PubMed	(heat[Title/Abstract] OR temperature[Title/Abstract]) AND
	(Ambient temperature[Title/Abstract] OR apparent temperature[Title/Abstract] OR temperature[Title/Abstract] OR heat[Title/Abstract] OR heat wave[Title/Abstract]) AND (low birth weight[Title/Abstract] OR LBW[Title/Abstract] OR morbidity[Title/Abstract] OR stillbirth[Title/Abstract] OR birth[Title/Abstract] OR pregnan*[Title/Abstract] OR cardiovascular[Title/Abstract] OR respiratory[Title/Abstract] OR mortality[Title/Abstract] OR mental health[Title/Abstract] OR mental[Title/Abstract] OR emergency room[Title/Abstract]))
Google Scholar	(heat OR temperature) AND (Ambient temperature OR apparent temperature OR temperature OR heat OR heat wave) AND (low birth weight OR LBW OR morbidity OR stillbirth OR birth OR pregnan* OR cardiovascular OR respiratory OR mortality OR mental health OR mental OR emergency room))

Web of Science	TI=(heat OR temperature) AND (Ambient temperature OR apparent temperature OR temperature OR heat OR heat wave) AND (low birth weight OR LBW OR morbidity OR stillbirth OR birth OR pregnan* OR cardiovascular OR respiratory OR mortality OR mental health OR mental OR emergency room)) OR AB=(heat OR temperature)
	AND (Ambient temperature OR apparent temperature OR temperature OR heat OR heat wave) AND (low birth weight OR LBW OR morbidity OR stillbirth OR birth OR pregnan* OR cardiovascular OR respiratory OR mortality OR mental health OR mental OR emergency room OR heat action plan))

7.1.2. Appendix 1.2 Search Terms Applied to Wildfires and Smoke Impacts

Wildfires and Smoke Impacts	Search terms
PubMed	Wildfire[Title/Abstract] AND (PM2.5[Title/Abstract] OR PM10[Title/Abstract] OR particulate matter[Title/Abstract] OR O3[Title/Abstract] OR smoke[Title/Abstract] OR disaster[Title/Abstract] OR evacuat*[Title/Abstract] OR damage[Title/Abstract] OR injury[Title/Abstract] OR safety[Title/Abstract] OR ozone[Title/Abstract] OR PAH[Title/Abstract] OR air pollution[Title/Abstract] OR burn*[Title/Abstract]) AND (respiratory[Title/Abstract] OR asthma[Title/Abstract] OR COPD[Title/Abstract] OR cardiovascular[Title/Abstract] OR emergency department[Title/Abstract] OR low birth weight[Title/Abstract] OR LBW[Title/Abstract] OR preterm[Title/Abstract] OR postnatal[Title/Abstract] OR birth[Title/Abstract] OR pregnan*[Title/Abstract] OR mortality[Title/Abstract] OR inflam*[Title/Abstract] OR CLRD[Title/Abstract] OR depression[Title/Abstract] OR anxiety[Title/Abstract] OR headache[Title/Abstract] OR diabetes[Title/Abstract] OR circulatory[Title/Abstract] OR poverty[Title/Abstract])
Google Scholar	Wildfire AND (PM2.5 OR PM10 OR particulate matter OR O3 OR smoke OR disaster OR evacuat* OR damage OR injury OR safety OR ozone OR PAH OR air pollution OR burn*) AND
	(respiratory OR asthma OR COPD OR cardiovascular OR emergency department OR low birth weight OR LBW OR preterm OR postnatal OR birth OR pregnan* OR mortality OR inflam* OR CLRD OR depression OR anxiety OR headache OR diabetes OR circulatory OR poverty)

Web of Science	TI=wildfire AND (PM2.5 OR PM10 OR particulate matter OR O3 OR smoke OR disaster OR evacuat* OR damage OR injury OR safety OR ozone OR PAH OR air pollution OR burn*) AND (respiratory OR asthma OR COPD OR cardiovascular OR emergency department OR low birth weight OR LBW OR preterm OR postnatal OR birth OR pregnan* OR mortality OR inflam* OR CLRD OR depression OR anxiety OR headache OR diabetes OR circulatory OR poverty)) OR AB=wildfire AND (PM2.5 OR PM10 OR particulate matter OR O3 OR smoke OR disaster OR evacuat* OR damage OR injury OR safety OR ozone OR PAH OR air pollution OR burn*) AND (respiratory OR asthma OR COPD OR cardiovascular OR emergency department OR low birth weight OR LBW OR preterm OR postnatal OR birth OR pregnan* OR mortality OR inflam* OR CLRD OR depression OR anxiety OR headache OR diabetes OR circulatory OR poverty))

7.1.3. Appendix 1.3 Search Terms Applied to Mobility and Physical Activity

Mobility and Physical Activity	Search terms
PubMed	((("climate change"[Title/Abstract] OR "global warming"[Title/Abstract] OR "extreme weather"[MeSH Terms] OR "precipitation"[Title/Abstract] OR "heat"[Title/Abstract] OR "temperature"[Title/Abstract] OR "heat wave"[Title/Abstract] OR "heatwave"[Title/Abstract] OR "cold"[Title/Abstract] OR [Title/Abstract] OR "weather"[Title/Abstract] OR "wildfire*"[Title/Abstract] OR "PM2.5"[Title/Abstract] OR "PM10"[Title/Abstract] OR "ozone"[Title/Abstract] OR "air pollution"[Title/Abstract] OR "GHG"[Title/Abstract] OR "particulate matter"[Title/Abstract] OR "smoke"[Title/Abstract] OR "greenhouse gas*"[Title/Abstract] OR "air quality"[Title/Abstract] OR "air quality index"[Title/Abstract] OR "AQI"[Title/Abstract] OR "pollution"[Title/Abstract] OR "air pollution"[Title/Abstract]) AND ("physical activity"[Title/Abstract] OR "mobility"[Title/Abstract] OR"activity"[Title/Abstract] OR "sedentary"[Title/Abstract] OR "human mobility"[Title/Abstract] OR "walk"[Title/Abstract] OR "pedestrian"[Title/Abstract] OR "bike"[Title/Abstract] OR "bicyc*"[Title/Abstract] OR "cycle*"[Title/Abstract] OR "cyclist"[Title/Abstract] OR "active travel"[Title/Abstract] OR "active transport*"[Title/Abstract] OR "transit"[Title/Abstract] OR "public transport*"[Title/Abstract]) AND ("race"[Title/Abstract] OR "racial*"[Title/Abstract] OR "ethnicity"[Title/Abstract] OR "indigenous"[Title/Abstract] OR "Native American"[Title/Abstract] OR "Alaska Native"[Title/Abstract] OR "Asian*"[Title/Abstract] OR "Pacific Islander"[Title/Abstract] OR "API"[Title/Abstract] OR "African American"[Title/Abstract] OR "hispanic*"[Title/Abstract] OR "latin**"[Title/Abstract] OR "marginalized"[Title/Abstract] OR "disparit*"[Title/Abstract] OR "disproportion*"[Title/Abstract] OR "climate justice"[Title/Abstract] OR "environmental justice"[Title/Abstract] OR "environmental racism"[Title/Abstract])) AND ("California"[Text Word] OR "CA"[Text Word]) AND 2000/01/01:3000/01/01[Date - Publication])
Google Scholar	allintitle: climate change physical activity – 36 results

Web of Science	(((TS= ("climate change" OR "global warming" OR "extreme weather" OR precipitation OR heat OR temperature OR heat wave OR heatwave OR cold OR weather OR wildfire OR ozone OR air pollution OR GHG OR "particulate matter" OR smoke OR greenhouse gas OR "air quality" OR "air quality index" OR AQI OR pollution OR "air pollution")) AND TS=("physical activity" OR mobility OR exercise OR "active travel" OR "active transport*" OR walk* OR bike OR sport OR transit)) AND TS=(race OR ethnicity OR disparities OR Black OR "African American" OR Hispanic OR White OR Caucasian OR Asian OR API OR Native OR minorit*)) AND TS=(California OR CA) AND TS=(US OR "United States")

7.1.4. Appendix 1.4 Search Terms Applied to Urban Greening

Urban Greening	Search terms
PubMed	green space[Title/Abstract] OR greenspace[Title/Abstract] OR green cover[Title/Abstract] OR NDVI[Title/Abstract] AND (Heat OR Wildfire OR Precipitation OR Mental health OR depression OR anxiety OR asthma OR allerg* OR autism OR cognitive OR test OR preterm birth OR PTB OR Low birth weight OR LBW OR stillbirth OR injury OR death OR respiratory OR sunburn OR melanoma OR immunosup* OR heat stroke OR health OR activity OR climate)

Google Scholar	(green space OR greenspace OR green cover OR NDVI) AND (Heat OR Wildfire OR Precipitation OR Mental health OR depression OR anxiety OR asthma OR allerg* OR autism OR cognitive OR test OR preterm birth OR PTB OR Low birth weight OR LBW OR stillbirth OR injury OR death OR respiratory OR sunburn OR melanoma OR immunosup* OR heat stroke OR health OR activity OR climate)
Web of Science	AB=(green space OR greenspace OR green cover OR NDVI) AND TS=(Heat OR Wildfire OR Precipitation OR Mental health OR depression OR anxiety OR asthma OR allerg* OR autism OR cognitive OR test OR preterm birth OR PTB OR Low birth weight OR LBW OR stillbirth OR injury OR death OR respiratory OR sunburn OR melanoma OR immunosup* OR heat stroke OR health OR activity OR climate)

7.1.5. Appendix 1.5 Search Terms Applied to Children's Health and Development

Children's Health and Development	Search terms
PubMed	Climate[Title/Abstract] AND (Child*[Title/Abstract] OR Student[Title/Abstract] OR Infant[Title/Abstract] OR pregnan*[Title/Abstract] OR birth[Title/Abstract] OR stillbirth[Title/Abstract]) AND (Heat[Title/Abstract] OR Wildfire[Title/Abstract] OR Precipitation[Title/Abstract] OR extreme[Title/Abstract] OR drought[Title/Abstract] OR Flood*[Title/Abstract] OR ozone[Title/Abstract] OR greenhouse[Title/Abstract] OR vector-borne[Title/Abstract] OR disease[Title/Abstract] OR West Nile[Title/Abstract] OR dust[Title/Abstract] OR Storm*[Title/Abstract] OR virus[Title/Abstract]) AND

	(Mental health[Title/Abstract] OR depression[Title/Abstract] OR anxiety[Title/Abstract] OR asthma[Title/Abstract] OR allerg*[Title/Abstract] OR cognitive[Title/Abstract] OR test[Title/Abstract] OR preterm birth[Title/Abstract] OR PTB[Title/Abstract] OR Low birth weight[Title/Abstract] OR LBW[Title/Abstract] OR stillbirth[Title/Abstract] OR injury[Title/Abstract] OR allergy[Title/Abstract] OR hay fever[Title/Abstract] OR death[Title/Abstract] OR displacement[Title/Abstract] OR respiratory[Title/Abstract] OR sunburn[Title/Abstract] OR melanoma[Title/Abstract] OR immunosup*[Title/Abstract] OR heat stroke[Title/Abstract] OR drowning[Title/Abstract] OR malnutrition[Title/Abstract] OR malaria[Title/Abstract] OR dengue[Title/Abstract] OR encephalitis[Title/Abstract] OR vibrio[Title/Abstract] OR west nile[Title/Abstract] OR diarrhea*[Title/Abstract])
Google Scholar	(Climate AND (Child* OR Student OR Infant OR pregnan* OR birth OR stillbirth)) AND ((Heat OR Wildfire OR Precipitation OR extreme OR drought OR Flood* OR ozone OR greenhouse OR vector-borne OR disease OR West Nile OR dust OR Storm* OR virus) AND (Mental health OR depression OR anxiety OR asthma OR allerg* OR cognitive OR test OR preterm birth OR PTB OR Low birth weight OR LBW OR stillbirth OR injury OR allergy OR hay fever OR death OR displacement OR respiratory OR sunburn OR melanoma OR immunosup* OR heat stroke OR drowning OR malnutrition OR malaria OR dengue OR encephalitis OR vibrio OR west nile OR diarrhea*))
Web of Science	AB=(Climate AND (Child* OR Student OR Infant OR pregnan* OR birth OR stillbirth)) AND TS=((Heat OR Wildfire OR Precipitation OR extreme OR drought OR Flood* OR ozone OR greenhouse OR vector-borne OR disease OR West Nile OR dust OR Storm* OR virus) AND (Mental health OR depression OR anxiety OR asthma OR allerg* OR cognitive OR test OR preterm birth OR PTB OR Low birth weight OR LBW OR stillbirth OR injury OR allergy OR hay fever OR death OR displacement OR respiratory

	OR sunburn OR melanoma OR immunosup* OR heat stroke OR drowning OR malnutrition OR malaria OR dengue OR encephalitis OR vibrio OR west nile OR diarrhea*))

7.1.6. Appendix 1.6 Search Terms Applied to Housing Affordability

Housing Affordability	Search terms
PubMed	(affordable housing[Title/Abstract] OR housing[Title/Abstract]) AND (redlining OR HOLC OR Asthma OR Health)
Google Scholar	(affordable housing OR housing) AND (redlining OR HOLC OR Asthma OR health)
Web of Science	AB= (affordable housing OR housing) AND TS=(redlining OR HOLC OR asthma OR health)

7.1.7. Appendix 1.7 Search Terms Applied to Food Security

Food Security	Search terms
PubMed	(Climate[Title/Abstract] AND (food security[Title/Abstract] OR nutrition[Title/Abstract] OR nutritional quality[Title/Abstract] OR nutritional density[Title/Abstract] OR nutrient[Title/Abstract]))) AND ((climate OR agricultur* OR temperature OR drought OR wildfire OR CO2 OR climate change OR warming OR storm OR flood OR water OR production OR yield OR livestock OR crop* OR protein OR growth))
Google Scholar	Climate AND (food security OR nutrition OR nutritional quality OR nutritional density OR nutrient))

	AND (climate OR agricultur* OR temperature OR drought OR wildfire OR CO2 OR climate change OR warming OR storm OR flood OR water OR production OR yield OR livestock OR crop* OR protein OR growth)
Web of Science	AB=(climate AND (food security OR nutrition OR nutritional quality OR nutritional density OR nutrient)) AND TS=(climate OR agricultur* OR temperature OR drought OR wildfire OR CO2 OR climate change OR warming OR storm OR flood OR water OR production OR yield OR livestock OR crop* OR protein OR growth)

7.1.8. Appendix 1.1 Search Terms Applied to Economic Security

Economic Security	Search terms
PubMed	((Economic OR economic security) AND (labor OR economy OR economic) AND (heat OR wildfire OR precipitation OR climate OR climate change OR extreme weather OR drought OR storm))
Google Scholar	(Economic OR economic security) AND (labor OR economy OR economic) AND (heat OR wildfire OR precipitation OR climate OR climate change OR extreme weather OR drought OR storm)
Web of Science	AB=(Economy OR economic security)) AND TS=(labor OR economy OR economic) AND TS=(heat OR wildfire OR precipitation OR climate OR climate change OR extreme weather OR drought OR storm)

7.2. Appendix 2.0: Summary of Included Studies

Paper #	Co-benefit area	Authors	Year	Study Population	Exposure/s	Outcome/s
1	Heat/Children	Basu and Ostro	2008	CA deaths, 1999-2003	Temperature	Cardiorespiratory related mortality
2	Heat	Basu et al.	2017	Women with preterm delivery, 1995-2009	Temperature	Preterm delivery (PTD)
3	Heat/Children	Basu et al.	2012	ED visits 2005-2008	Temperature	ED visits during warm seasons
4	Heat/Children	Basu et al.	2015	Infant deaths, 1999-2011	Temperature	Infant mortality from all causes
5	Heat/Children	Basu et al.	2018	ED visits, 16 CA climate zones, 2005-2013	Temperature	Mental health ED visits
6	Heat/Children	Basu et al.	2018	Low birth weight and normal-weight infants, 1999–2013	Temperature	Low birth weight (LBW)
7	Heat/Children	Basu, Sarovar, and Malig	2016	CA fetal deaths, 1999-2009	Temperature	Stillbirth
8	Heat/Children	Basu, Malig, Ostro	2010	CA births, 1999-2006	Temperature	Preterm birth during warm season
9	Heat	Chang et al.	2023	CA ED visits	Temperature	Drug related ED visits
10	Wildfire/Children	Chen et al.	2023	CA ED visits, 2016–2019	Smoke events	ED visits
11	Heat	Dialesandro et al.	2021	20 Southwestern metropolitan regions	Race and income	Temperature disparities
12	Housing	Estien et al.	2024	Eight redlined CA cities	Census tract historical redlining grades	Environmental inequalities
13	Greening/Children	Gailey et al.	2023	Live births between 2005-2015	Residential greenspace	Birth outcomes
14	Housing/Children	Gao et al.	2023	Live hospital births, 1997-2017	Census tract historical redlining grades	Severe maternal morbidity (SMM)
15	Ozone/Children	Gharibi et al.	2018	CA Central Valley ED visits, 2015	Ozone exposure	Asthma ED visits
16	Heat/Wildfire	Ha et al.	2024	CA singleton preterm births	Temperature,wildfire smoke, PM2.5	Preterm birth
17	Wildfire/Children	Heaney et al.	2022	CA hospitaliations, wildfire seasons 2004–2009	Wildfire smoke PM2.5	Cardiorespiratory hospitalizations

18	Wildfire/Children	Heft-Neal et al.	2021	CA singleton births, 2006-2012	Wildfire PM2.5 exposure in pregnancy	Preterm birth
19	Mobility	Hennessy and Syal	2023	Electric vehicle (EV) purchasers	Sociodemographic factors	EV adoption and rebate use
20	Heat/Children	Jhun et al.	2018	Infant deaths, 1972-2006 for 210 US cities	Temperature	Sudden Infant Death Syndrome (SIDS)
21	Heat/Children	Jiao et al.	2023	Mothers in Kaiser Permanente Southern California	Heatwave expsosure, 2008-2018	Premature Rupture of Membranes (PROM)
22	Heat	Joe et al.	2016	CA deaths	2006 California heat wave	Mortality
23	Heat/Children	Knowlton et al.	2008	CA hospitalizations and ED visits	2006 CA heat wave	All cause ED visits and hospitalizations
24	Wildfire	Kramer et al.	2022	Two metro CA regions during 2020 wildfire season	Wildfire exposure	Pollution, healthoutcomes, sociodemographics
25	Wildfire	Lee et al.	2009	Hoopa Valley Indian Reservation	Wildfire smoke PM10 from 1999 wildfire	Clinic care for 6 health conditions
26	Wildfire	Liu et al.	2017	Medicare enrollees in Western US, 2004-2009	Wildfire smoke PM2.5	Respiratory hospital admissions
27	Heat	Malig et al.	2019	CA adult hospitalizations	Temperature	Renal system hospitalizations
28	Heat/Wildfire	Masri , Jin, and Wu	2022	CA census tracts, 2018-2020	PM2.5, Temperature	Compound risk days (heat and wildfire)
29	Wildfire	Masri et al.	2021	Area burned by wildfires in CA, 2000-2020	Census tract characteristics	Wildfire area burned and frequency
30	Mobility	N. Johnson, Fitch-Polse, and Handy	2023	Electric bike (e-bike) incentive program participants	e-bike incentive programs	Travel behaviors, GHG emissions, demographics
31	Housing	Nardone et al.	2020	ED visits in eight redlined CA cities	Census tract historical redlining grades	Asthma ED visits
32	Mobility	Patterson and Harley	2019	West Oakland residents	Freeway rerouting	Air pollution, residential displacement
33	Greening/Children	Rahai, Wells, and Evans	2023	Minority elementary school children throughout CA	School greenspace and literacy program	Reading improvement
34	Wildfire	Reid et al.	2023	Air basins affected by 2008 Northern CA wildfires	PM2.5 and O3 exposure	Respiratory ED visits and hospitalizations
35	Wildfire	Scher and Ellwanger	2009	200 university students	Wildfire exposure, 2003	Depression, anxiety, physical symptoms
36	Greening/Children	Tallis et al.	2018	5th grade students from 495 elementary schools	School greenspace, race/ethnicity	Standardized test scores

37	Wildfire/Children	Thilakaratne et al.	2022	CA ED visits and hospitalizations, 2008 to 2016	Wildfire smoke PM2.5	Cardiorespiratory ED visits and hospitalizations
38	Mobility	Winter et al.	2019	Urban park visitors in Los Angeles, CA	Park characteristics	Usage, physical activity, ozone exposure
39	Mobility	Wu et al.	2019	Residents of Sacramento region	Transportation planning scenarios	Health outcomes by sociodemographic factors
40	Mobility	Yougeng Lu	2021	Los Angeles County residents	Mobility	PM 2.5 exposure
41	Greening/Children	Younan et al.	2015	9-18 year olds in Risk Factors for Antisocial Behavior Study	Neighborhood greenspace	Parent reported agressive behaviors
42	Mobility	Yu et al.	2023	EV purchasers, 2015-2020	Sociodemographic factors	EV ownership, Near roadway air quality

7.3. Appendix 3.0: Summary of Available Datasets, Tools, and Online Resources

A. Demographic Variables

DATA SOURCE	SOURCE	DESCRIPTION	LINK or REFERENCE	Paper #
American Community Survey demographic estimates	U.S. Census Bureau	Demographic characteristics including race/ethnicity, housing, education,	https://www.census.gov/programs-surveys/acs	11, 28, 29, 19, 40
Demographics ED/hospital visits	California Department of Health Care Access and Information (HCAI), Formerly California's Office of Statewide Health Planning and Development (OSHPD)	Collects and manages data from multiple health plans and facilities, including ED /hospital admissions, discharges, and demographics	https://hcai.ca.gov/	27, 9, 5, 23, 37, 15, 14
County and state population estimates	State of California Department of Finance	Population demographic projections	https://www.dof.ca.gov/Forecasting/Demographics/Projections/	37
2010 Decennial Census Data	U.S. Census Bureau	Demographic characteristics including race/ethnicity, housing, education,	https://www.census.gov/programs-surveys/decennial-census/decade.2010.html#list-tab-693908974	32
1990 Decennial Census Data	U.S. Census Bureau	Demographic characteristics including race/ethnicity, housing, education,	https://www.census.gov/library/publications/1992/dec/cp-1.html	32
Death Profiles by County	CA Department of Public Health	Death counts for California counties based on death certificates	https://data.chhs.ca.gov/dataset/death-profiles-by-county	22, 8, 4, 1
Vital Records Data and Statistics	CA Department of Public Health	Birth/death certificates, fetal death/still birth certificates	https://www.cdph.ca.gov/Programs/CHSI/Pages/Data-and-Statistics-.aspx	8, 16, 18, 13, 6, 39
Demographics of e-bike rebate program users	Contra Costa County and UC Davis	Demographic characteristics	Data available on request https://www.sciencedirect.com/science/article/pii/S0967070X23001725?via%3Dihub#da0010	39
Demographics of park users in City of Los Angeles	Researchers from US Forest Service and Cal State Polytechnic University	Gender, age group, ethnicity, activity level	Data not publicly available	38

B. Health Outcomes

DATA SOURCE	SOURCE	DESCRIPTION	LINK or REFERENCE	Paper #
Birth and death records	Center for Health Statistics and Informatics, CA Department of Public Health	Infant mortality, preterm birth, low birth weight, stillbirth, deaths	https://www.cdph.ca.gov/Programs/CHSI/Pages/Data-and-Statistics-.aspx	22, 1
Birth outcomes	Kaiser Permanente Southern California/ Kaiser Permanente Northern California, Electronic Health Record database	Gestational age at delivery	Not publicly available	2, 21
Medicare Claims data	Centers for Medicare and Medicaid Services	Hospital admissions	https://www.cms.gov/data-research/statistics-trends-and-reports/basic-stand-alone-medicare-claims-public-use-files	26
Morbidity and Mortality	CA Department of Public Health Environmental Health Investigations Branch	ED visits and hospitalization data	https://www.cdph.ca.gov/Programs/CCDPHP/DEODC/EHIB/pages/home.aspx	34
Morbidity and Mortality	California Department of Health Care Access and Information (HCAI)	ED visits and hospitalization data	https://hcai.ca.gov/	37,34
Morbidity and Mortality	National Center for Health Statistics (NCHS, Centers for Disease Control and Prevention (CDC)	ED visits and hospitalization data, deaths	https://www.cdc.gov/nchs/index.htm	20
Morbidity and Mortality	Indian Health Service, Hoopa Reservation Clinic Data	Visits for respiratory and circulatory illness	Not publicly available	25
Mortality	California Department of Health Services, Health Data and Statistics Branch	Death Statistical Master Files	https://data.chhs.ca.gov/dataset/death-profiles-by-county	22,8, 4

C. Meteorological Data

DATA SOURCE	SOURCE	DESCRIPTION	LINK or REFERENCE	Paper #
Air Quality and Meteorological Information System	California Air Resources Board	Air Quality and Meteorological Information System	https://www.arb.ca.gov/aqmis2/aqmis2.php	23
California Irrigation Management Information System (CIMIS)	California Department of Water Resources	Weather stations collecting air temperature, relative humidity, wind speed	http://www.cimis.water.ca.gov/	2,8,7,4,3,5, 6
Daymet Version 4 (Daily Surface	NASA	Gridded estimates of daily weather and climatology variables	Thornton et al. Daymet: Daily Surface Weather Data on a 1-km Grid for	9
Weather and Climatological Summaries)			North America, Version 4. ORNL Distributed Active Archive Center; 2020 https://daac.ornl.gov/DAYMET/guides/Daymet_Daily_V4.html	
gridMET	UC Merced	Maxi/min temperature, precipitation accumulation, wind, humidity	https://www.climatologylab.org/gridmet.html	21,16,28
Heat index (HI) algorithm	US National Weather Service	Daily maximum heat index	https://www.wpc.ncep.noaa.gov/html/heatindex_equation.shtml	21
Landsat 8 Operational Land Imager (OLI) Tier 1	U.S. Geological Survey	Land surface temperature	https://www.usgs.gov/landsat- missions	11
National Climatic Data Center	National Oceanic and Atmospheric Administration (NOAA)	Meteorological data	https://www.sciencebase.gov/catalog/item/5526e945e4b026915857c713	7,8,4,5,34,1
NCEI first-order Automated Surface Observing System and Cooperative Observer (COOP) Summary of the Day	National Weather Service	Daily minimum and maximum temperatures, snowfall, 24-hr precipitation	https://data.ucar.edu/dataset/daily-meteorological-data-for-u-s- cooperative-stations-from-ncdc- td3200	2,42
North American Regional Reanalysis (NARR)	National Centers for Environmental Prediction (NCEP),	Temperature, humidity	https://journals.ametsoc.org/view/journals/bams/87/3/bams-87-3-343.xml	27

D. Air Quality

DATA SOURCE	SOURCE	DESCRIPTION	LINK or REFERENCE	Paper #
Air Quality System Data Mart	US Environmental Protection Agency	Air quality data	http://www.epa.gov/ttn/airs/aqsdatamart/	5
California Air Quality and Meteorological Information System	California Air Resources Board	Air Quality and Meteorological Information System	https://www.arb.ca.gov/aqmis2/aqmis2.php	7
GEOS-CHEM, version v9-01-03	Harvard University, Atmospheric Chemistry Modeling Group	Global 3-D model of atmospheric chemistry driven by meteorological input from the Goddard Earth Observing System (GEOS) of the NASA Global Modeling and Assimilation Office	https://geoschem.github.io/	17,26
Global Fire Emissions Database		Wildfire emissions estimates	https://acp.copernicus.org/articles/10/11707/2010/acp-10-11707-2010.html	26
Hazard Mapping System Fire and Smoke Product	Office of Satellite and Product Operations, NOAA	Smoke plume data	https://www.ospo.noaa.gov/Products/land/hms.html	37, 18, 10
Machine learning model		Daily, ZCTA-level estimates of mean total and wildfire-specific PM2.5 concentrations	https://doi.org/10.1016/j.envint.2022.107719	10
PurpleAIR Sensors	PurpleAir, Inc.	Particulate Matter data (PM1.0, 2.5, 10)	https://www2.purpleair.com/	28, 24, 40

E. Wildfire Data

DATA SOURCE	SOURCE	DESCRIPTION	LINK or REFERENCE	Paper #
Wildland fires	National Interagency Fire Center	Current and historic wildland fire perimeters	https://data-nifc.opendata.arcgis.com/search	28, 29
Fire Impact Questionnaire	Developed by authors	Assess direct and indirect impact of wildfire on respondent's life	Scher, C. D., & Ellwanger, J. (2009). Fire-related cognitions moderate the impact of risk factors on adjustment following wildfire disaster. Journal of Anxiety Disorders, 23(7), 891–896. https://doi.org/10.1016/j.janxdis.2009.05.007	35
Fire and Resource Assessment Program (FRAP)	California Department of Forestry and Fire Protection	Fire Perimeters	https://frap.fire.ca.gov/mapping/gis-data/	28,29

F. Environmental Data

DATA SOURCE	SOURCE	DESCRIPTION	LINK or REFERENCE	Paper #
CalEnviroScreen 3.0	California Office of Environmental Health Hazard Assessment	Census tract level pollution burden score based on environmental, health, and socioeconomic information	https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30	31
CalEnviroScreen 4.0	California Office of Environmental Health Hazard Assessment	Census tract level pollution burden score based on environmental, health, and socioeconomic information	https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-40	12, 24, 42
Home Owners' Loan Corporation (HOLC) redlining maps	Mapping Inequality, University of Richmond	GIS files of historically redlined cities neighborhood scores	https://dsl.richmond.edu/panorama/redlining/#loc=5/39.096/-94.592	19
Landsat 8 OLI Level 1	US Geological Survey and NASA	atmospherically corrected surface reflectance, land surface temperature, and top of atmosphere derived from the data produced by the Landsat 8 OLI/TIRS sensors	https://developers.google.com/earth-engine/datasets/catalog/landsat-8	12
National Agriculture Imagery Program (NAIP)	US Dept of Agriculture	High-resolution NDVI imagery layer for continental US	https://naip-usdaonline.hub.arcgis.com/	36, 41
Normalized Difference Vegetation Index (NDVI)	National Centers for Environmental Information, NOAA	Gridded daily NDVI derived from the Surface Reflectance Climate Data Record (CDR) since 1981	https://www.ncei.noaa.gov/products/climate-data-records/normalized-difference-vegetation-index	13
CA School Campus Database	Developed by Stanford Prevention Research Center and currently published by GreenInfo Network	GIS parcel-level data set with outlines for all public schools and colleges/universities in CA	https://www.californiaschoolcampusdatabase.org/	33

G. Education Outcomes

DATA SOURCE	SOURCE	DESCRIPTION	LINK or REFERENCE	Paper #
Standardized Testing and Reporting (STAR)	CA Department of Education	Standardized test scores for CA from 1998-2013. No longer administered by CDE)	https://www.cde.ca.gov/re/pr/star.asp	36

H. Transportation

DATA SOURCE	SOURCE	DESCRIPTION	LINK or REFERENCE	Paper #
Traffic-Related Air Pollution	California Air Resources Board	CA emissions from onroad mobile sources using EMFAC2021 v1.0.2 growth model	https://ww2.arb.ca.gov/msei-modeling-tools-emfac-software-and-technical-support-documentation https://arb.ca.gov/emfac/	32
CA Clean Vehicle Rebate Project (CVRP)	Center for Sustainable Energy on behalf of CARB	data from consumers who purchased or leased an eligible clean vehicle, received a rebate, and responded to a voluntary CVRP Consumer Survey	https://cleanvehiclerebate.org/en/rebate-statistics	19
California Integrated Transport and Health Impacts Model (ITHIM)	University of California, Davis	Transportation model/tool that contrasts transport planning alternatives to estimate health impacts and costs	https://skylab.cdph.ca.gov/HealthyMobilityOptionTool-ITHIM/ Maizlish N, Tomari K, Jiang C, Weiher A, Grajdura S, London JK, Rudolph L. California ITHIM, R/Shiny Version. User's Guide and Technical Manual. Davis, CA: University of California; 2019	39
CA e-bike rebate program	Institute of Transportation Studies, University of California, Davis (ITS-Davis)	Survey data from three CA rebate programs including demographics, and travel behaviors [Redwood Coast Energy Authority (RCEA), Peninsula Clean Energy (PCE), and Contra Costa County (CC) rebate programs]	Data available upon request	30
CA onroad vehicle population estimates	California Air Resources Board	Estimates of vehicle types based on vehicle registration data from CA DMV	https://arb.ca.gov/emfac/fleet-db	42
CA onroad vehicle population and infrastructure	California Energy Commission	Aggregated vehicle registration data	https://www.energy.ca.gov/files/zev-and-infrastructure-stats-data	42
GEOS-Chem	Open access model	Global model of atmospheric chemistry using meterological input from Goddard Earth Observing System (GEOS)	https://geoschem.github.io/	26, 17
Mobile Emissions Toolkit for Analysis (META)	California Air Resources Board	CA onroad population and emissions from medium and heavy-duty vehicles	https://arb.ca.gov/emfac/meta/	42, 32

Research LINE(RLINE) source model for near roadway pollution dispersion	RLINE source dispersion model	Model for mobile source pollutants alongs roadways a	Snyder, M. G., Venkatram, A., Heist, D. K., Perry, S. G., Petersen, W. B., & Isakov, V. (2013). RLINE: A line source dispersion model for near-surface releases. Atmospheric Environment, 77, 748–756. https://doi.org/10.1016/j.atmosenv.2013.05.074	32
Travel demand model/ Activity-Based Model (ABM) /	Southern California Association of Governments (SCAG)	Simulates daily travel patterns and sociodemographic characteristics of individuals in SCAG region	https://scag.ca.gov/activity-based-model	42, 40

7.4. Appendix 4: Conceptual Model