Final Report

Improved Assessment and Tracking of Health Impacts for California Communities Most Burdened by Pollution

Principal Investigator:
Michael Jerrett, PhD

Prepared for:

California Air Resources Board and the California Environmental Protection Agency
Research Division
PO Box 2815
Sacramento, CA 95812

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Prepared by:

The Regents of the University of California, Los Angeles
Office of Contract and Grant Administration
10889 Wilshire Blvd., Suite 700
Los Angeles, CA 90095-1406
(310) 794-0236

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Table of Contents

Table of Contents: Tables

Table of Contents: Figures

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Abstract

The report, *Improved Assessment and Tracking of Health Impacts for California Communities Most Burdened by Pollution*, outlines the development of tools and methods to assess and communicate the health impacts of air quality interventions. Sponsored by the California Air Resources Board (CARB), this project aimed to address gaps in evaluating the health benefits of Assembly Bill (AB) 617, which prioritizes pollution-burdened communities through localized air quality improvements. The project focused on improving the assessment of public health outcomes associated with environmental policies, particularly in communities disproportionately affected by air pollution.

A key outcome of this project was the development of the CalHealthMap dashboard, a web-based platform designed to provide accessible, zipcode-level visualizations of health metrics linked to air pollution. The dashboard integrates multiple health indicators, including asthma-related ER visits, cardiovascular disease, and mortality rates, allowing users to explore community health trends through interactive features. Stakeholder engagement played a critical role in the dashboard's iterative development, ensuring usability and relevance for community members, policymakers, and researchers. Key refinements based on stakeholder feedback included step-by-step navigation, simplified metric descriptions, and benchmark comparisons to statewide and "healthy community" standards. A significant gap identified through stakeholder discussions was the need for a dedicated regional workshop for agencies and policymakers. Recommended by AIRE Collaborative members, such a workshop would help align state and local agency efforts, foster collaboration between agencies and community stakeholders, and ensure that the dashboard remains policy-relevant and integrated with existing environmental programs. Additionally, the workshop would support long-term engagement and impact, ensuring the dashboard continues to meet evolving policy and community needs.

In addition, this report details the application of quasi-experimental statistical models, including Difference-in-Differences (DiD), to evaluate the effectiveness of air quality interventions. Specifically, the project assessed the Goods Movement Corridors (GMC) policy, which aimed to reduce emissions from transportation and freight activities in heavily polluted areas. Using multiple statistical approaches, the analysis examined birth outcomes (low birth weight and pre-term birth rates). Results were mixed, with some models suggesting a modest impact on pre-term birth rates, while others found no significant policy effect.

Both components of the project faced key limitations. For Part 1 (CalHealthMap Dashboard), challenges included data availability constraints, as recent health data were limited, affecting the ability to provide up-to-date insights. Additionally, resource limitations restricted mobile optimization, which could impact accessibility for certain users. The long-term sustainability of the dashboard remains uncertain, as ongoing funding and maintenance are needed to ensure its continued relevance and effectiveness. For Part 2 (Causal Modeling Analysis), several methodological constraints should be acknowledged. The limited number of time points in the pre-post and DiD models restricts the ability to assess long-term trends, and the assumption of parallel trends between policy-affected and control areas cannot be directly tested. The Interrupted Time-Series (ITS) analysis assumes a linear trend in birth outcomes, which may not accurately reflect real-world variability, and the short follow-up period limits the ability to detect long-term policy

effects. The lack of a true counterfactual in some models further complicates causal attribution, while potential residual confounding—such as unmeasured maternal characteristics or neighborhood-level stressors—may have influenced birth outcomes independently of the policy.

This report underscores the importance of integrating rigorous statistical methods and providing accessible public health information to inform on environmental policy. While methodological limitations highlight the complexity of policy evaluation, continued investment in data infrastructure and reporting will strengthen future assessments on communication of impacts. The CalHealthMap dashboard and similar tools have the potential to play a crucial role in advancing environmental justice and public health equity across California and beyond.

Executive Summary

Introduction: The report, *Improved Assessment and Tracking of Health Impacts for California Communities Most Burdened by Pollution*, was prepared for the California Air Resources Board (CARB) to address the need for improved methods and tools to evaluate the health impacts of air quality interventions and communicate community health trends across the state. This initiative aligns with Assembly Bill (AB) 617, which prioritizes air quality improvements in communities disproportionately burdened by pollution. These communities experience elevated health risks, including asthma, cardiovascular disease, and increased mortality.

The project was structured into two key components:

1. CalHealthMap Dashboard (Part 1) – A web-based tool designed to communicate zipcode-level health outcomes related to air pollution.
2. Causal Modeling Framework (Part 2) – A statistical framework developed to evaluate the effectiveness of air quality interventions.

Methods: This project was conducted in two phases, each employing distinct analytical approaches to assess community health outcomes and air quality interventions. In Part 1, methods were developed to analyze key health metrics derived from emergency room (ER) datasets, including asthma-related and cardiovascular disease-related visits as well as mortality rates, adjusting for age and sex to ensure accurate community health assessments. Stakeholder engagement was a critical component, involving community workshops, focus groups, and peer review sessions. Feedback from stakeholders guided iterative improvements to the CalHealthMap dashboard, enhancing accessibility and usability. Key features included step-by-step navigation, clear explanations of complex metrics, and comparisons to statewide and "healthy community" benchmarks to support diverse user needs. In Part 2, advanced statistical modeling was applied to evaluate the impact of air quality interventions. Quasi-experimental methods, including Difference-in-Differences (DiD), were used to assess the effects of the Emission Reduction Plan for Ports and Goods Movement (ERPPGM), also refered to as the Goods Movement Corridors (GMC) policy. This initiative aimed to reduce emissions in heavily polluted freight and transportation zones.

Results: The CalHealthMap dashboard (Part 1) emerged as a user-friendly, web-based tool designed to visualize and assess the health impacts of air pollution. It provides detailed health metrics, integrating spatial smoothing and benchmark comparisons to generate actionable insights. Stakeholder feedback emphasized the need for clear, actionable data to inform advocacy and policy decisions. For example, monitoring respiratory and cardiovascular conditions was identified as a top priority, with additional suggestions to include neurological and dermatological health outcomes for a more comprehensive understanding of the links between air pollution and health. Refinements to the tool improved usability, accessibility, and data presentation, ensuring its relevance to community members, researchers, and policymakers. Despite its success, the project faced challenges, including limited availability of recent data, resource constraints for mobile optimization, and the need for sustained funding to expand its capabilities.

The causal modeling (Part 2) offered a framework for evaluating interventions by leveraging multiple statistical approaches to assess the policy's impact on birth outcomes. For low birth weight (LBW) rates, the Pre- & Post-Analysis indicated a slight but statistically significant increase post-policy (OR = 1.019, 95% CI: 1.009, 1.029). However, all other models, including 2x2 Difference-in-Differences (DiD), Interrupted Time-Series (ITS) Analysis, and Generalized DiD, found no statistically significant policy effect on LBW rates. Similarly, our pre-term birth analyses produced mixed findings. The Pre- & Post-Analysis indicated a statistically significant decline in pre-term birth rates post-policy (OR = 0.906, 95% CI: 0.899, 0.913). The ITS Analysis also found a slight but significant decrease in pre-term births compared to projected trends (OR = 0.973, 95% CI: 0.958, 0.988), suggesting the policy may have contributed to this reduction. However, the 2x2 DiD model (OR = 0.995, 95% CI: 0.985, 1.005) found no evidence of a differential change in pre-term birth rates between policy-exposed and control areas. Likewise, the Generalized DiD model (OR = 1.028, 95% CI: 0.984, 1.075) did not support a policy effect when accounting for trends across multiple regions. These findings highlight the complexity of evaluating policy interventions and suggest that unmeasured factors or dataset limitations may influence birth outcomes.

Conclusions: This project developed tools to assess and communicate the health impacts of air pollution in California's most burdened communities. Part 1 resulted in the CalHealthMap dashboard, a user-friendly platform providing granular health insights to support policy and advocacy. Part 2 established a causal modeling framework to evaluate air quality interventions, yielding mixed findings on birth outcomes and highlighting the complexity of policy impact assessment. While challenges such as data limitations and sustainability remain, this work provides a foundation for ongoing efforts to improve health tracking and inform evidence-based decision-making.

Background

The purpose of this project was to develop a health tracking system in response to Assembly Bill (AB) 617, which aims to protect communities disproportionately impacted by air pollution. This initiative, directed by the California Air Resources Board (CARB) and local air districts, provides funds for community-based air monitoring and the creation of Community-Specific Emission Reduction Plans (CERP). While these plans aim to address pollution sources and improve environmental conditions, a critical gap emerged: the absence of a systematic way to track potential health improvements resulting from these emission reduction efforts. Without such tracking, it would be challenging to evaluate the effectiveness of these programs and ensure they meet community health needs.

In collaboration with the Public Health Institute's (PHI) Tracking California program, the current project titled "*Improved Assessment and Tracking of Health Impacts for California Communities Most Burdened by Pollution*", utilized individual morbidity and mortality data from small geographic areas (at zip code level) for two primary objectives. The first objective focused on designing and developing a user-friendly health tracking dashboard system called CalHealthMap. The CalHealthMap dashboard would serve as a proof of concept for CARB, demonstrating how health tracking systems can be designed to monitor the health impacts of air quality improvements over time. CalHealthMap was developed with the intention of not only providing health insights but also guiding CARB in the potential development of future health tracking dashboards. Throughout the project, the development process was deeply rooted in collaboration with community groups, local agencies, non-profit organizations, and individual community members to understand their needs and expectations for future health tracking systems.

The second objective focused on identifying and evaluating policies that could improve health outcomes in communities impacted by air pollution. In collaboration with community stakeholders, agencies, and researchers, the team explored suitable policies, ensuring the dashboard would support ongoing and future policy evaluations. This aspect included the consideration of historical interventions to assess their health impact on communities near transportation corridors and ports. Given the evolving nature of AB 617 interventions, many CERPs are still in their planning or early implementation stages, presenting challenges for immediate evaluation. The project team collaborated with CARB, community groups, community-based organizations (CBOs) and community members to explore suitable policies for analysis. Ultimately, the 2007 Goods Movement Actions (GMA) policy was selected for evaluation which focused on health outcomes, particularly birth outcomes, for residents living near goods movement corridors and ports, compared to control areas further from these corridors. The project research team implemented difference-in-difference (DiD) models, based on advanced quasi-experimental methods, to evaluate public health improvements.

The current report details the tasks and subtasks outlined in the project description, covering the process of framework development, data collection, stakeholder engagement, dashboard creation, and reporting. It also explores the data gaps and recommendations gathered from community input, offering insight into how future health tracking systems can be improved. By following a structured framework and prioritizing community involvement, the project lays the foundation for a scalable health tracking tool that can evolve to meet the changing needs of California's most vulnerable communities and policies developed to protect public health.

Task 1: Develop Health Indicators from Administrative Data

Develop a sustainable set of health indicators, using data to track community health trends influenced by air pollution. Identify relevant health indicators that reflect the impact of emission reduction efforts in AB 617 communities.

Subtask 1: Community Engagement and Outreach

Engage with AB 617 community members, local stakeholders, and air district staff in the Bay Area, Central Valley, and Los Angeles regions. The outreach will involve providing accessible background information on air pollution's health effects and gathering input on prioritized health indicators. On-the-ground networking and regional meetings further helped build relationships with stakeholders.

Deliverables

- Agendas and notes from monthly planning meetings.
- Quarterly conference calls with AIRE Collaborative members to coordinate outreach activities.
- Outreach plan and materials translated into multiple languages.
- Documentation of meetings, agenda, notes, and feedback from AB 617 stakeholders.

Subtask 2: Health Metrics Identification

Review past meeting notes to identify priority health indicators. Refine metrics and explore the role of community-generated data in filling data gaps during AIRE collaborative meetings.

Deliverables

- Summary report on health indicators and identified data gaps.

Subtask 3: Identify Interventions for Health Outcome Evaluation

The contractor collaborated with CARB and community organizations to identify suitable air quality interventions for analysis. This subtask focused on developing criteria to ensure the selected interventions have sufficient data, are statistically valid, and are relevant to affected communities.

Task 2: Develop a Causal Modeling Framework

Use quasi-experimental models, such as the difference-in-difference (DiD), to evaluate the impact of air quality interventions. Assesses how emission reduction policies impact community health outcomes over time.

Task 3: Develop a Web-Based Dashboard

An online dashboard will be created to display the health metrics identified in Task 1, making use of data sources available to PHI's Tracking California. This dashboard and its underlying data processing requirements will be designed such that the dashboard could be updated regularly to reflect the ongoing health status of AB 617 communities.

Subtask 1: Dashboard Design and Community Review

Coordinate with community partners to design a user-friendly dashboard. Ensured the dashboard met community needs and displayed complex statistical findings in accessible formats. The dashboard will also feature report cards comparing community health outcomes over time.

Deliverables

- A functional web-based dashboard.
- Documentation of software code and user manuals to support dashboard maintenance.

Subtask 2: Data Display and Reporting

In addition to real-time data on health outcomes associated with air quality, the dashboard will include visualizations that will better enable stakeholders to monitor improvements in health outcomes.

Task 4: Reporting and Project Documentation

Provide CARB with regular project updates and submit a final report detailing the study's findings, methodologies, and recommendations.

Deliverables

- Quarterly progress reports.
- Draft and final versions of the project report, including lay-friendly summaries for community members.
- Presentation of project findings at CARB's Chair's Seminar.

Guided by the tasks and subtasks, the CalHealthMap dashboard was created as a proof of concept for the CARB to explore how health outcomes can be monitored over time and guide future health tracking efforts. The development of the dashboard involved extensive collaboration with CBOs, state and local agencies, and residents to ensure it reflected both community needs and policy priorities. Additionally, the project team evaluated health outcomes from emission reduction efforts, using the 2007 Goods Movement Actions (GMA), also commonly referred to as the Goods Movement Corridors (GMC), policy for analysis. The following sections outline the methods used to engage communities, identify data gaps, and develop the dashboard, as well as the results from evaluating a policy's impact on health outcomes in communities near transportation corridors and ports. These efforts offer a framework for future health tracking systems and insights to enhance public health interventions.

Part 1, Section 1: Develop Health Indicators from Administrative Data (Task 1)

Introduction

The methods employed in this project reflect a rigorous, data-driven approach to assessing the health impacts related to air pollution within communities disproportionately affected by pollution. Central to this approach was the incorporation of community engagement as a key element, ensuring that the health tracking system was both scientifically robust and aligned with the lived experiences and priorities of affected communities. Through workshops, focus groups, surveys, and continuous feedback loops, residents, local organizations, and stakeholders provided essential insights that informed the selection of health indicators and refined the usability of the system. This iterative engagement process not only ensured that the tracking system met the needs of its users but also fostered trust and collaboration throughout the project's development.

A strong partnership was built with the Allies in Reducing Emissions (AIRE) Collaborative, a network of environmental justice organizations in California dedicated to improving air quality and public health in communities disproportionately affected by pollution. AIRE, established in response to AB 617's mandate to address statewide air quality inequities, is focused on fostering community-led air monitoring and emissions reduction strategies. Their work includes creating air quality monitoring systems with emerging technologies, conducting stakeholder workshops and trainings, and collaborating with researchers to test innovative monitoring tools.

Our engagement process was iterative and collaborative, providing AIRE members with multiple opportunities to shape the project. Through this collaboration, led by Christian Torres from Comité Civico del Valle (CCV) and Daniela Flores from the Imperial Valley Equity and Justice Coalition, we gained critical insights into local health priorities and metrics, environmental challenges, air pollution interventions, and the usability of the proposed tracking system. This participatory approach not only strengthened the scientific and technical aspects of the project but also fostered trust and transparency between the project team and the communities involved.

Throughout the project, we maintained an open dialogue with community members via workshops, focus groups, surveys, and continuous feedback loops. This engagement was essential for identifying relevant health indicators and ensuring the tracking system's accessibility and user-friendliness. The active involvement of community members also helped address potential challenges and refine the system to better meet user needs. Overall, our community engagement efforts underscored the value of collaborative problem-solving and affirmed the community's role as an indispensable partner in achieving the project's objectives.

Methods

Community Engagement and Outreach (Task 1, Subtask 1)

Extensive efforts were made to ensure that the health tracking system was developed in close collaboration with the communities most affected by air pollution. Below is a summary of the key community engagement activities with the AIRE collaborative, CARB, community members, and broader stakeholder groups:

Identifying Community Needs and Concerns

The project team conducted initial consultations with community members, local organizations, CARB staff, and air district staff to understand the specific health concerns and priorities of the communities disproportionately affected by air pollution. These consultations helped in identifying the most relevant health indicators and air quality interventions for evaluation.

Collaboration with Local Organizations

The project partnered with the AIRE Collaborative to facilitate community engagement and ensure that it addressed the community's needs effectively. Meetings began in late 2022 and continued through 2024, with a gradual increase in activity over time. During the first year, engagement activities were paced to lay a strong foundation, which evolved into more frequent interactions in the second year to support successful workshop development and participant recruitment.

Workshops and Focus Groups

During the summer of 2024, several workshops were organized to gather input from key decision-makers and community members on the design and functionality of the health tracking system. Workshop outreach aimed to provide accessible background information on health effects from air pollution and gather input on prioritized health indicators. AIRE Collaborative members conducted on-the-ground networking and recruitment to help increase workshop attendance, particularly DAC members, local stakeholders, air district staff in the Bay Area, Central Valley, and Los Angeles regions,, and other communities disproportionally impacted by air pollution. These workshops provided a valuable forum for stakeholders to share their concerns, suggestions, and expectations, ensuring their perspectives shaped the CalHealthMap tool's development. Additionally, focus groups were conducted to explore the lived experiences of community members impacted by air pollution, review the enhanced health tracking system, and provide feedback on its functionality. These sessions deepened our understanding of the social and environmental context in which the health tracking system would be used, guiding the project to develop a tool that was well-aligned with the community's needs and realities.

Surveys and Feedback Mechanisms

Online surveys were used to gather qualitative feedback on health concerns, air quality perceptions, and the usability of the CalHealthMap tool. Continuous feedback mechanisms were established, including emails and community meetings, to ensure that community members could provide input throughout the project lifecycle.

Public Demonstrations and Pilot Testing

Public demonstrations of the pilot CalHealthMap tool were held to showcase its features and gather real-time feedback in a "Community Peer Review" process that occurred in late 2024. These community peer-reviews were essential in refining the system functionality based on user experiences. The system was pilot tested with the AIRE Collaborative, Oakland area community stakeholder group, CARB, and various collaborating entitles to evaluate its effectiveness and gather detailed feedback on its functionality and usability.

Outcomes and Impact

The feedback from the community informed critical design and functionality aspects of the CalHealthMap tool, making it more user-friendly and relevant to community needs. For specific examples of community feedback, see Table 6. The project established a sustainable framework for ongoing community engagement, ensuring that the health tracking system can be continually improved and adapted based on community feedback.

Through these comprehensive engagement efforts, the project not only developed a scientifically valid and responsive health tracking system but also fostered a sense of ownership and empowerment among community and AIRE Collaborative members. The active participation of the community was vital in ensuring that the health tracking system would be a valuable tool for monitoring and improving public health in communities disproportionately affected by air pollution.

Deliverables

- Agendas and notes from monthly planning meetings.
- Quarterly conference calls with AIRE Collaborative members to coordinate outreach activities.
- Outreach plan and materials translated into multiple languages.
- Documentation of meetings, agenda, notes, and feedback from AB 617 stakeholders.

Health Metrics Identification (Task 1, Subtask 2)

Through the Community Engagement and Outreach efforts outlined in Task 1, Subtask 1, we were able to identify and refine health metrics related to air pollution that are of highest concern to the community. In collaboration with our project partners at Tracking California, we accessed critical health data for modeling purposes including data from the Healthcare Access and Information (HCAI) and the California Comprehensive Death File (CCDF). Working closely with our project team and community collaborators, we further refined these metrics and explored the potential of community-generated data to address data gaps, particularly during AIRE collaborative meetings.

Health Metrics: Morbidity and Mortality Data Sources (2012 – 2018)

The Healthcare Access and Information (HCAI) dataset is a comprehensive resource used for analyzing healthcare utilization and outcomes in California. This dataset includes detailed information on hospital emergency room (ER) visits, inpatient discharges, and outpatient surgeries. It covers a wide range of variables, including patient demographics (age, sex, race, ethnicity), clinical data (diagnoses, procedures, admission source, discharge status), and administrative details (facility type, length of stay, charges). The HCAI dataset allows for in-depth analysis of healthcare trends, patient outcomes, and service utilization patterns. It supports public health research by providing insights into disease prevalence, healthcare access disparities, and the impact of health policies. Despite its richness, the dataset may have limitations in data completeness and coding accuracy. Overall, however, the HCAI dataset is crucial for monitoring and improving healthcare delivery and public health in California.

The California Comprehensive Death File (CCDF) mortality dataset is an essential tool for public health research, providing detailed records of deaths across the state. It includes key demographic information such as date of birth, date of death, sex, marital status, and education level. The dataset also offers comprehensive geographic data, including residence and place of death zip codes, as well as census tract details. Cause of death is documented with both immediate and ICD-10 coded causes, allowing for standardized epidemiological studies. Despite its comprehensiveness, the dataset may have occasional gaps, and projections must account for changes in demographics and public health behaviors over time. Overall, the CCDF dataset supports identifying mortality trends, assessing health disparities, evaluating public health interventions, and conducting detailed epidemiological research.

The following candidate health outcomes have been shown in the literature to be associated with air pollution exposures (Turner et al. 2016; Markozannes et al. 2022) and are most likely to be sensitive to changes in air quality and may be selected after consultation with the community:

Table 1. Neighborhood-level health metrics (by zip code) included for visualization in the CalHealthMap tool. This table provides a list of health outcomes or conditions, along with their corresponding International Statistical Classification of Diseases (ICD-10) codes or data sources. The outcomes include a range of morbidity and mortality conditions such as diabetes (ICD-10 codes E10–E14), asthma (J45), cardiovascular diseases (I20–I25, I30–I51, I60–I69, I70), cerebrovascular disease (I60–I69), and respiratory conditions (J00–J98, including COPD and allied conditions J19–J46).

Health Outcome or Condition (Morbidity & Mortality)	**International Statistical Classification of Diseases (ICD-10) code (Primary Diagnosis) or Source***
Diabetes	E10–E14
Asthma	J45
Disease of the Circulatory System + Diabetes	I00–I99, E10–E14
Ischemic heart disease	I20–I25
Cardiovascular	I20–I25, I30–I51, I60–I69, I70
Dysrhythmias, heart failure, cardiac arrest	I30–I51
Cerebrovascular disease	I60–I69
All-cause Respiratory	J00–J98
COPD and allied conditions	J19–J46

*Health outcomes include ICD codes listed here and all subcodes as well. For example, “Asthma” includes the parent asthma category (J45) as well as subcategories like “J45.2” for mild intermittent asthma, “J45.3” for mild persistent asthma, etc.

Data Analyses: Morbidity and Mortality

One approach to examining excess disease counts as compared to what one would expect given a reference population is the calculation of Standardized Incidence Rates (SIRs) (Becher and Winkler 2017) and Relative Risks (RRs) (Tenny and Hoffman 2024). An SIR is a ratio that estimates the observed occurrence of an event in a population relative to the expected occurrence of the event in a larger comparison population. For example, if 20% of individuals in a large reference population have a disease, then in a region with 20 individuals, one would expect 20*0.2 = 4 diseased individuals. If 6 individuals have the disease in the region then the SIR is 50% higher than expected. Such computations can be adjusted for demographic variable such as age and sex, so that expected counts take these factors into account.

A relative risk is like an SIR except the computation is based on a statistical model, such as a Poisson-based count model, and consists of a modeled value as opposed to an empirical point estimate. Such modeling has advantages since it can estimate measures of uncertainty, such as confidence limits and exceedance probabilities (e.g. the probability that the RR is great than one) and allow for spatial "smoothing", where data from nearby regions can inform estimates of parameters in the region in question. Such modeling is extremely useful in small areas where data is sparse, and SIRs can become "noisy" and unreliable.

HCAI and CCDF datasets consists of data collected at the individual level from 2015 – 2018 and includes a variety of demographic and clinical variables, but variables that we are primarily interested in are age, sex, patient zip code, and primary diagnosis. Before beginning the analysis, the data was subset by health condition and modified so that age and sex were categorized into four and two groups, respectively. The categories for age are: 00-19, 20-44, 45-64, and 65+, while the categories for sex are: female (F), male (M), and unknown (U). Although race/ethnicity data was available, it was excluded from the analysis due to small sample sizes within geographic areas, which introduced high variability and uncertainty in the model estimates.

The goal of the analysis is to obtain estimates for the relative risks and standardized incidence ratios of ER visits for each primary diagnosis using a spatial regression model with the R-INLA package (Rue, Martino, and Chopin 2009). Since our outcome (number of ER visits) is a count, we analyze our data using a Poisson regression.

If we let Y_i represent the observed counts of ED visits in zip code i then our model can be specified as follows:

$$Y_i \sim Poisson(E_i\theta_i), i, \dots, n, \tag{1}$$

such that E_i is the expected number of ER visits in zip code i and θ is the relative risk in zip code i. The logarithm of θ_i can be generally expressed as:

$$\log(\theta_i) = \beta_0 + \mu_i + \nu_i, \tag{2}$$

where β_0 is the intercept where and represents baseline log risk, and μ_i and ν_i represent structured and independent spatial effects, respectively. A conditionally auto-regressive (CAR) (Besag 1974) distribution is used to model μ_i which is a structured spatial effect. With this, the distribution can be specified as: $\mu_i|\mu_{-i} \sim N\left(\bar{\mu}_{\delta_i}, \frac{\sigma^2_{\mu_i}}{n_{\delta_i}}\right)$.

On the other hand, $\nu_i \sim N(0, \sigma_\nu^2)$ is the unstructured spatial effect, often known as the error term. Finally, the relative risk, θ_i is used to determine if the risk of ER visit is higher $\theta > 1$ (or lower) in zip code i when compared to the average risk in the reference population. Note that the probability $p = \Pr(\theta > 1)$ denotes the exceedance probability mentioned above and is an important measure of uncertainty. In our study, we have defined two reference groups, which yield two separate sets of relative risks and SIRs. These reference groups are further explained in the following subsections.

Reference Group 1. The “Healthy Places Index" (HPI), is a metric developed by the Public Health Alliance of Southern California (PHASC) to measure the healthiness of various neighborhoods and communities (https://www.healthyplacesindex.org/). The HPI defines a healthy community as one that provides residents with access to quality education, good jobs, safe housing, clean air and water, healthcare, and strong social support using 25 indicators across these areas. In our study, the HPI scores provided in the PHASC's public database were used to define the reference group in our first set of relative risk and SIR calculations. To begin, the HPI scores for every zip code in California obtained from the PHASC database were merged with the HCAI dataset by zip code. Next, the merged dataset was filtered using a pre-selected HPI cutoff value to identify the zip codes with “heathy” communities, defined as the top 25% of the HPI. The quantiles selected to define a “healthy” community have been frequently used in epidemiological studies and was selected after extensive consultation with the AIRE collaborative, community members, and agency partners. The higher the HPI score, the healthier the community. We then divided the total number of observed ER visits in each age/sex category by the total number of individuals belonging to that age/sex category in the population, which was estimated using the American Community Survey (ACS) census data (year of ACS were matched to year used with ER data). This calculation provided the expected ER visit rate for each age/sex combination in a healthy population. Using these rates, the expected number of cases was calculated for each zip/age/sex combination. The total number of observed ER visits in each zip code was then divided by total number of expected ER visits in the same area.

In other words, the SIR in the i^{th} zip code was calculated as follows:

$$\mathrm{SIR_i} = \frac{\text{Observed ED Visits}_i}{\text{Expected ED Vists}_\mathrm{i}}, \tag{3}$$

where $\text{Oberved ER Visits}_\mathrm{i}$ is the total number of observed ER visits in zip code i and $\text{Expected ER Visits}_\mathrm{i}$ is the expected number of ER visits in zip code i, calculated based on the assumption that the zip code has the same average rate of ER visits as zip codes with an HPI score above the cutoff. To calculate the relative risks, we supplied R with the expected counts calculated for each zip code, and the neighborhood matrix needed to define the spatial random effects. The “inla” function within the R-INLA package was then used to compute the posterior estimates of the relative risks for each zip code.

Reference Group 2 The reference group in our second set of relative risk and SIR calculations was determined using the expected number of ER visits in as the statewide population, after adjusting for age and sex. The expected rate was calculated by dividing the total number of observed ER visits in each age/sex category by the total number of individuals belonging to that age/sex category in the population, as estimated using the ACS census data. With this expected rate, we then calculated expected number of cases for each zip/age/sex combination. Subsequently, we divided the total number of observed ER visits in each zip code by the expected number of ER visits in the same zip code, yielding the SIR for the i^{th} zip code. Mathematically, the formula for

SIR_i remains the same as described in (Becher and Winkler 2017), but with Expected ER Visits_i representing the expected number of ER visits in zip code i, calculated under the assumption that the zip code has the same average rate of ER visits as zip codes across the rest of California. The relative risks in this version were calculated using the same methods, with the sole variation being the calculation of expected counts for each zip code, which were determined using the reference group defined in this section.

Deliverables

- Summary report on health indicators and identified data gaps.

Results

Community Engagement and Outreach (Task 1, Subtask 1)

Community engagement played a pivotal role in shaping the outcomes of this project, ensuring that the development of the health tracking system aligned with the needs and priorities of communities disproportionately affected by air pollution. These communities, which are disproportionately affected by air pollution, provided essential feedback throughout the project, influencing key decisions and guiding the direction of the final product. The collaborative and iterative engagement process offered residents, local organizations, and stakeholders multiple opportunities to participate, allowing the project team to gather critical insights on local health concerns, environmental priorities, and the system's usability. This participatory approach not only strengthened the scientific and technical aspects of the project but also fostered trust and transparency with the communities involved. The information gathered through workshops, focus groups, surveys, and continuous feedback loops was integral in identifying the most relevant health indicators and refining the tracking system to be accessible and user-friendly. Additionally, community input helped the team address potential challenges early, ensuring that the system met user needs effectively. The following section outlines the specific engagement activities conducted, the feedback collected from participants, and how this input was incorporated into the design and functionality of the final health tracking system.

The project team conducted extensive consultations with community members, local organizations, CARB staff, and air district staff to better understand the health concerns and priorities of communities disproportionately affected by air pollution. These consultations played a crucial role in identifying the most relevant health indicators and air quality interventions for evaluation. A timeline and general topics discussed during the various meetings are included in Table 2 below.

Table 2. Community meeting dates and general topics discussed for AIRE Collaborative, regional workshops, and other meetings since November 2022. This table outlines the timeline of key meetings along with their primary discussion points. Topics include project updates, development of the CalHealthMap dashboard, strategies for community engagement, and planning for regional workshops. Key focus areas addressed include health metric criteria, visualization tools, dashboard accessibility, and policy impacts.

Meeting Date	General Topics Discussed

November 17, 2022	Review of partners, collaborators, and roles in the project. Discussions on data visualization tools, criteria for health metrics, regional workshops, and policy impact models. Emphasis on community involvement and metrics reflecting health impacts on disadvantaged communities.
June 2023	Discussion on internal vs. public dashboard versions, regional workshops organized by phases, border community challenges, and developing health metrics to track emissions reductions. Identified capacity-building opportunities to educate communities on using both quantitative and qualitative metrics.
February 16, 2024	Project updates, dashboard strategy, accessing data from Mexico for border regions, shifting from workshops to focus groups, administrative updates including contracts and stipends.
March 1, 2024	Developing vulnerability indices, refining the CalHealthMap Index, tracking health indicators, ensuring data accessibility, gathering feedback on the dashboard design and goals.
May 10, 2024	Update on meeting with CARB, finalized workshop dates and outreach materials. Separate workshops planned for residents and organizations, with a focus on using the dashboard for a public health campaign linking air quality and AB 617 interventions.
June 7, 2024	CARB's involvement with agenda setting and outreach. Discussion on using environmental indices, dashboard development, and the need for accessible language to connect with communities. Introduced the idea of exporting mini reports for local comparisons.
June 21, 2024	Workshop logistics and outreach. Clarifying AIRE members' role, encouraging feedback on outreach strategies, and planning final preparation for CBO/resident workshops.
July 5, 2024	Workshop debriefs, reflections on breakout sessions, and feedback from members. Highlighted challenges with community engagement and discussed future agency collaborations.
August 16, 2024	Follow-up on workshops and proposed a community peer review session for the dashboard. Coordination for upcoming meetings with AB 617 steering committees and discussions about aligning with environmental justice goals.
February 16, 2024	Project updates, dashboard strategy, accessing data from Mexico for border regions, shifting from workshops to focus groups, administrative updates including contracts and stipends.
March 1, 2024	Developing vulnerability indices, refining the CalHealthMap Index, tracking health indicators, ensuring data accessibility, gathering feedback on the dashboard design and goals.

AIRE Collaborative Meetings

Between November 2022 and August 2024, CCV facilitated a series of meetings with the AIRE Collaborative to design and guide the development of regional community-based workshops.

These workshops were intended to shape a health tracking system that incorporated substantive input from community stakeholders. The collaborative effort prioritized establishing clear and effective communication to ensure that the health tracking tool reflected the priorities and needs of the communities it was designed to serve. However, early discussions revealed a key challenge: it was difficult to engage participants in developing workshops and providing feedback on a health tracking system they had not yet experienced. To address this, the team recognized the importance of creating a mockup dashboard. A working draft provided a tangible reference point, enabling participants to interact meaningfully with the proposed tool and offer informed feedback on its design and functionality. Additionally, the mockup helped build regional support by demonstrating the potential of the tool. In response, a prototype of the CalHealthMap Dashboard was developed to serve as a foundation for discussions with the AIRE Collaborative and subsequent regional workshop participants. This prototype allowed members to explore proposed features and functionalities, fostering more focused and productive dialogues about the tool's design, usability, and overall effectiveness.

Recognizing the barriers many communities face in accessing and interpreting data, AIRE Collaborative members emphasized the importance of ensuring that the dashboard would be both user-friendly and accessible. With their guidance, the mockup dashboard was refined to include educational resources and a streamlined, intuitive interface, making it more accessible to diverse users. These collaborative efforts reflect the purpose of the dashboard as a practical, community-oriented resource designed to support the advancement of environmental justice and health equity.

Discussions within the AIRE Collaborative focused on the development of health metrics related to air pollution that could effectively link improvements in air quality to measurable health outcomes, such as reductions in asthma rates and incidences of cardiovascular disease. Members emphasized the importance of designing metrics that are not only sensitive to changes in emissions but also actionable, providing clear and meaningful insights into community health trends. Particular attention was given to the unique challenges faced by border communities, which experience distinct environmental and health concerns that may not be fully captured or represented in a health tracking system like this one. These challenges, and the resulting data limitations, are further explored in the data gaps section.

During the first year of the project, engagement activities were deliberately paced to establish a strong foundation for collaboration and communication. In the second year, interactions became more frequent to support the successful development of the regional workshops and the recruitment of participants.

Community Outreach and Planning

After initial discussions on health metrics and the development of a mockup dashboard tool, the AIRE Collaborative shifted its focus to planning regional workshops. These meetings involved detailed discussions about the timeline, structure, and content of the workshops. The AIRE Collaborative played a crucial role in designing the workshops, providing feedback on materials, and assisting with recruitment efforts. These regional workshops would serve as a platform for stakeholders to share their concerns, offer suggestions, and articulate their expectations for the dashboard's design and functionality. Importantly, the workshops would enable the project team to explore the lived experiences of community members, providing deeper insights into how air pollution affects daily life and how a health tracking tool, such as the CalHealthMap Dashboard, could be used by key community stakeholders. The AIRE Collaborative designed a total of three virtual workshops: two focused on community engagement and one designed for agencies. The agency workshop, aimed to ensure that CARB and other agencies understood the needs of the communities. It also sought to promote collaboration between regional communities and agencies, fostering a sustainable tool that would continue to benefit communities long after the project's conclusion.

Input from the regional workshops was identified as critical for shaping a health tracking system that truly reflected the realities, needs, and priorities of the communities it aimed to serve. To achieve this, the CCV team, in collaboration with the AIRE Collaborative, developed a Community Outreach Plan outlining a comprehensive strategy to engage communities and stakeholders in the regional workshops. This plan was specifically designed to reach communities disproportionately affected by air pollution and other vulnerable populations, ensuring that their feedback was fully integrated into the dashboard's design. The outreach campaign was scheduled to launch in January 2024, in partnership with AIRE Collaborative members.

To ensure broad and meaningful participation, AIRE Collaborative members tailored outreach strategies to meet the unique needs of their respective regions. Participating community-based organizations included Casa Familiar (San Diego), Coalition for a Safe Environment (Los Angeles), Central California Environmental Justice Network and Valley LEAP (Central Valley), and West Oakland Environmental Indicators Project (Northern California), among others. Outreach activities targeted residents, community stakeholders, and local air districts, employing a combination of digital and in-person strategies to maximize engagement. Key outreach strategies encompassed a wide range of approaches, both digital and on-the-ground. These included mass texting, distribution of digital and physical flyers, phone banking, engagement with community messengers, and in-person announcements at public meetings. The CCV and the Imperial Valley Equity and Justice Coalition (IV Equity) spearheaded community engagement efforts, offering tutorials on effective outreach strategies such as the use of texting platforms and mail merge tools. Recognizing the importance of accessibility, outreach materials were translated into Spanish, ensuring they were accessible to a significant portion of non-English-speaking participants. CCV and IV Equity hosted drop-in technical support hours and biweekly meetings to share outreach successes, address challenges, and refine strategies.

Despite initial delays, targeted outreach efforts successfully encouraged community participation in the workshops. For example, the West Oakland Environmental Indicators Project (WOEIP) announced the workshops at a June West Oakland Community Action Plan (WOCAP) Steering Committee meeting and followed up with emails to residents, agencies, and community-based organizations (CBOs). Casa Familiar shared workshop details with seven nonprofit organizations, distributed invitations to an environmental justice listserv with over 200 contacts and promoted the events at two community gatherings. The Central California Environmental Justice Network (CCEJN) distributed information and flyers to over 17 local and state organizations and CBOs, conducted social media and email outreach, made phone calls, and engaged directly with 50 community members. The LEAP Institute contributed by sending email invitations to 18 individuals and two CBOs using contact lists from previous events. Together, these coordinated outreach efforts resulted in a broad and inclusive strategy that successfully fostered community engagement in the workshops. Registrations were collected via an online form (see Appendix).

Workshops and Focus Groups

In June 2024, the AIRE Collaborative hosted two virtual workshops on June 25th and 27th via Zoom, gathering over 100 attendees, including residents, representatives from community-based organizations (CBOs), and other stakeholders. The primary purpose of these workshops was to guide the development of a comprehensive health tracking system designed to address the health needs of communities most impacted by pollution. Through active and collaborative discussions, attendees provided critical input to shape the functionality and focus of the system.

Participants emphasized the importance of creating a platform capable of tracking access to key community resources, such as green spaces, healthy food options, and healthcare services. They also highlighted the value of integrating additional tools, such as educational programs, real-time fire alerts, and detailed information on local pollution risks, to enhance awareness and preparedness within affected communities. Attendees envisioned the platform not only as a data repository but also to empower communities with actionable information.

The potential benefits of the health tracking system were a central focus of the discussions. Attendees emphasized how the platform could help communities identify environmental contaminants, implement preventive measures, and monitor health conditions linked to air pollution. They also recognized its role in educating both residents and political representatives about the health impacts of air quality, thereby fostering advocacy and driving meaningful policy change. Monitoring respiratory and cardiovascular conditions was identified as a top priority, with additional suggestions to include neurological and dermatological health outcomes for a more comprehensive understanding of the links between air pollution and health.

Participants proposed initiatives such as community-led data collection efforts or community-based testimonials. These activities could further empower residents to take an active role in contributing to the platform, while also generating localized data. Challenges related to equity in accessing and understanding air quality data were also discussed, particularly for disadvantaged communities. Attendees stressed the importance of offering facilitation and capacity-building sessions to equip communities with the skills needed to engage with the platform effectively and use the data for advocacy.

The workshops concluded with plans to refine the prototype health tracking system based on the feedback received. Post workshop, the AIRE Collaborative and stakeholders continued reviewing the dashboard's functionalities to ensure alignment with community needs and priorities set forth in the workshops. Peer review sessions were scheduled to further evaluate and validate the system's design, ensuring it remains a responsive and effective tool for addressing the environmental and health concerns of the most affected communities. Three Peer Review sessions were conducted—first with the AIRE Collaborative, which included community leaders from across California; second with a focused community group based in Oakland; and third with representatives from California state agencies, including OEHHA, CARB, and CDPH. Detailed feedback and steps taken to address are provided in detail in Table 6.

Health Metrics Identification and Data Gaps (Task 1, Subtask 2)

The proposed health metrics for the CalHealthMap Dashboard include a range of conditions found to be related to air pollution, such as cerebrovascular disease, cardiovascular diseases, diseases of the circulatory system, respiratory conditions like asthma and chronic obstructive pulmonary disease (COPD), and all-cause mortality. These metrics were initially outlined in the project's early stages and later reviewed during the AIRE Collaborative workshops, where they received unanimous support from participants, with a suggested addition of a "total" outcome category that incorporated all morbidity outcomes into a single endpoint. In addition to the identified metrics, community feedback during the regional workshops highlighted additional health outcomes of significant importance, including birth outcomes, cancers, skin and allergy conditions, and kidney and neurological conditions. Unfortunately, resource and data limitations prevented the inclusion of these metrics in the current dashboard. For example, the latency period for cancers makes them difficult to track without long-term data and thus was omitted from the CalHealthMap dashboard. While birth outcomes like premature births and low birth weight were examined in relation to specific air pollution interventions (and outlined further in subsequent sections), their inclusion into the CalHealthMap dashboard was beyond the project's scope. Additionally, the HCAI and CCDF datasets do not capture milder health cases that could be identified through community-level sources such as school or workplace absences, school nurse visits, and prescription refills. While we attempted to collaborate with several local school districts to obtain school-level health data, this information was either unavailable for our research or too fragmented to be integrated into a statewide dashboard.

Feedback from workshops also emphasized the importance of including data from community-generated sources. For example, residents of border communities highlighted the need for cross-border healthcare usage data to fully understand the environmental health burden in these areas. Without such data, the true impacts of air pollution on border populations will likely remain unclear. One workshop participant noted, "Access to healthcare is different for us on the border. If the data only reflects U.S. healthcare usage, it's incomplete. We need both sides of the story to advocate for the health resources we need." Community members expressed enthusiasm for community-generated data sources such as survey informed health data. Adding context to identified health metrics, workshop participants suggested including community testimonials to reinforce the value of this collaborative approach. Another workshop participant remarked, "This dashboard should do more than give numbers; it should tell our stories. Environmental racism is real, and if we're not intentional about the data we collect, we won't address the disparities people of color face." These statements underscore the importance of a dashboard that goes beyond data aggregation to empower communities and advocate for equitable health outcomes.

In addition to health metrics, workshop participants also suggested the addition of environmental datapoint like tree-planting, fire alerts, pesticide monitoring, sewage-related illness data, air pollution data, toxic waste sites, information about green spaces, work loss days or school attendance. Participants also highlighted the potential for the dashboard to serve as an educational resource that could focus on relevant air pollutants, exposure prevention, and environmental stewardship. Participants expressed a strong desire for the dashboard to serve as a tool for advocacy, particularly to highlight the health disparities experienced by disadvantaged communities. They stressed that data-driven advocacy—such as demonstrating how poor air quality affects workdays lost or school attendance—could provide compelling evidence for local governments and elected officials to implement targeted interventions. The dashboard's ability to highlight disparities and resource gaps could also guide funding allocations and inform environmental policy. Participants suggested that collaborative advocacy campaigns using dashboard data would amplify community voices and translate their concerns into meaningful public health improvements.

A significant gap identified through discussions was the need for a dedicated regional workshop for agencies and policymakers. Such a workshop, recommended by AIRE Collaborative members, would ensure that the health tracking dashboard remains relevant and impactful over the long term. It would aim to align state and local agency efforts, foster collaboration between agencies and community stakeholders, and ensure that the dashboard remains policy-relevant and integrated with existing environmental programs. While agency workshops were strongly recommended, the current project lacks the necessary resources to coordinate these efforts, given the extensive recruitment and planning required. However, we strongly encourage future projects to allocate resources for this initiative to maximize the dashboard's long-term impact and policy integration. Further, participants recommended securing additional funding to extend hosting beyond the current contract period and support annual data updates. The timeliness of data was flagged as a significant concern, particularly for advocacy efforts. Furthermore, user testing and the development of communication materials, such as tutorials and standalone guides, were strongly encouraged to improve accessibility and ensure that the tool meets the needs of its diverse user base.

Part 1, Section 2: Develop a Web-Based Dashboard (Task 3)

Introduction

To develop the web-based dashboard, we analyzed data from the Department of Healthcare Access and Information (HCAI) on treat-and-release emergency room (ER) visits in California adjusting for age and sex. We modeled the outputs using Poisson regression, incorporating both structured and unstructured spatial effects to capture spatial dependencies and uncertainties in risk estimates. We were able to identify areas with excess risks by comparing disease counts in each zip code to expected values based on these reference groups (state average and healthy communities). This approach enables a refined understanding of relative risk across different demographic and geographic segments, with spatial modeling techniques enhancing the validity of our findings. Spatial smoothing techniques leverage information from surrounding regions to inform parameter estimation and error assessment.

The resulting pilot web-based dashboard, CalHealthMap (to be hosted on UCLA's C-Solutions website), provides a platform for visualizing health outcomes with a focus on community needs and use. This community-informed dashboard offers customizable visualizations by health outcome, data summaries, data downloads, and educational resources, making it an accessible and versatile tool. Developed through an extensive multi-year collaboration with community members, CalHealthMap reflects the unique perspectives and priorities of the population it serves. This participatory approach not only shaped the pilot tool to effectively address health disparities but also lays the groundwork for future advancements in health tracking and community health initiatives.

This section details the engagement methods, data sources, and statistical frameworks used throughout the project, demonstrating how collaborative input and robust analytical techniques were combined to create a comprehensive, accessible tool for understanding and addressing environmental health challenges in communities disproportionately affected by air pollution.

To develop a web-based dashboard in Esri Dashboards, we followed a structured methodology to create an interactive, user-friendly tool that meets the needs of stakeholders and the community. The first step involved data preparation and integration. We collected and cleaned data from various sources, such as health metrics, air quality measurements, and demographic information, ensuring consistency and accuracy. This included addressing missing values, standardizing formats, and aligning data across sources. Geographic data layers, including zip codes and census tracts, were created or imported into Esri's ArcGIS software, ensuring spatial accuracy through geocoding where necessary. Health and environmental data were then integrated with these geospatial layers in ArcGIS Pro or ArcGIS Online, enabling seamless visualization and dynamic updates within the dashboard.

The dashboard was designed with a user-centric approach, incorporating insights from community workshops and user testing to enhance usability. Layout choices, color schemes, and widget placements were made to optimize readability and navigation. Essential dashboard components, such as interactive maps, charts, and filters, were customized to facilitate intuitive data exploration. For instance, users can interact with maps to zoom in, pan across regions, or click on locations to view specific data points. Additionally, line graphs, bar charts, and pie charts visualize trends over time, distributions by demographic groups, and comparisons across geographic areas. Filter options, including time periods, demographic categories, and specific health conditions, were added to allow users to tailor their view based on their interests. The dashboard's layout was optimized for accessibility across various devices, including desktops, tablets, and mobile phones.

To enhance data interactivity and provide real-time updates, we linked data layers to live data sources wherever feasible, such as daily air quality updates, ensuring users have access to the latest information. Interactive elements like pop-ups and tooltips were added to provide context, displaying relevant information when users click on data points, such as health metrics or demographic breakdowns. Cross-filtering capabilities allow users to apply filters across multiple widgets simultaneously, enabling deeper analysis by showing how specific selections impact related data visualizations.

User feedback and iterative development were crucial throughout the process. We conducted testing sessions with stakeholders and community members to collect feedback on usability, clarity, and functionality, which informed adjustments to improve layout, interactivity, and overall user experience. To support users in navigating the dashboard, we developed comprehensive documentation and tutorials, including user guides and training sessions, to familiarize stakeholders with the tool's features and promote engagement.

Finally, we deployed the dashboard on Esri Online, embedding it into the project's website for browser-based access. Access permissions were configured as needed to ensure data security and privacy. We also established a plan for ongoing data updates and technical maintenance, including regular uploads, system checks, and updates to maintain accuracy and responsiveness over time. This methodical approach allowed us to create a comprehensive, user-friendly Esri Dashboard, empowering users with real-time data insights and supporting data-driven decision-making.

Methods

Dashboard Design and Community Review (Task 3, Subtask 1)

In the summer of 2024, a series of targeted workshops was conducted to collect input from both key decision-makers and community members regarding the design and functionality of the CalHealthMap health tracking system. These workshops aimed to equip participants with essential information on the health impacts of air pollution and gather their insights on the most relevant health indicators. With support from the AIRE Collaborative, outreach efforts were amplified through grassroots networking and recruitment, successfully drawing participation from DAC members, local stakeholders, air district staff across the Bay Area, Central Valley, and Los Angeles, as well as other communities facing disproportionate pollution exposure. These workshops created a collaborative space for stakeholders to articulate their concerns, provide suggestions, and share expectations, ensuring that their voices directly influenced CalHealthMap's development.

In parallel, focus groups offered an opportunity to gain deeper insights into the lived experiences of individuals impacted by air pollution. These sessions reviewed the functionality of the health tracking system, providing participants with a chance to evaluate its design and share valuable feedback. This approach enabled the team to better understand the unique social and environmental contexts in which CalHealthMap would be applied, allowing for adjustments that aligned the system closely with community needs.

To broaden the feedback pool, we conducted online surveys that allowed community members to share qualitative input on their health concerns, perceptions of air quality, and impressions of the CalHealthMap tool's usability. Continuous feedback was facilitated through email updates and regular community meetings, ensuring that community members could remain engaged and offer input throughout the project's progress.

In late 2024, we introduced the CalHealthMap tool through public demonstrations, initiating a "Community Peer Review" process to gather immediate feedback on the system's features and usability. This peer review was invaluable in fine-tuning the system based on firsthand user feedback. Additionally, the tool underwent pilot testing with several groups, including AIRE Collaborative members, stakeholders from the Oakland area, the California Air Resources Board (CARB), and other partners. This pilot phase provided a thorough evaluation of CalHealthMap's performance, allowing us to collect comprehensive feedback on its functionality and effectiveness, which guided further refinements to better serve the needs of the end users.

Data Display and Reporting (Task 3, Subtask 2)

The web-based dashboard aims to serve as an interactive platform for community members, policymakers, and researchers to access and visualize health data. It will be hosted on UCLA's Center for Health Climate Solutions (C-Solutions) website and will offer several essential features:

1. **User-Friendly Interface**: The dashboard will be designed with an intuitive user interface that will allow users to easily navigate through various health metrics and data visualizations. The interface will include interactive maps, charts, and graphs that will present data in an accessible and engaging format.
2. **Comprehensive Data Integration**: The dashboard will integrate health outcome data from HCAI and CDPH to show both morbidity and mortality outcomes. This integration will ensure that users have access to a wide range of health indicators aggregated at the zip code level.
3. **Health Indicators Tracking**: Users will be able to track specific health indicators over time (2015 – 2018), providing insights into trends and patterns in community health. These indicators will be particularly focused on conditions sensitive to air quality changes, such as respiratory and cardiac conditions, and overall mortality rates.
4. **Community Engagement**: The dashboard will facilitate community engagement by allowing residents to explore data relevant to their neighborhoods. This transparency will help build trust and empower communities with the information needed to advocate for continued environmental and health improvements.
5. **Customizable Visualizations**: Users will be able to customize visualizations to focus on specific regions, years, or health outcomes. This flexibility will allow for tailored analyses and presentations, making the dashboard a valuable tool for various stakeholders, including community groups, public health officials, and researchers.
6. **Educational Resources**: The dashboard will include educational resources and contextual information to help users understand the data and the significance of air

quality interventions. These resources will ensure that the information is not only accessible but also comprehensible to a non-technical audience.

In summary, the dashboard will be a comprehensive, interactive tool that enhances the accessibility and transparency of health data related to air quality interventions. It will support informed decision-making and promote community engagement by providing clear, actionable insights into the health impacts of environmental policies.

Deliverables

- A functional web-based dashboard integrated into the C-Solutions website.
- Documentation of software code and user manuals to support dashboard maintenance.

Results

Dashboard Design and Community Peer Review (Task 3, Subtask 1)

Data Preparation and Integration for CalHealthMap

The development of the CalHealthMap dashboard relied on thorough data preparation and integration processes. HCAI data was post-processed and analyzed using project-specific models developed and detailed in Task 1, Subtask 2. Models were executed in collaboration with our project partners and on Tracking California's computing infrastructure. The insights generated were further refined and transformed to meet the unique requirements of the Esri Dashboard platform.

The dashboard was designed with extensive input from community stakeholders to ensure its usability and relevance (view Table 6 for reference). Incorporating this input required significant transformations of the data to enable the envisioned functionality. For example, the HCAI data had to be structured with specialized joining columns, standardized labels, and aggregated metrics to support dynamic filtering and cross-referencing of health outcomes, years, and regions. These transformations ensured that users could easily navigate the dashboard's features, such as dropdown menus and filtering options, and analyze data intuitively.

Geospatial data played a critical role in the dashboard's design, and it was prepared using the "sf" package in R. Spatial data from the project's models was standardized to a common coordinate reference system (CRS 3310) to ensure compatibility with the Esri Dashboard platform. To optimize performance, geometries were simplified to reduce file sizes without compromising spatial accuracy, keeping the resulting files within the technical constraints of the platform.

In addition to spatial processing, advanced transformations were performed on the modelled data within the R programming environment to prepare the data for the Esri Dashboard environment. Metrics were scaled and rounded for clarity in visualization. Special concatenated fields, such as "Outcome (Year)," were also created to enable interactive data exploration and enhance usability within the Esri Dashboard platform. This post-processed data was transformed and consolidated into a unified dataset encompassing all health outcomes, years, and models, ensuring consistency across the various dashboard widgets.

Finally, the datasets were exported from R into multiple formats, including geopackage files for spatial layers and CSV files for time-series analysis, and integrated into the Esri Dashboard platform. This process involved testing and iterative adjustments to align the data with the dashboard's interactive features, enabling seamless navigation and meaningful exploration of health trends. By tailoring the data specifically to the needs of the dashboard and incorporating community feedback throughout development, the project team created a tool that is highly customized and accessible. All R code used in the data preparation process are included in the project GitHub at https://github.com/carb-ucla/rr-smr-materials.

Communication

A critical aspect of developing the CalHealthMap dashboard was ensuring that textual content complemented the visual and interactive elements and communicated information clearly to the end users. Through guidance by the AIRE Collaborative, agencies, and community members, these efforts aimed to make the dashboard not only a tool for health data visualization but also an accessible and informative resource for users with diverse needs. Text content was carefully curated and integrated into the dashboard to provide context, guide navigation, and enhance understanding of the data presented.

The tool description crafted was to provide users with a clear understanding of the purpose and scope of the CalHealthMap dashboard. The project team worked to ensure the language was accessible and informative, emphasizing the dashboard's role in mapping community health trends over space and time and enabling comparisons with statewide averages or the healthiest communities (detailed in the "Community Peer Review Process" section). Drawing from scientific research and community input, we highlighted the focus on ER visit and mortality outcomes, particularly those associated with air pollution, while acknowledging other health determinants. This explanation was carefully detailed (and detailed further below) to clarify that ***elevated risks in specific zip codes should not be interpreted as causal links*** but as insights to guide further investigation and action. The text included in the dashboard is as follows:

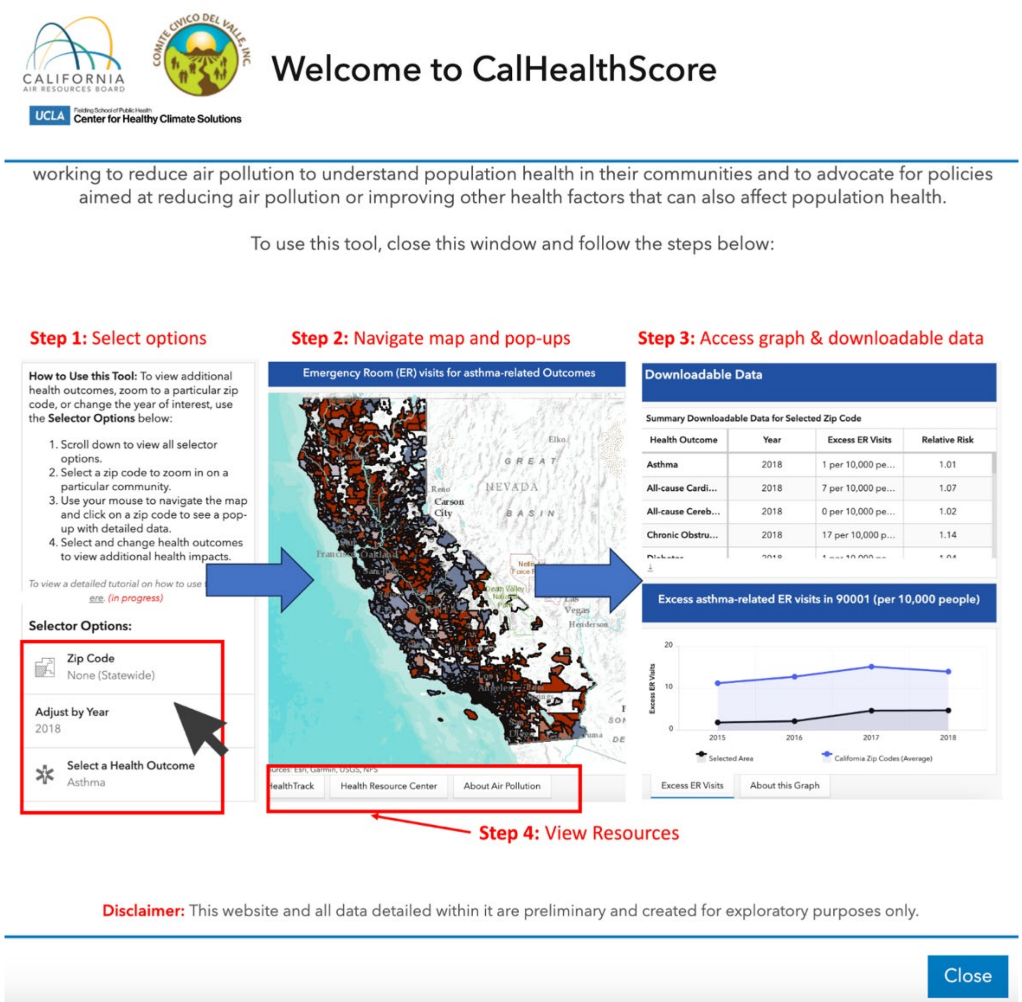
> *UCLA's Center for Healthy Climate Solutions (C-Solutions) and Comite Civico del Valle created CalHealthMap with funding from the California Air Resources Board (CARB). This pilot dashboard maps your community's health status and trends by allowing you to explore specific health outcomes in comparison with statewide averages or with the healthiest communities. We have focused on emergency room (ER) visit and mortality outcomes that have established associations with air pollution exposures, but these same outcomes can also be influenced by other determinants of health such as smoking and poverty. Thus, a finding of elevated risks for an ER visit or mortality outcome in a specific zip code cannot be interpreted as a causal relationship between air pollution and that health outcome. The goal of this pilot site is to enable communities working to reduce air pollution to understand population health in their communities and to advocate for policies aimed at reducing air pollution or improving other health factors that can also affect population health.*

Another disclaimer further down in the text was included to manage user expectations and clarify the tool's limitations. The inclusion of the statement, "CalHealthMap does not identify specific causes of health differences, which typically arise from a blend of social, environmental, and lifestyle factors," was critical to ensuring users understand that the dashboard provides insights into health outcomes without attributing these outcomes to any single cause (e.g. air pollution). This was particularly important given the complexity of factors influencing health, such as socioeconomic conditions (e.g. poverty) and individual behaviors (e.g. smoking).

Additionally, the note that "the tool is not designed to provide public advocacy training" helps define the scope of the dashboard. While the tool empowers users with data to advocate for policies or initiatives, it does not replace the role of advocacy organizations or training programs, an element that was of particular focus during the AIRE Collaborative meetings. By including this disclaimer, we aimed to set appropriate boundaries for how the tool should be used, preventing potential misinterpretation or misuse of the data. Overall, the disclaimer underscores the tool's role as a resource for exploration and understanding, rather than as a prescriptive solution or a comprehensive advocacy guide.

To assist users in navigating the CalHealthMap dashboard effectively, we developed a guide outlining the steps for exploring its features that were included in three locations: (1) on the splash screen (Figure 3), (2) included on the left hard selector bar and, (3) included in the “About this Tool” tab located behind the map window. Users begin by selecting a zip code from the "Selector Options" panel on the left side of the dashboard, which allows them to zoom in on a specific community. They can then use their mouse to navigate the map and click on a zip code to view a pop-up containing detailed health outcome information for that area. By adjusting the "Health Outcome" or "Year" options, users can customize their analysis to explore additional health outcomes or compare data across different years. To access resources, view charts, or download data, users can interact with the additional windows available on the dashboard. These windows can be expanded for a better view by selecting the icon located in the upper-right corner of each embedded window. This detailed guide ensures that users can easily navigate the dashboard's features and gain valuable insights into community health trends. These directions were developed from input provided by the AIRE Collaborative and other community members during regional meetings and tested through the Peer-Review process and further user testing (scheduled for December 2024).

Figure 1. CalHealthMap Splash Screen displayed to users before accessing the full website, providing step-by-step visual instructions for navigating the tool. The splash screen guides users through key actions: selecting options from the "Selector Options" panel (Step 1), navigating the map and pop-ups for geographic and health outcome data (Step 2), accessing graphs and downloadable data for further analysis (Step 3), and viewing additional resources (Step 4). This introductory screen ensures users understand the tool's functionality and usability prior to engagement.



The project team was also guided through development of key informational gaps and user needs. Based on the input, the team designed text elements to clarify each dashboard feature including detailed data terms (

Table 3) included on the “About this Tool” tab, health outcomes (Table 4 and Table 20) included on the “Health Resource Center” tab, and guides on how to interpret the visualized metrics (Figure 5).

Table 3. Glossary of data terms used in the CalHealthMap Dashboard to describe health metric outputs. The table defines key metrics, including the total number of cases (per 10,000 people), excess cases (per 10,000 people), standardized mortality ratio (SMR), relative risk (RR), and confidence intervals (lower and upper limits). These terms help users interpret health data, comparing observed outcomes to state averages and highlighting areas with higher or lower risks.

Data Term	Description
Total Number of Cases (per 10,000 people)	Total Number of Cases (per 10,000 people) shows the number of people (modeled, accounting for age and sex) in a specific zip code who went to the ER for a health outcome issue, like asthma, or how many people who passed away died from a particular cause. This total is reported for every 10,000 people in the area, helping us understand the overall health burden within that community.
Excess Number of Cases (per 10,000 people)	Excess Number of Cases (per 10,000 people) tells us how many more people than expected (modeled, accounting for age and sex) in a specific zip code went to the ER for a health outcome, like asthma, or how many more deaths from a particular cause occurred than expected. This metric indicates whether a health outcome in a specific zip code is more or less frequent than what is expected if the community's health burden had been the same as in the reference population (for example, in either the statewide population or California's healthiest communities).
Standardized Morbidity or Mortality Ratio (SMR)	The Standardized Morbidity or Mortality Ratio (SMR) is the number of ER visits for a health outcome (for example, asthma) or deaths in a specific zip code, compared to the number expected. Specifically, it is a ratio of the observed cases of a health outcome, over the number of cases expected. So, an SMR of 1 indicates that the health burden in a specific zip code is no different than in the reference population (for example, in either the statewide population or California's healthiest communities). An SMR above 1 indicates more cases than expected, while an SMR below 1 indicates fewer cases than expected. This metric helps identify zip codes with unusually high or low numbers of cases of ER visits or deaths, compared to either the rest of the state or California's healthiest communities.
Relative Risk (RR)	Relative Risk (RR) is the chance of an ER visit for a health outcome (for example, asthma) or deaths in a specific zip code, compared to the state average. An RR of 1 means that the risk for the health outcome in a specific zip code is no different than in the reference population (for example, in either the statewide population or California's healthiest communities). If the RR is higher than 1, it means the risk is greater than expected, while an RR below 1 means the risk is lower than expected. Note: For improved accuracy, the calculation of RR in CalHealthMap utilizes a method called spatial smoothing. This means the RR in one zip code is partly based on information from nearby zip codes. Using data from neighboring areas helps generate more reliable results, especially in places with fewer people or limited data.

Lower Limits (LL) & Upper Limits (UL)	The lower and upper limits of the RR define the boundaries of a confidence interval: The Lower Limit (LL) represents the minimum plausible value of the RR, while the Upper Limit (UL) indicates the maximum plausible value. If the confidence interval includes 1, then the risk for the health outcome in the zip code is not meaningfully different from the risk in the reference population (for example, in either the statewide population or California's healthiest communities).
California's Healthiest Communities	California's healthiest communities are the 25% of zip codes with the highest Healthy Places Index (HPI) scores. The defines a healthy community as one that provides residents with access to quality education, good jobs, safe housing, clean air and water, healthcare, and strong social support using 25 indicators across these areas. The higher the HPI score, the healthier the community.

A description of the dashboard and information from Table 18 are included in the "About this Tool" tab on the dashboard and shown in Figure 2 below.

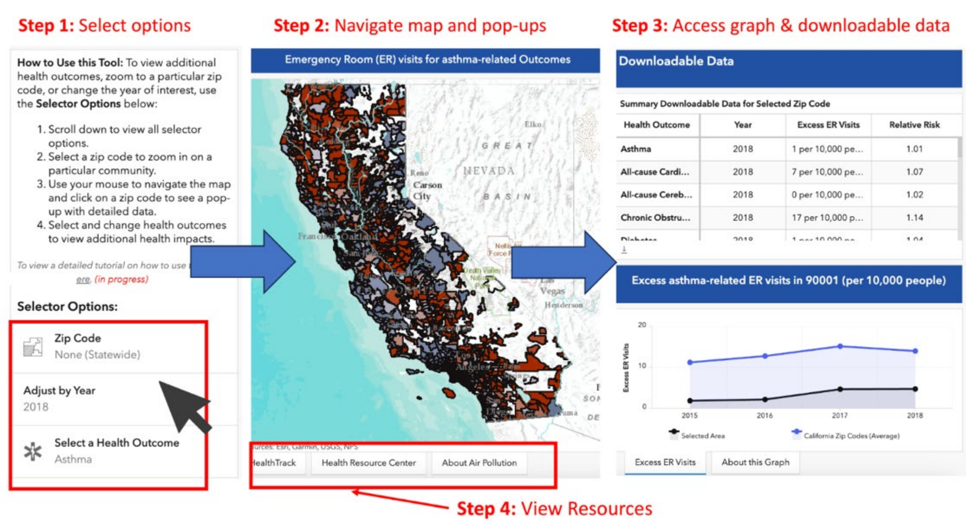
Figure 2. Screenshot of the "About this Tool" tab on the CalHealthMap dashboard. This section provides an overview of the dashboard's purpose and functionality, explaining how it allows users to explore health outcomes associated with air pollution across California communities. The tab includes visual step-by-step instructions on selecting zip codes, navigating maps and pop-ups, accessing graphs and downloadable data, and viewing additional resources. Clear text explanations and visual aids guide users on how to effectively interact with the tool and interpret its outputs. A disclaimer notes the preliminary nature of the data and its focus on public advocacy training.

UCLA's Center for Healthy Climate Solutions (C-Solutions) and Comite Civico del Valle created CalHealthScore with funding from the California Air Resources Board (CARB). This pilot dashboard maps your community's health status and trends by allowing you to explore specific health outcomes in comparison with statewide averages or with the healthiest communities. We have focused on emergency room (ER) visit and mortality outcomes that have established associations with air pollution exposures, but these same outcomes can also be influenced by other determinants of health such as smoking and poverty. Thus, a finding of elevated risks for an ER visit or mortality outcome in a specific ZIP code cannot be interpreted as a causal relationship between air pollution and that health outcome. The goal of this pilot site is to enable communities working to reduce air pollution to understand population health in their communities and to advocate for policies aimed at reducing air pollution or improving other health factors that can also affect population health.

CalHealthScore does not identify specific causes of health differences, which typically arise from a blend of social, environmental, and lifestyle factors. The tool is not designed to provide public advocacy training.

How to Use This Tool:

To view a detailed tutorial on how to use this tool, click the link here. (in progress)



Step 1: In the "**Selector Options:**" (left), select a zip code to zoom in on a particular community.
Step 2: Use your mouse to navigate the map and click on a zip code to see a pop-up with detailed health outcome.
Step 3: Adjust the "Health Outcome" or "Year" view additional health outcomes or years.
Step 4: To access resources, charts, and downloadable data, view the additional windows; expand by selecting the icon below (found on upper-right corner of each embedded window):

Glossary of Data Terms

- **Total Number of Cases (per 10,000 people)** shows the number of people (modeled) in a specific zip code went to the ER for a health issue, like asthma, or how many people passed away from a particular cause. This total is reported for every 10,000 people in the area, helping us understand the overall health burden within that community.
- **Excess Number of Cases (per 10,000 people)** tells us how many more people visited the ER for a health problem, like asthma, or how many more deaths occurred than we expected in a specific zip code. This modeled comparison is made by adjusting for factors like age and sex, and it shows whether the health outcomes in that area are higher or lower than what we'd normally expect if the rates were the same as in other areas.
- The **Standardized Mortality Ratio (SMR)** compares the number of ER visits (for asthma, COPD, etc.) or deaths in a specific zip code to the state average. An SMR of 1 means the rate is as expected. An SMR above 1 indicates more cases than expected, while an SMR below 1 indicates fewer. This measure helps identify zip codes with unusually high or low rates of ER visits or deaths compared to the rest of the state, guiding public health efforts.
- **Relative Risk (RR)** compares the chance of ER visits (for asthma, COPD, etc.) or deaths in a specific zip code to the state average. An RR of 1 means the risk in that zip code is the same as the state's. If the RR is higher than 1, it means the risk is greater, and if it's less than 1, the risk is lower. This helps us find areas where people may need more healthcare or have higher death rates. To make sure the results are accurate, we use a method called **spatial smoothing**. This means the RR in one zip code is partly based on information from nearby zip codes. Using data from neighboring areas helps us get more reliable results, especially in places with fewer people or limited data.
- The **lower and upper limits** of the Relative Risk (RR) define the boundaries of a confidence interval, typically at 95%. These limits indicate the range where the true RR is likely to fall. The **Lower Limit (LL)** represents the minimum plausible value of RR, while the **Upper Limit (UL)** shows the maximum plausible value. If the interval includes 1, the difference in risk may not be statistically significant, meaning the zip code's risk may not differ meaningfully from the state average.

Information specific to health outcomes from Table 4 and Table 5 are included in the "Health Resource Center" and detailed below.

Table 4. Glossary of "parent" health outcomes on the CalHealthMap Dashboard. This table defines key health categories, including cardiovascular and cerebrovascular conditions (e.g., heart disease, stroke), respiratory issues (e.g., asthma, COPD), circulatory complications (e.g., hypertension, diabetes-related impacts), and mortality data (excluding accidents). These categories provide context for understanding health outcomes linked to air pollution and broader community health impacts.

Health Outcome	Description
Cardiovascular	Refers to the effects of heart conditions like heart disease and stroke on well-being, with risks such as heart attacks and reduced blood flow. Two sub-categories of cardiovascular disease included in this tool include dysrhythmia and ischemic heart disease (IHD).
Cerebrovascular	Refer to conditions that affect blood flow to the brain, including stroke and other brain blood vessel disorders.
Respiratory	Affect the lungs and airways, such as asthma, pneumonia, bronchitis, respiratory infections, and chronic obstructive pulmonary disease (COPD). We have also separated out two related conditions (asthma and COPD) to view in the map independently due to their strong link to air pollution exposures.
Circulatory	Include conditions like heart disease, stroke, and hypertension, affecting the heart and blood vessels, while diabetes is a metabolic disorder that impairs the body's ability to regulate blood sugar, often leading to complications in the circulatory system such as cardiovascular disease.
Diabetes	Includes conditions related to the body's ability to regulate blood sugar, including complications such as nerve damage, kidney disease, and increased risk of heart disease.
Mortality	This category includes deaths from various causes with the exception of accidents and injuries. Mortality data provides a broader context for understanding the severe, long-term health impacts on communities.

We expanded the description of the “parent” health outcome categories to include the health outcome subcategories as to include all outcomes tracked within the CalHealthMap dashboard (Table 5). This fuller more complete list of health outcomes contained additional details (if previously detailed above), a description of the outcome, and the specific International Classification of Diseases, 10th Revision (ICD-10) codes used to identify them.

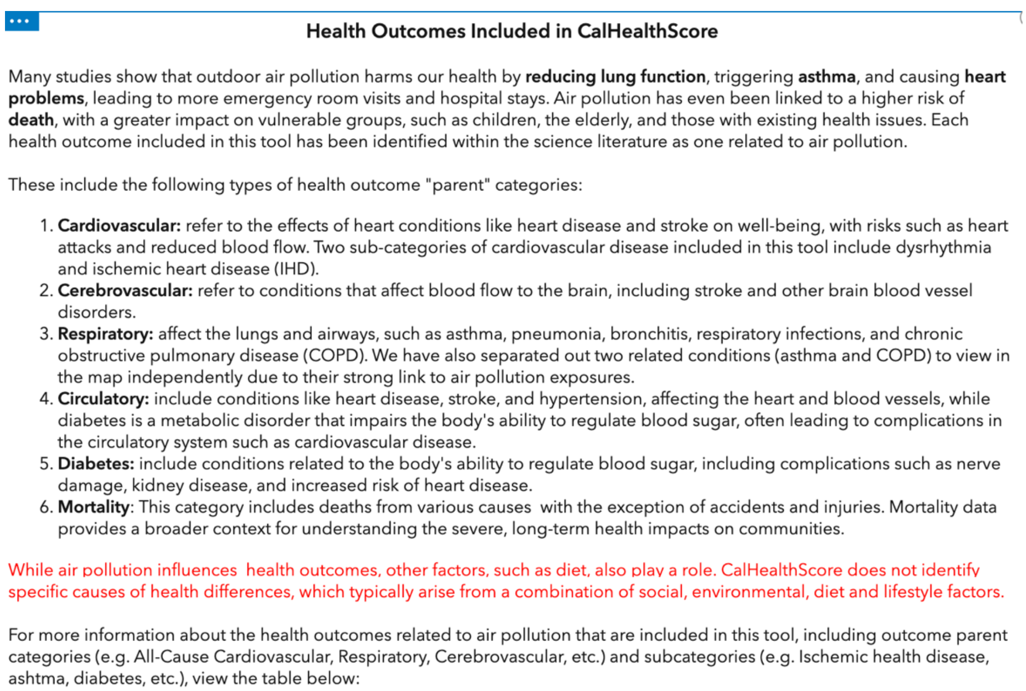
Table 5. Glossary of health outcomes on the CalHealthMap Dashboard. This table outlines key health outcomes, their descriptions, and associated ICD-10 codes. Categories include cardiovascular health (e.g., dysrhythmia and ischemic heart disease), cerebrovascular conditions (e.g., strokes), and respiratory outcomes (e.g., asthma and COPD). It also includes diseases of the circulatory system and diabetes, highlighting the impact of high blood sugar on circulation.

Health Outcome	Description	ICD - 10 Codes
All-cause Cardiovascular	Health outcomes related to the heart and its blood vessels, such as heart attacks and coronary artery disease. We include "All-cause Cardiovascular" outcomes, separately highlighting dysrhythmia and ischemic heart disease due to their link to air pollution.	I20-I25, I30–I51, I60-I69, I70
↳ Dysrhythmia	Dysrhythmia, or arrhythmia, occurs when the heart beats irregularly. It affects 1.5-5% of the population, with atrial fibrillation being common. Symptoms can include dizziness, chest pain, and shortness of breath. Severe cases increase risks of stroke and cardiac arrest.	I30-I51
↳ Ischemic heart disease	Ischemic Heart Disease (IHD) occurs when blockages in coronary arteries reduce blood supply. This can cause angina or heart attacks. It is a leading cause of death, with risk factors including high cholesterol, air pollution, and smoking.	I20–I25
All-cause Cerebrovascular	Strokes, especially ischemic strokes, result from blocked blood vessels supplying the brain. This category covers disorders affecting brain blood vessels.	I60-I69
All-cause Respiratory	All-cause respiratory health outcomes cover conditions such as asthma, COPD, and pneumonia. Air pollution and respiratory infections worsen these conditions, impacting overall respiratory health.	J00-J98
↳ Asthma	Asthma affects airways, causing inflammation and breathing difficulties. Triggers include allergens, smoke, and cold air. Symptoms are managed through medications and avoiding triggers.	J45
↳ Chronic Obstructive Pulmonary Disease (COPD)	COPD, often caused by smoking or pollutant exposure, makes breathing difficult by causing airflow blockages. It is prevalent among older adults, with symptoms like coughing and wheezing.	J19-J46
Diseases of the Circulatory System and Diabetes	High blood sugar damages blood vessels over time, leading to atherosclerosis and poor circulation. These issues can cause complications like slow healing of wounds.	I00–I99, E10–E14

↳ Diabetes	Diabetes impairs glucose processing, with Type 1 preventing insulin production and Type 2 affecting insulin use. Managing diabetes reduces risks of complications like heart disease and nerve damage.	E10–E14
Total ER Visits	Reflects the total number of emergency room visits across all outcomes. Monitoring total ER visits offers insights into healthcare needs and accessibility.	Aggregated across all outcomes
Mortality	Mortality refers to the total number of deaths from all causes, providing an overview of population health and identifying health disparities.	All mortality codes excluding those related to accidents and injuries

A screenshot of the "Health Resource Center" tab with health outcome information is included in Figure 3 below:

Figure 3. Screenshot of the CalHealthMap "Health Resource Center" tab, which provides detailed information about health outcomes included in the tool. The "Health Resource Center" serves as an educational feature, helping users understand the data displayed in the dashboard and its connection to public health and environmental factors. This tab explains how specific health conditions, such as cardiovascular disease, cerebrovascular disease, respiratory issues, diabetes, and mortality, are related to air pollution exposure. It includes descriptions of these health outcomes, their subcategories, and associated ICD-10 codes to ensure clarity for users.



Health Outcomes Included in CalHealthScore

Many studies show that outdoor air pollution harms our health by **reducing lung function**, triggering **asthma**, and causing **heart problems**, leading to more emergency room visits and hospital stays. Air pollution has even been linked to a higher risk of **death**, with a greater impact on vulnerable groups, such as children, the elderly, and those with existing health issues. Each health outcome included in this tool has been identified within the science literature as one related to air pollution.

These include the following types of health outcome "parent" categories:

1. **Cardiovascular:** refer to the effects of heart conditions like heart disease and stroke on well-being, with risks such as heart attacks and reduced blood flow. Two sub-categories of cardiovascular disease included in this tool include dysrhythmia and ischemic heart disease (IHD).
2. **Cerebrovascular:** refer to conditions that affect blood flow to the brain, including stroke and other brain blood vessel disorders.
3. **Respiratory:** affect the lungs and airways, such as asthma, pneumonia, bronchitis, respiratory infections, and chronic obstructive pulmonary disease (COPD). We have also separated out two related conditions (asthma and COPD) to view in the map independently due to their strong link to air pollution exposures.
4. **Circulatory:** include conditions like heart disease, stroke, and hypertension, affecting the heart and blood vessels, while diabetes is a metabolic disorder that impairs the body's ability to regulate blood sugar, often leading to complications in the circulatory system such as cardiovascular disease.
5. **Diabetes:** include conditions related to the body's ability to regulate blood sugar, including complications such as nerve damage, kidney disease, and increased risk of heart disease.
6. **Mortality**: This category includes deaths from various causes with the exception of accidents and injuries. Mortality data provides a broader context for understanding the severe, long-term health impacts on communities.

While air pollution influences health outcomes, other factors, such as diet, also play a role. CalHealthScore does not identify specific causes of health differences, which typically arise from a combination of social, environmental, diet and lifestyle factors.

For more information about the health outcomes related to air pollution that are included in this tool, including outcome parent categories (e.g. All-Cause Cardiovascular, Respiratory, Cerebrovascular, etc.) and subcategories (e.g. Ischemic health disease, ashtma, diabetes, etc.), view the table below:

Health Outcome	Description	ICD - 10 Codes
All-cause Cardiovascular	Health outcomes related to the heart and its blood vessels, such as heart attacks and coronary artery disease. We include "All-cause Cardiovascular" outcomes, separately highlighting dysrhythmia and ischemic heart disease due to their link to air pollution.	I20-I25, I30–I51, I60-I69, I70
⤷ Dysrhythmia	Dysrhythmia, or arrhythmia, occurs when the heart beats irregularly. It affects 1.5-5% of the population, with atrial fibrillation being common. Symptoms can include dizziness, chest pain, and shortness of breath. Severe cases increase risks of stroke and cardiac arrest.	I30-I51
⤷ Ischemic heart disease	Ischemic Heart Disease (IHD) occurs when blockages in coronary arteries reduce blood supply. This can cause angina or heart attacks. It is a leading cause of death, with risk factors including high cholesterol, air pollution, and smoking.	I20-I25
All-cause Cerebrovascular	Strokes, especially ischemic strokes, result from blocked blood vessels supplying the brain. This category covers disorders affecting brain blood vessels.	I60-I69
All-cause Respiratory	All-cause respiratory health outcomes cover conditions such as asthma, COPD, and pneumonia. Air pollution and respiratory infections worsen these conditions, impacting overall respiratory health.	J00-J98
⤷ Asthma	Asthma affects airways, causing inflammation and breathing difficulties. Triggers include allergens, smoke, and cold air. Symptoms are managed through medications and avoiding triggers.	J45
⤷ Chronic Obstructive Pulmonary Disease (COPD)	COPD, often caused by smoking or pollutant exposure, makes breathing difficult by causing airflow blockages. It is prevalent among older adults, with symptoms like coughing and wheezing.	J19-J46
Diseases of the Circulatory System and Diabetes	High blood sugar damages blood vessels over time, leading to atherosclerosis and poor circulation. These issues can cause complications like slow healing of wounds.	I00–I99, E10–E14
⤷ Diabetes	Diabetes impairs glucose processing, with Type 1 preventing insulin production and Type 2 affecting insulin use. Managing diabetes reduces risks of complications like heart disease and nerve damage.	E10–E14
Total ER Visits	Reflects the total number of emergency room visits across all outcomes. Monitoring total ER visits offers insights into healthcare needs and accessibility.	Aggregated across all outcomes
Mortality	Mortality refers to the total number of deaths from all causes, providing an overview of population health and identifying health disparities.	All mortality codes excluding those related to accidents and injuries

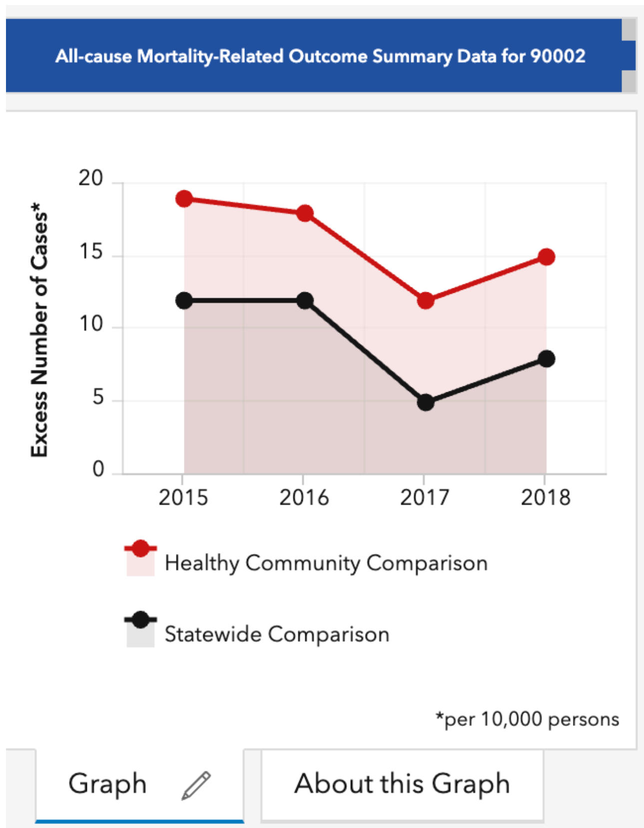
*ICD codes (International Classification of Diseases) are a standardized system used by healthcare providers to classify and code diagnoses, symptoms, and medical procedures for record-keeping and billing purposes.

The CalHealthMap dashboard also includes an "About Air Pollution" tab to provide users with essential background on air pollution and its impact on health and the environment. This section features concise text that explains air pollution as “harmful substances like gases, chemicals, and particles released into the air from sources such as vehicles, factories, and wildfires". The text highlights the direct connection between polluted air and serious health issues, which are central to the tool and its purpose. To enhance user understanding and promote additional learning, the tab includes a direct link to the CARB Community Air Protection Program Resource Center found at https://ww2.arb.ca.gov/capp/ocap_resource_center. This link offers comprehensive information about air pollution and strategies for improving air quality at the community level, allows end users to further explore air pollution, and understand their root causes and broader implications of exposure. To enhance engagement (and provide mix media options), the tab includes a short, informative CARB video that visually explains the sources, impacts, and solutions related to air pollution, further helping contextualize the health outcomes presented in the dashboard.

Figure 4. Screenshot of the CalHealthMap "Health Resource Center" tab featuring a video about the fundamentals of air quality and its impact on health. The video, produced by CARB, explains how air pollution from sources like traffic, industries, and wildfires affects health and the environment. The tab provides additional educational content and links to CARB's Community Air Protection Program Resource Center, offering users deeper insights into air pollution's role in public health outcomes.

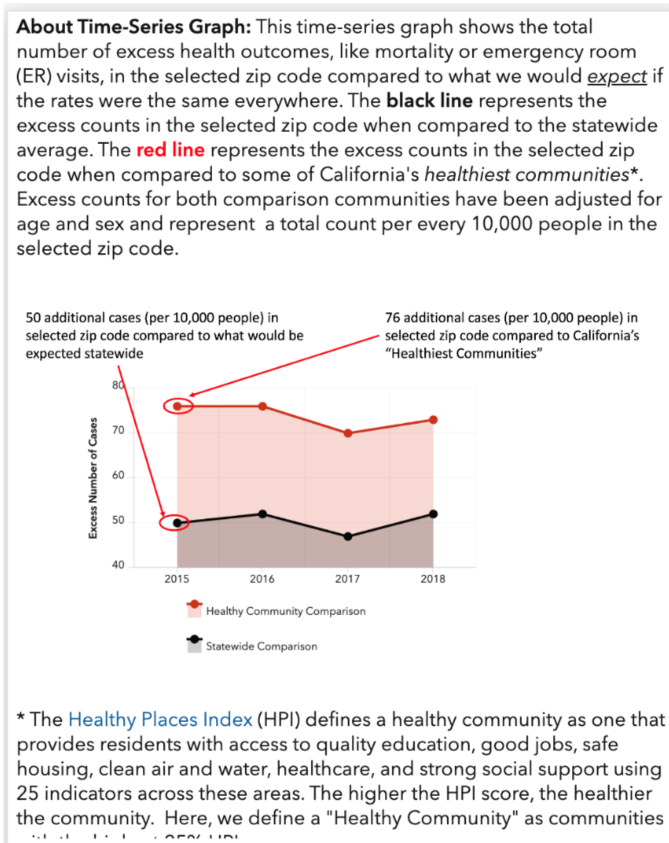
The technical challenge lay in embedding dynamic and static text into the Esri Dashboard platform. This required leveraging the platform's customization options, including configuring pop-ups for geographic features and creating informative widgets that could help guide the user in a way that was intuitive. Text fields were designed to update based on user interactions, ensuring that the content remained relevant as filters and selections were applied. For example, when a user selected a specific zip code (from Selector Options), the corresponding text provided a summary of key health outcomes and comparisons to statewide averages or the healthiest communities though a time-series graph located on the right side of the map and show in Figure 5 below.

Figure 5. Time-series graph displaying excess numbers of cases for a selected geography (zip code 90002) and health outcome (all-cause mortality) from 2015 to 2018. The graph compares trends against two baselines: the "Healthy Community Comparison" (red line) and the "Statewide Comparison" (black line), normalized per 10,000 persons. This visualization helps users assess disparities over time relative to healthier communities and the state average.



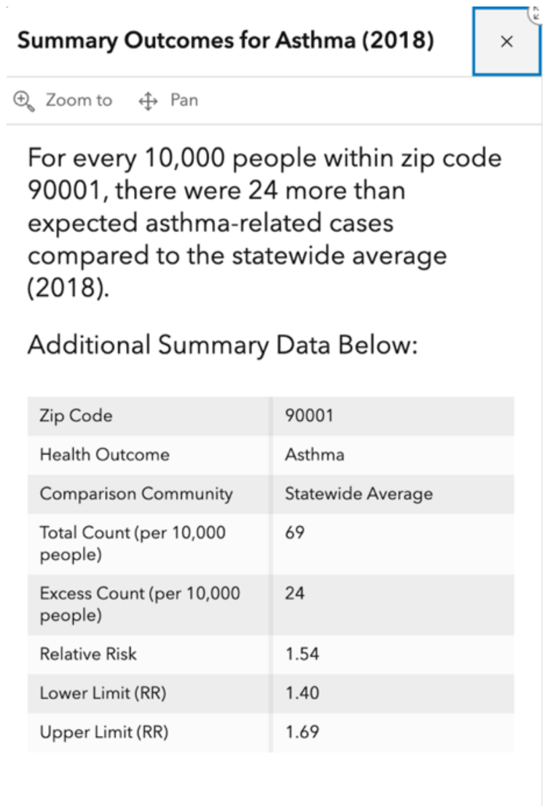
To ensure readability, the “About this Graph” text content was developed through a collaborative editing process to ensure clarity to the end user (Figure 6). The black line on the graph represents the excess counts compared to the statewide average, while the red line reflects comparisons with the healthiest communities as defined by the Healthy Places Index (HPI). These excess counts are adjusted for age and sex and are displayed as a total per 10,000 people in the selected zip code, ensuring standardized and meaningful comparisons. The concept of "Healthy Communities" is based on the HPI, which identifies communities with the highest 25% scores (as detailed in Section 1, subsection 2). These scores reflect access to quality education, good jobs, safe housing, clean air and water, healthcare, and strong social support across 25 indicators. A link to the HPI website at https://www.healthyplacesindex.org/ is included for additional context.

Figure 6. Screenshot of the "Time-Series" graph description from the CalHealthMap dashboard. The description explains that the graph displays the total number of excess health outcomes (e.g., mortality or emergency room visits) in the selected zip code compared to two baselines: the statewide average (black line) and a "Healthy Community" benchmark (red line). Excess counts are adjusted for age and sex and normalized per 10,000 people. Additional context is provided about the "Healthy Places Index" (HPI), which defines a healthy community based on factors such as education, housing, air quality, and healthcare access, with higher HPI scores indicating healthier communities.



Another feature leveraging the platform's customization options is the integration of configured pop-ups for geographic features. These pop-ups were created using the "Pop-up" widget in the ArcGIS Web Map application, enabling users to access detailed, on-demand information for specific zip codes or areas of interest directly from the map. The pop-ups provide a summary of key health data for the selected geography, including metrics for a selected health outcome (e.g. total and excess counts per 10,000 people) using statewide average and "healthy community" baseline comparisons. For instance, users viewing asthma outcomes in a specific zip code can see not only how many total asthma (ER) cases are at that geography for that year, but how many of these cases exceed the expected average using both statewide averages and healthier communities. The text within the pop-ups is tailored to provide context, explaining what the data represents and guiding users on how to interpret the metrics (Figure 7).

Figure 7. Screenshot of the dashboard's pop-up widget displaying health outcome data for a selected geography (zip code 90001) in 2018. The widget provides a summary of asthma-related outcomes, stating that for every 10,000 people in the area, there were 24 more asthma-related cases than expected compared to the statewide average. Additional data includes the total count per 10,000 people (69), relative risk (1.54), and confidence intervals (lower limit: 1.40, upper limit: 1.69). This pop-up allows users to access detailed, localized health metrics for their selected area.



Summary Outcomes for Asthma (2018)

Zoom to   Pan

For every 10,000 people within zip code 90001, there were 24 more than expected asthma-related cases compared to the statewide average (2018).

Additional Summary Data Below:

Zip Code	90001
Health Outcome	Asthma
Comparison Community	Statewide Average
Total Count (per 10,000 people)	69
Excess Count (per 10,000 people)	24
Relative Risk	1.54
Lower Limit (RR)	1.40
Upper Limit (RR)	1.69

The CalHealthMap dashboard also includes a "Downloadable Data" section, enabling users to access and save detailed summary data for further analysis or printing. To use this feature, users first select a zip code from the selector panel on the left side of the map and navigate to their area of interest. After selecting a zip code, users can scroll to the "Downloadable Data" tab and click the down arrow icon, as shown in the provided instructions. Once selected, the data is automatically downloaded to the user's designated "Downloads" folder or associated directory. To ensure clarity and usability, a glossary of the data terms is included with the downloaded dataset and is also available in the "About this Tool" tab behind the map. This feature streamlines access to data, empowering users to explore, analyze, and share insights about community health outcomes with ease. Additional details about the downloadable data will be discussed in the example dashboard run below.

Community Peer Review Process

The peer review process for the CalHealthMap dashboard involved gathering input from community stakeholders to assess the tool's usability, accessibility, and clarity. This feedback, collected through mock-ups, interactive sessions, and written comments, played a crucial role in refining the dashboard. Stakeholders identified several areas for improvement, which were carefully assessed and addressed. A summary of all feedback is included in Table 6.

Table 6. Feedback and Actions Taken During Peer Review and public consultation process for CalHealthMap Dashboard: This table summarizes the feedback received from public and community stakeholders during the peer review of the CalHealthMap dashboard and public consultation. Each entry includes the date, the status of the feedback (addressed or identified as a gap), a description of the comment or suggestion, and the corresponding actions taken to improve the dashboard. The feedback spans multiple categories, including naming, data accessibility, usability, visualization, and gaps for future iterations, highlighting the iterative process of refining the tool based on user input.

DATE	STATUS	COMMENT	HOW COMMENT WAS ADDRESSED
8/21/2024	Addressed	Required change: Need to change the name “CAHealth Tracking”: too similar to Tracking CA and not descriptive of what the tool does	Changed to CalHealthMap
8/21/2024	Addressed	Appears to be targeted at academics/researchers with experience navigating these types of tools and data not community members. • More communication around the outcomes, especially the lesser-known ones o Such as DCS or Dysrhythmias o Unclear what the differences are b/w the outcomes, respiratory vs asthma – more information needed on why would/should someone select one over the other?	Created a "Health Resource Center" with additional information about each health outcome.
8/21/2024	Addressed	Suggest updating the naming for the layers in the map view and/or disabling selection of layers	Done
8/21/2024	Addressed	The tool may be overwhelming/is not immediately intuitive o Too many steps/clicks to get information o Not clear what order to do these steps in o The map selection is not synced with the filter for the health outcome summary table and time trend and leads to two separate ways to interact with the data (adds to confusion about what order to interact with the tool) § Suggest A) syncing zip code selection on the map with the data displayed in the table and time trend or B) creating very clear instructions/ sections of the tool (i.e. use these drop-down filters to display data in the table and time trend, or zoom to a community/ click on the map to show the different relative risks)	Updated tool to address the following: 1. map now has a set selection as default 2. Added a splash screen to view instructions prior to map usage and an "How to Use This Tool" instructions under the "About this Tool" tab 3. Error in map sync has been addressed

8/21/2024	Addressed	Data Understandability o Not clear what a user should do with the numbers in the Health Outcome Summary. o Relative Risk, SMR, and exceedances are abstract terms. Having all three of them displayed in one place is too much to take in, even for public health professionals o Not clear how to interpret the different relative risks in the pop-up. The explanation of what the relative risk means (i.e. X% increased risk) is very helpful but it's confusing to have three different comparisons listed together without more explanation of why it's important to list all three and what users should do with these different measures. § Suggest removing bar chart comparing the relative risks unless there is a clear case of why it would be helpful to compare these measures o Consider "What is the most basic information they need to be actionable" when deciding what data points to include.	Included a data glossary to the site to help explain the metrics. Also included some more detailed text of what it means in the pop-ups. Updated the bar chart to include data from excess counts for both comparison communities with details on the subsequent "about" tab.
9/12/2024	Addressed	First impressions - unclear how to even begin. How to navigate isn't clear right when it first loads up. The user didn't know if things would move on their own or if the person needed to scroll down or expand/maximize windows (for example the summary data table). wasn't intuitive to click and then it expands.	Included a step-by-step image in splash screen
9/12/2024	Addressed	It was confusing to the user that the statement in red & graphic on the right side rather than on the left side where the ip code and selector bar are located. Select a zip code from the Selector Bar to view risks of all health outcomes. Recs to improve: Increase text size and include "Instructions - how to navigate this tool?" or change color of instruction box or somehow call out more clearly Change the statement in red & graphic to the same size as the selector bar & panel	Changed the text color, clarified instructions, and made font larger
9/12/2024	Addressed	Map - User asked, "is purple bad is green good?" User could understand that the gradient corresponds to severity but it's unclear how to interpret if dark purple is good or dark green is good etc. Recs to improve: User said that a red, green, yellow like the stop light would be more initiative. Red labeling or worse outcome and green is the better outcome on the scale.	Updated color to blue/red gradient.

9/12/2024	Addressed	Title / expectations of what they would find: User thought they would find air pollution data because of the title. The user was surprised to see the data on the map be about health. User recommends this gets clarified Rec to improve: Change the title to "Dashboard for health outcomes associated with Air Pollution (2015 - 2018)" or something that really clarified what they will find.	Updated title headline to "CalHealthMap for Health Outcomes Related to Air Pollution"
9/12/2024	Addressed	Resources section - User thinks this looks clunky and really hard to read. Found the information helpful though so recommends that there is a Resources Bar on the top right rather than trying to display the information. The hyperlink should take you to a full screen displaying that information. Rec to improve: Hyperlink Resources on a tab that gets expanded. Something like this: http://publichealth.lacounty.gov/media/coronavirus/data/ see attached.	moved the resources tabs to behind the map so that the tab screen is larger and easier to navigate
9/12/2024	Addressed	It's really hard to scroll down on each individual box. The Summary Data for Zip Code was particularly hard. User recommended to also put the Summary Data for Zip Code on a tab that gets expanded. User asked if there is any way to make the summary data table more colorful or less boring About the Data is empty	Most of the windows were moved to other parts of the dashboard that require less scrolling. however, the summary downloadable data is still in a small window, and this may cause some issues with some users. An introductory tab was placed over the data which may help with this issue but there is a lot of information on the dashboard, and we could not arrange each in a large window.
9/17/2024	Addressed	explanations for the data and terms we are using on the site such as relative risk, SMR, exceedance" – to help people understand how to use the information.	Added
9/17/2024	Addressed	The description of CalHealthMap is very minimal and needs to be enhanced and there should be references for the data and a link for the methodology.	Included more background information to help expand on te project details. Added link for detailed methods.

10/23/2024	Addressed	Reminded us to include more detailed methods	methods included via weblink on dashboard selector bar
9/13/2024	Addressed	Suggested making title with a drop-down menu. Questioned the separation of windows, suggesting combining titles like "asthma and air pollution" into one window. Questioned the separation of windows suggesting combining titles like "asthma and air pollution" into one window. Suggested using the median instead of the average for data presentation, as some neighborhood might skew the numbers	move all separate tabs/windows into new, larger tab area behind the map
9/13/2024	Addressed	Suggested using better titles but keeping them separate. Recommended maximizing the map for users who prefer maps to take up more screen space. Suggested testing the dashboard on a laptop since most people would view it that way. Suggested adding a feature to see more than one zip code at a time and linking to every AB 617 page.	move all separate tabs/windows into new, larger tab area behind the map
9/13/2024	Addressed	Expressed difficulty accessing the video and resources. Suggested making the page scrollable for easier navigation instead of having all content on one non-scrollable page. Suggested finding a way to let users know that the map is expandable	move all separate tabs/windows into new, larger tab area behind the map
10/3/2024	Addressed	It is a little bit awkward to get back. I accidentally zoomed out with my mouse. The bar that was there hit itself automatically.	Enabled the dashboard reset function.
10/3/2024	Addressed	"looking at diabetes in my zip code but in 2017 it is the same but the relative risk is the same, the year suggested it should be the same, but maybe I am missing something else."	JM confirmed analyses is correct.
10/3/2024	Addressed	"My comment is that I couldn’t open the dashboard, but I couldn’t do it on my phone. I would like to have a bigger map and have it more clarified and simplified. A lot of the time we don’t really know how to navigate a map, and I would better want to have all the impacts of asthma in our communities. I want to see if asthma has increased or decreased over the years."	Rearranged the dashboard to allow for more space for the map
10/3/2024	Addressed	Maybe there could be some instructions to download the data for the selected zip code.	Splash screen and additional instructional tab included on the dashboard with step-by-step instructions

10/3/2024	Addressed	It seems odd to say there are 4 fewer emergencies	Updated to read "For every 10,000 people within zip code 90004, there were 6 fewer than expected all-cause mortality-related cases compared to the statewide average (2018)."
8/21/2024	Identified gap	Hosting & Maintenance o Link to the tool will be placed here https://trackingcalifornia.org/#gsc.tab=0 as an external tool o Can host on Tracking CA until the end of the contract (March 2025) o Additional funding will be required to host past the contract end date. o Additional funding will be required to update the data annually o Considering it's on UCLA's ArcGIS site- a maintenance plan will need to be established to coordinate the data updates. o We strongly encourage additional funding and resources be devoted to § conduct user testing to ensure its meeting the needs of the targeted audience § develop additional communications components such as tutorials and/or stand-alone communications products aimed at helping people understand the utility of the tool and how to use the tool	A discussion on hosting, maintenance, and testing should be had towards the end of the project
9/12/2024	Identified gap	Pretty bluntly, user said that 6-year-old data is unhelpful. User says that when advocates want to use data in their advocacy, you need more recent data. User feels that it's helpful to see the data over time but worries that not having data for the past 3 years makes it hard to use the data to express concerns about the current state of health outcomes. For example, for the 92231-zip code, they saw a change in excess level for the better and so he was left really wanting to know how this compares to today!	This comment will be added to the data gaps document
9/13/2024	Identified gap	Suggested adding more contrast to the website, yellow to guide eyes to the videos. Also suggested placing arrows on the toolbars at the top to make more intuitive as there is no arrow indicator for drop-down in the middle	We are limited in our customization to the dashboard and may not be able to add some of these suggested design elements.
9/13/2024	Identified gap	Suggested linking the state's AQI to the website, as research shows the link between AQI and health impacts.	This will take additional resources and will be included in the data gaps section of the report

9/17/2024	Identified gap	Also, I'm not clear what the community "tab" is intended to do because I get different responses when I click on different communities – not sure if it's just intended to show where AB 617 communities are or go to the zip code data for these communities.	The community tab includes the borders of the AB617 areas. The community has shown great interest in keeping the boundary data here. CARB has been hesitant about including this information, so the boundaries were included as general "community boundaries" instead of referencing it by the AB617 name.
10/23/2024	Identified gap	Suggested incorporating download capabilities for shapefiles	This can be considered for future iterations.
10/23/2024	Identified gap	Suggested including a clear statement on what excess means and what it DOES NOT mean - stated that the map is a bit "disingenuous"	This will take additional resources and will be included in the data gaps section of the report
9/18/2024	Identified gap	Include "no data" for zips without data in legend	The dashboard legend is not very flexible, and we have not be successful in adding this additional feature at this time.
10/3/2024	Identified gap	"It is quite difficult to navigate because I am on my phone."	We are limited in our resources and cannot create a mobile version for the current pilot.
10/3/2024	Identified gap	I want to give my testimony; I live in east Oakland in the place most contaminated along the freeway and I already went through with my two girls that have asthma	We are limited in our resources and cannot include testimonies for the current pilot. However, it may be possible to include a single testimonial video for the current dashboard.

10/3/2024	Identified gap	suggested adding air pollution data (live) with the ability to toggle on and off the data	We are limited in our resources and cannot include environmental data at this time.

Efforts were also made to improve the accessibility and understandability of the data. Users noted that terms like "Relative Risk," "SMR," and "Exceedance" were too abstract and overwhelming. The navigation and usability of the tool were another major focus. Stakeholders highlighted issues such as too many steps to access information, unclear instructions, and confusing navigation. Users found the original map colors and gradient scale unclear, and summary tables were deemed difficult to read.

In response to many of these comments, the project team addressed as many as possible. For example, to simplify user interaction, a splash screen with step-by-step instructions was introduced, along with a “About This Tool” tab. The map selection was synchronized with data filters to reduce confusion, and content was consolidated into larger tabbed sections behind the map for easier access. Visualization improvements were also prioritized., the color gradient was replaced with a red/blue scale to better represent severity, font sizes were increased, and the layout was refined for better readability. Summary data windows were enhanced, and screen space was better utilized by rearranging elements. All of the elements that the project team was able to discuss was marked as “Addressed” in Table 6 and is reflected in the description of the dashboard in the earlier section.

Unfortunately, not all peer reviewed comments could be addressed during the pilot phase of the dashboard development. For instance, stakeholders requested the ability to compare multiple zip codes, access air quality data, lack of mobile use, the inability to provide shapefiles for download, and inclusion of more recent health outcome data (2019 and later). While constrained by resources, the team noted unmet requests for future iterations (see Data Gaps project Deliverable).

Overall, the peer review process led to significant improvements in the CalHealthMap dashboard, making it more intuitive, accessible, and visually appealing. While resource and time constraints prevented the implementation of some features, the feedback gathered was invaluable in shaping the tool and identifying areas for future development. This iterative process has ensured the tool is better suited to meet the needs of its users and stakeholders.

Using CalHealthMap: Example Use Case

To illustrate the dashboard’s functionality, the following example use case has been included here for consideration:

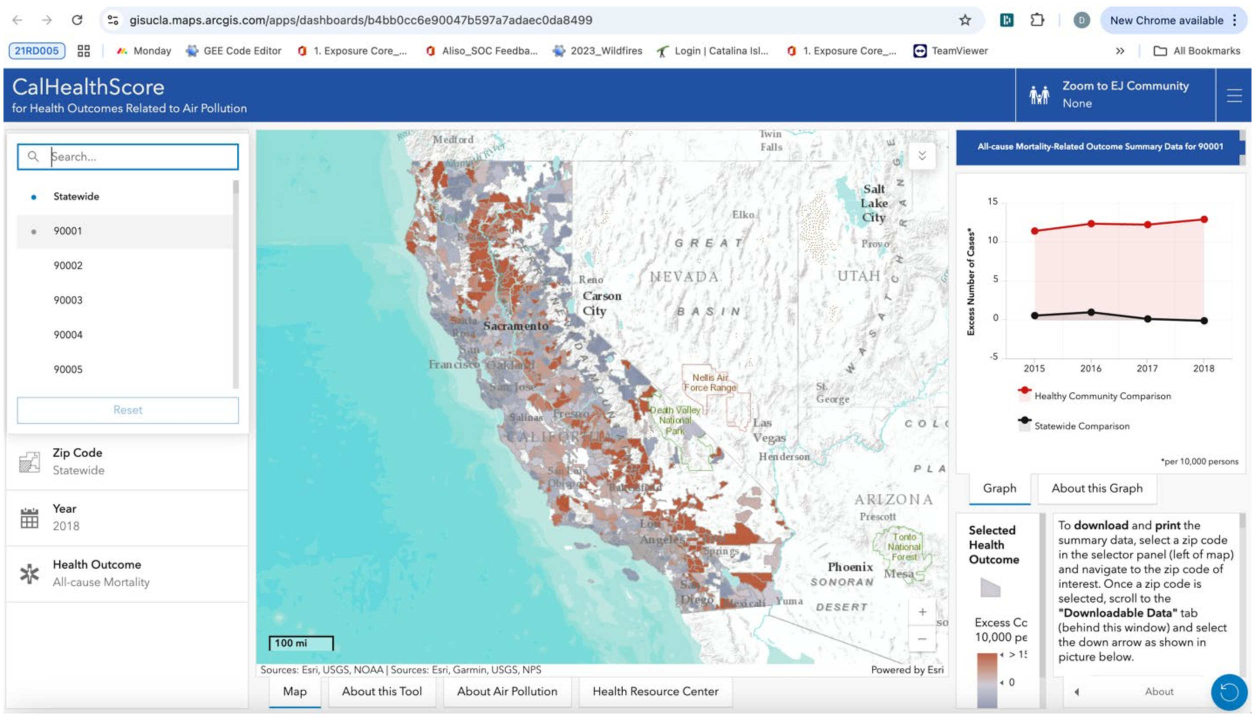
A community member is interested in understanding whether asthma-related ER visits in their neighborhood of zip code 90001 (located within the area of Los Angeles County) are higher than expected and how this compares to other areas in California. They want to use this information to support a local campaign advocating for air quality improvements in their neighborhood.

Using the Dashboard

1. **Selecting the Zip Code**: The user begins by navigating to the "Selector Options" panel on the left side of the dashboard and selecting zip code 90001. The map zooms into the

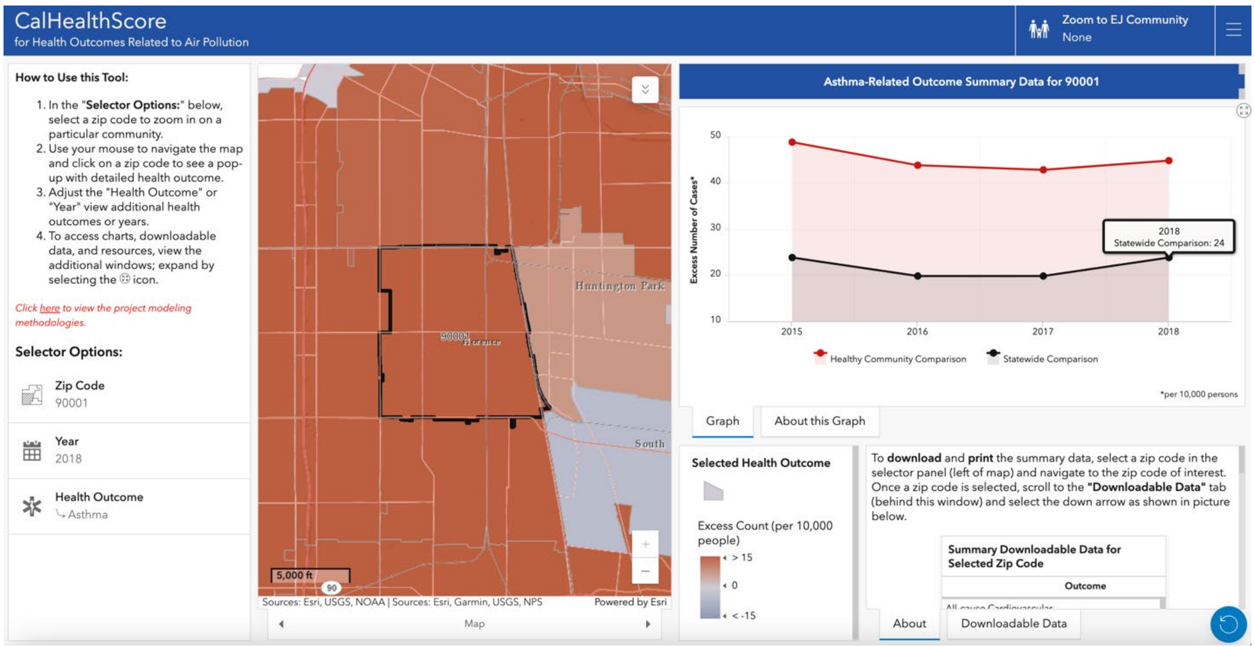
community of interest, highlighting the selected area and activating corresponding data elements (Figure 8).

Figure 8. Screenshot of the CalHealthMap dashboard showing zip code 90001, located in Los Angeles County, selected in the "Selector Options" panel on the left. The map highlights the selected area while the data visualizations on the right provide insights into asthma-related ER visits for the zip code compared to statewide averages. This example demonstrates the dashboard's functionality for users interested in exploring health outcomes associated with air pollution in their communities.



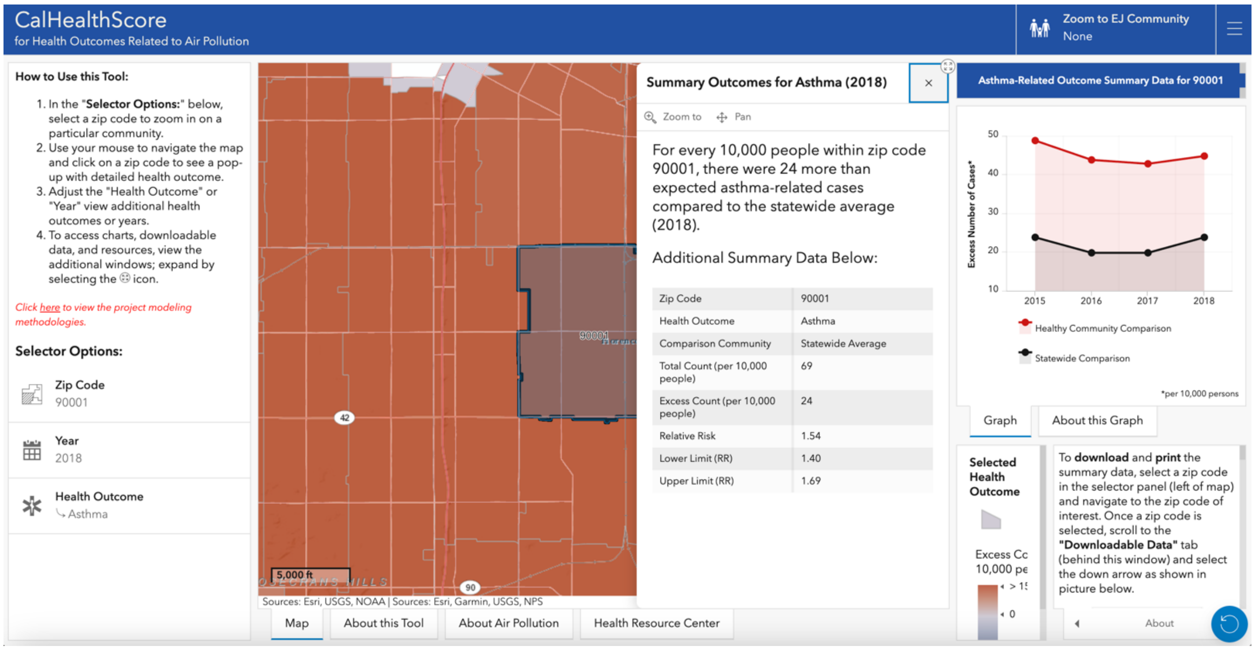
Visualizing Trends in the Time-Series Graph: To explore trends over time, the user navigates to the time-series graph (Figure 9). Here, they see how asthma-related ER visits in zip code 90001 have changed across multiple years. The black line shows excess counts compared to the statewide average, while the red line reflects comparisons with California's healthiest communities. This allows the user to assess whether disparities have widened or narrowed over time.

Figure 9. Screenshot of the CalHealthMap dashboard displaying the time-series graph for asthma-related ER visits in zip code 90001. The graph visualizes trends over multiple years, showing how excess counts compare to both the statewide average (black line) and California's healthiest communities (red line). This feature enables users to assess whether disparities in asthma-related health outcomes have widened or narrowed over time, providing valuable insights into historical trends and potential areas for advocacy or intervention.



Exploring Health Outcomes via Pop-Ups: To help interpret the time-series graph, the user clicks on zip code 90001 on the map to open a pop-up summary. The pop-up displays detailed information about asthma-related ER visits, including metrics such as the total count per 10,000 people, the excess count compared to the statewide average, and comparisons with California's healthiest communities (Figure 10). For example, for 2018, the pop-up indicates: "For every 10,000 people within zip code 90001, there were 24 more than expected asthma-related cases compared to the statewide average (2018)." This concise yet informative summary provides immediate insight into the issue.

Figure 10. Screenshot of the CalHealthMap dashboard illustrating detailed health outcome metrics for zip code 90001. After selecting the zip code on the map, a pop-up summary provides specific information about asthma-related ER visits. The summary includes data such as the excess number of cases compared to the statewide average and comparisons with California's healthiest communities. In this example, the pop-up states: "For every 10,000 people within zip code 90001, there were 24 more than expected asthma-related cases compared to the statewide average (2018)."



Downloading Data for Advocacy: The user downloads the asthma data for zip code 90001 using the "Downloadable Data" tab (Figure 11). This feature provides a ready-to-use dataset, including key metrics and a glossary of terms, which can be incorporated into presentations, reports, or grant proposals to advocate for policy changes aimed at improving air quality.

Figure 11. Screenshot of the CalHealthMap dashboard illustrating detailed health outcome metrics for zip code 90001. After selecting the zip code on the map, a pop-up summary provides specific information about asthma-related ER visits. The summary includes data such as the excess number of cases compared to the statewide average and comparisons with California's healthiest communities. In this example, the pop-up states: "For every 10,000 people within zip code 90001, there were 24 more than expected asthma-related cases compared to the statewide average (2018)."

Table 7. Example of a downloaded Excel file output from the CalHealthMap dashboard, containing detailed health outcome data for a selected zip code (90001). The below spreadsheet (exported as CSV) includes columns for metrics such as health outcome type, year, zip code, SMR, RR, upper and lower limits, total cases (per 10,000), and excess cases (per 10,000).

Outcome__Year_	**YEAR**	**ZIP**	**SMR**	**RR**	**LL**	**UL**	**Total Cases**	**Excess Cases**
All-cause Cardiovascular (2018)	2018	90001	1.35	1.35	1.23	1.48	74	19
All-cause Cerebrovascular (2018)	2018	90001	1.55	1.52	1.28	1.78	20	7
All-cause Mortality (2018)	2018	90001	1.07	1.07	0.95	1.2	40	3
All-cause Respiratory (2018)	2018	90001	1.39	1.39	1.34	1.44	536	151
Asthma (2018)	2018	90001	1.53	1.54	1.4	1.69	69	24
Chronic Obstructive Pulmonary Disease (COPD) (2018)	2018	90001	1.44	1.44	1.35	1.53	168	51
Diabetes (2018)	2018	90001	2.22	2.22	2.01	2.44	67	37
Diseases of the Circulatory System and Diabetes (DCS Diabetes) (2018)	2018	90001	1.68	1.68	1.6	1.77	241	98
Dysrhythmias (2018)	2018	90001	0.95	0.95	0.82	1.1	25	-1
Ischemic Heart Disease (2018)	2018	90001	1.89	1.85	1.6	2.13	28	13
Total ER Visits (2018)	2018	90001	1.47	1.47	1.43	1.51	778	249
All-cause Cardiovascular (2017)	2017	90001	1.29	1.29	1.17	1.41	71	16
All-cause Cerebrovascular (2017)	2017	90001	1.46	1.42	1.19	1.67	18	5
All-cause Mortality (2017)	2017	90001	1.2	1.19	1.06	1.33	46	7
All-cause Respiratory (2017)	2017	90001	1.4	1.4	1.36	1.45	578	166
Asthma (2017)	2017	90001	1.4	1.4	1.27	1.54	70	20
Chronic Obstructive Pulmonary Disease (COPD) (2017)	2017	90001	1.49	1.49	1.41	1.58	201	66
Diabetes (2017)	2017	90001	2.02	2.02	1.82	2.23	61	31
Diseases of the Circulatory System	2017	90001	1.57	1.57	1.49	1.66	221	80

and Diabetes (DCS Diabetes) (2017)								
Dysrhythmias (2017)	2017	90001	0.9	0.92	0.79	1.06	25	-2
Ischemic Heart Disease (2017)	2017	90001	1.75	1.73	1.49	2.01	26	11
Total ER Visits (2017)	2017	90001	1.45	1.45	1.4	1.49	799	246
All-cause Cardiovascular (2016)	2016	90001	1.51	1.51	1.39	1.63	96	32
All-cause Cerebrovascular (2016)	2016	90001	1.51	1.49	1.25	1.76	18	6
All-cause Mortality (2016)	2016	90001	1.02	1.03	0.91	1.17	39	1
All-cause Respiratory (2016)	2016	90001	1.37	1.37	1.32	1.41	553	148
Asthma (2016)	2016	90001	1.41	1.41	1.28	1.55	70	20
Chronic Obstructive Pulmonary Disease (COPD) (2016)	2016	90001	1.47	1.47	1.39	1.55	204	65
Diabetes (2016)	2016	90001	2.08	2.08	1.87	2.31	58	30
Diseases of the Circulatory System and Diabetes (DCS Diabetes) (2016)	2016	90001	1.65	1.65	1.56	1.74	222	88
Dysrhythmias (2016)	2016	90001	1.4	1.39	1.24	1.55	51	14
Ischemic Heart Disease (2016)	2016	90001	1.77	1.76	1.51	2.03	26	11
Total ER Visits (2016)	2016	90001	1.44	1.44	1.4	1.48	775	236
All-cause Cardiovascular (2015)	2015	90001	1.39	1.39	1.28	1.51	98	28
All-cause Cerebrovascular (2015)	2015	90001	1.55	1.47	1.25	1.71	22	7
All-cause Mortality (2015)	2015	90001	1.03	1.04	0.92	1.18	40	2
All-cause Respiratory (2015)	2015	90001	1.23	1.23	1.19	1.28	501	95
Asthma (2015)	2015	90001	1.46	1.46	1.33	1.6	77	24
Chronic Obstructive Pulmonary Disease (COPD) (2015)	2015	90001	1.36	1.36	1.27	1.45	139	37
Diabetes (2015)	2015	90001	2.07	2.07	1.85	2.31	54	28

Diseases of the Circulatory System and Diabetes (DCS Diabetes) (2015)	2015	90001	1.58	1.58	1.49	1.67	210	77
Dysrhythmias (2015)	2015	90001	1.3	1.3	1.16	1.46	50	12
Ischemic Heart Disease (2015)	2015	90001	1.61	1.59	1.35	1.86	22	8
Total ER Visits (2015)	2015	90001	1.32	1.32	1.28	1.36	711	171

Accessing Additional Context: Finally, to deepen their understanding, the user visits the "Air Pollution Information" tab to learn more about how air pollution affects respiratory health and contributes to disparities in asthma outcomes. They also review the Healthy Places Index (HPI) criteria to understand how California's healthiest communities are defined (figures shown earlier in report).

Part 2: Develop a Causal Modeling Framework (Task 2)

Introduction

The project also included a task mandating the development of a causal modeling framework that could be employed to evaluate whether emissions reductions programs led to quantiable improvements in health outcomes. As originally proposed, we sought to identify specific policies implemented implemented under AB617. After extensive searching and consultation with community partners and CARB staff, we concluded that none of the policies promulgated under AB617 had been implemented for a long enough period to actually influence health outcomes. The fallback originally specified in the contract was to essentially replicate and methodologically extend an earlier study on goods movement that we had conducted under funding from the Health Effects Institute (HEI) https://www.healtheffects.org/publication/improvements-air-quality-and-health-outcomes-among-california-medicaid-enrollees-due. In this earlier study, we used data from MediCal, the healthcare provider for people living in poverty in California, to assess the efficacy of the goods movement program, implemented in 2006. Participants were chose in they suffered from at least one of six serious chronic diseases (e.g., diabetes, heart failure, etc.). In this study, we showed that the goods movement program did causally influence utilization of emergeny rooms by the cohort members, who were considered a highly susceptible group because of their impoverished economic circumstance and pre-existing conditions. Here we expanded that study to investigate adverse birth outcomes in relation to the goods movement policies. Specifically, we expanded our methodological approach to illustrate different causal modeling frameworks and to investigate different important health outcomes.

The prenatal period is widely recognized as a particularly sensitive developmental window. Growing evidence suggests that prenatal exposure to air pollution is associated with adverse outcomes, including higher rates of infant mortality, pre-term birth, low birth weight, and impaired lung development (Bekkar et al. 2020; Markozannes et al. 2022). Research also indicates that these negative birth outcomes may increase the risk of adverse developmental impacts throughout the life course. For example, children born preterm (<37 weeks' gestation) are at high risk for long term development of neurological disorders, multiple developmental problems, respiratory problems, and cognitive deficits. Similarly, low birth weight (<2500g) infants have greater risks for short-term morbidity (e.g. respiratory distress syndrome, retinopathy) and mortality in infancy. Later in life, these children have a greater risk for neurodevelopmental delays, abdominal adiposity, and increased insulin resistance (Jornayvaz et al. 2016; Mitha et al. 2024; Mathai et al. 2012).

The goods movement sector, including ports and logistics corridors, is a major source of local, regional, and global air pollution. These emissions disproportionately affect socially disadvantaged groups who are more likely to live near these facilities and experience higher levels of exposure. This double burden is compounded by factors such as poorer health behaviors, higher rates of chronic disease, and increased psychosocial stress, leading to more severe health impacts in these communities (Institute of Medicine (US) Committee on Environmental Justice 1999). In 2006, the CARB and local air quality management districts implemented the "Emission Reduction Plan for Ports and Goods Movement" (ERPPGM), aiming to mitigate the health and environmental impacts of goods movement (CARB 2006). Goals of this plan included reducing statewide goods movement emissions to 2001 levels or lower by 2010, cutting diesel particulate matter health risks from goods movement by 85% by 2020, and achieving a 50% reduction in nitrogen oxides (NOx) emissions from international goods movement in the South Coast Air Basin by 2020. Significant emission reductions were achieved during the initial implementation years, with $PM_{2.5}$, PM_{10}, and diesel particulate matter levels decreasing by 69%, NOx by 50%, and sulfur oxides (SOx) by 75% at the Port of Los Angeles between 2005 and 2010 (Port of Los Angeles 2019). These reductions contributed to noticeable improvements in air quality, with annual average $PM_{2.5}$ levels decreasing by a factor of 1.5 to 1.7 in neighborhoods surrounding the Los Angeles and Long Beach Ports.

The objective of Task 2 was to assess whether emissions reduction policies targeting goods movement improved birth outcomes, such as preterm births and low birth weight, in areas near ports and goods movement corridors compared to control areas. Previous research has demonstrated significant declines in air pollution near goods movement corridors and port facilities (Su et al. 2016; 2020), and preliminary in-house analyses showed potential additional impacts on birth outcomes. This task focuses on developing modeling techniques to evaluate the spatially varying causal effects of goods movement policies to identify where health benefits are most pronounced, if at all. By advancing methodological approaches and analyzing birth outcomes in the context of the ERPPGM, the study aimed to assess the causal effect of the Goods Movement Corridors (GMC) policy on birth outcomes using Difference-in-Difference (DiD) modeling and provide evidence of the health benefits of goods movement policies. It was hypothesized that reductions in tailpipe emissions and subsequent declines in ambient concentrations of pollutants would result in improvements in birth outcomes; however, results indicate limited statistically significant or mixed differences in birth outcomes between the areas post-policy implementation, even after adjusting for confounding factors.

Methods

The statistical analyses conducted for Task 2 primarily focused on assessing the health impacts of air pollution interventions in disadvantaged communities (DACs) as mandated by AB 617. The project utilized well-established DiD quasi-experimental models to assess the causal impacts of air quality interventions on birth outcomes. These models compared health outcomes before and after interventions in treatment groups, or those likely to be affected by regulatory or policy actions (GMC buffer zones), against control groups that were not subject to the interventions but were similar in sociodemographic characteristics and exposure profiles. These control communities adjust for or "difference out" confounding factors which may simultaneously affect health in ways that have nothing to do with policy. As such, DiD methods allow investigators to examine the causal effect of policy interventions on health or other outcomes while controlling for myriad non-policy based confounding factors, as described in Lechner et al (2011). Control communities were chosen based on their similarity to the treatment communities in terms of sociodemographic characteristics and exposure profiles similar to Su et al (2020).

To estimate the causal effect of the ERPPGM policy, we compared birth weights after its implementation in areas directly adjacent to ports and goods movement corridors with those in areas near truck-restricted roads and background areas away from major roads. The dataset includes all births that occurred from 2004 to 2011 in the policy area (GMC: locations within 500 meters of truck-permitted freeways and ports), the near policy area (NGMC: locations within a 500-meter buffer of a truck-prohibited roadway or within 300 meters of connecting roadways), and the control area (CTRL: locations outside the other two corridors).

Data Sources: Birth Outcomes (2004 – 2011)

The California Comprehensive Death File (CCDF) birth dataset is a vital resource for public health research, providing detailed records of births across the state. It includes extensive demographic information such as the date of birth, sex, race, ethnicity, and maternal and paternal details. Additionally, the dataset documents clinical data related to the birth, including birth weight, gestational age, and delivery method. Geographic information, such as the place of birth and residence of the mother, is also captured. This dataset allows researchers to analyze birth trends, assess maternal and infant health outcomes, and identify disparities in birth outcomes across different demographic and geographic groups.

We chose to focus on birth outcomes rather than other health endpoints, such as ER-based outcomes from HCAI datasets, because we had access to home address data for birth outcomes, whereas only zip code data was available for ER records. This distinction allowed us to create a buffer zone around the GMC and determine whether a home address fell within or outside the buffer (or distance from corridor). This spatial specificity supports a more refined and accurate analysis of exposure impacts, which would not have been feasible using the coarser geographic resolution provided by ER data.

Two main outcomes of interest were considered: (1) Low Birth Weight (LBW), categorized as 0 for births not classified as low birth weight and 1 for those classified as low birth weight, with newborns weighing less than 2500g defined as low birth weight; and (2) Preterm Birth, categorized as 0 for births not occurring preterm and 1 for those occurring preterm, with infants born at less than 37 weeks of gestation considered preterm. Additional covariates included in the model to control for potential confounding were: maternal age (<20, 20-25, 26-30, 31-35, 36+), maternal education, prenatal care (yes/no), parity (1st, 2nd, 3+), sex, maternal race/ethnicity (white (non-Hispanic), Hispanic (any race), black, Asian/Pacific Islander, other/unknown), and season of birth. Table 8 lists each of the variables described above, along with the corresponding names used to identify them in the birth outcomes dataset.

Table 8. Descriptions and variable names from the Birth Outcomes Dataset. This table lists key variables used in the dataset, providing both a description and the corresponding dataset variable name. Variables include maternal age at baseline ("age_m_cat"), sex of the child ("sex2"), maternal education level ("edu_m"), maternal race/ethnicity ("racem5"), prenatal care ("prenatal"), parity ("parity"), and season of birth ("season_dob").

Variable Description	Dataset Variable Name
maternal age at baseline	*"age_m_cat"*
sex	*"sex2"*
maternal education	*"edu_m"*
maternal race/ethnicity	*"racem5"*
prenatal care	*“prenatal”*
parity	*"parity"*
season of birth	*"season_dob"*

The exposure period was defined as 2007-2011, while the control period was defined as 2012-2015.

Results

To assess the impact of the policy implementation on Low Birth Weight (LBW) rates, we applied a series of statistical approaches, beginning with simpler analyses and progressively incorporating more complex quasi-experimental methods. This stepwise approach allowed us to first explore broad patterns before refining estimates by controlling for potential confounders and accounting for temporal and spatial variations. However, across all analytical approaches, we did not observe statistically significant effects of the policy on LBW rates.

We began with a Pre-Post Analysis, comparing LBW rates within the Goods Movement Corridors (GMC) area before and after the policy implementation. This approach provided an initial look at potential changes without requiring a control area. Next, we employed a Controlled Pre-Post (2×2 Difference-in-Differences, DiD) approach, comparing changes in LBW rates in the GMC area against concurrent trends in the near-GMC (NGMC) and control (CTRL) areas. This method accounts for time- and space-fixed confounders but were unable to directly test the parallel trends assumption. To further examine trends over time, we conducted an Interrupted Time Series (ITS) Analysis, estimating post-policy LBW trends based on pre-policy trends within the GMC area. This approach allowed us to assess whether there were deviations from expected trends following policy implementation. Finally, we applied a Controlled Interrupted Time Series (Generalized Difference-in-Differences, DiD) approach, comparing temporal trends in LBW rates before and after the policy implementation across the GMC, NGMC, and CTRL areas. This method provided the advantage of testing the parallel trends assumption while controlling for space- and time-fixed confounders. These methods are further detailed in Table 9.

Table 9. This table summarizes the statistical methods used to assess the policy's impact on Low Birth Weight (LBW) rates. It includes five columns: Statistical Approach, Description, Key Advantages, Key Limitations, and Findings. Each method provided different insights. The Pre-Post Analysis compared LBW rates before and after policy implementation within the Goods Movement Corridors (GMC). The Controlled Pre-Post (Difference-in-Differences, DiD) compared trends in GMC against near-GMC (NGMC) and control (CTRL) areas. The Interrupted Time Series (ITS) Analysis estimated post-policy LBW trends based on pre-policy data. The Controlled Interrupted Time Series (Generalized DiD) analyzed temporal trends across GMC, NGMC, and CTRL, allowing visualization of parallel trends.

Statistical Approach	***Description***	***Key Advantages***	***Key Limitations***
Pre- & Post-Analysis	Compared LBW rates within GMC area before and after policy.	Avoids need for a control area.	Assumes all changes are attributable to policy after adjusting for covariates.
2x2 DiD	Compared changes in LBW rates in GMC area against changes in NGMC and CTRL.	Accounts for time- and space-fixed confounders.	Cannot directly test parallel trends assumption; depends on careful selection of control areas.
ITS Analysis	Estimated post-policy LBW trends based on pre-policy trends within GMC area.	Does not require a control area; utilizes temporal variability.	Assumes linearity in trend; may lack power due to limited post-policy data.
Generalized DiD	Compared temporal trends in LBW rates before and	Tests parallel trends while	Dependent on appropriate control area selection;

	after policy across GMC, NGMC, and CTRL areas.	controlling for space/time-fixed confounders.	potential instability in outcome rates over time.

Low-Birth Weight

While our analysis leveraged multiple statistical approaches to comprehensively assess the policy's impact, we found mixed evidence regarding its association with LBW rates. The Pre- & Post-Analysis indicated a slight but statistically significant increase in LBW rates post-policy (OR = 1.019, 95% CI: 1.009, 1.029). However, all other models, including 2x2 DiD, ITS Analysis, and Generalized DiD, found no statistically significant policy effect on LBW rates. These findings highlight the complexity of evaluating policy interventions and suggest that other unmeasured factors may be influencing birth outcomes in these areas and/or other limitations exist in the datasets (and detailed further in the Discussion section). A more detailed analyses can be found in the Appendix.

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Table 10. This table presents the results of multiple statistical approaches used to evaluate the impact of the policy on low birth weight (LBW) rates. It includes the estimated causal odds ratios (ORs) with 95% confidence intervals (CIs) from adjusted models (crude model results not included here), the direction of association (increase, decrease, or no change), whether the results are statistically significant, and an interpretation of the findings.

Statistical Approach	***Effect Estimate (adjusted model)***	***Direction of Association***	***Significant?***	***Interpretation***
Pre- & Post-Analysis	OR: 1.019 (95% CI: 1.009, 1.029)	↑	Yes	Policy does appear to have a slight impact on LBW rates.
2x2 DiD	OR (GMC vs. CTRL): 1.00 (95% CI: 0.987, 1.013)	→	No	No evidence that policy implementation changed LBW rates compared to control areas.
ITS Analysis	OR: 0.992 (95% CI: 0.973, 1.011)	↓	No	No significant deviation from expected LBW trends post-policy.
Generalized DiD	OR (averaged) = 0.995 (95% CI: 0.943, 1.050)	↓	No	Findings reinforce the lack of a policy effect on LBW rates, with a slight but non-significant downward trend in averaged effect estimates.

Pre-term Birth

Again we leveraged multiple statistical approaches for the pre-term birth analyses where we found mixed evidence regarding its association. The Pre- & Post-Analysis indicated a statistically significant decline in pre-term birth rates post-policy (OR = 0.906, 95% CI: 0.899, 0.913). Similarly, the Interrupted Time-Series (ITS) Analysis found a slight but significant decrease in pre-term births compared to projected trends (OR = 0.973, 95% CI: 0.958, 0.988), suggesting that the policy may have played a role in reducing pre-term births. However, the 2x2 Difference-in-Difference (DiD) and Generalized DiD, found no statistically significant policy effect on pre-term birth rates. Specifically, the 2x2 DiD model (OR = 0.995, 95% CI: 0.985, 1.005) indicated no evidence of a differential change in pre-term birth rates between policy-exposed and control areas and the Generalized DiD model (OR = 1.028, 95% CI: 0.984, 1.075) did not support a policy effect when accounting for trends across multiple regions. A more detailed analyses can be found in the Appendix.

Table 11. This table presents the results of multiple statistical approaches used to evaluate the impact of the policy on pre-term births. It includes the estimated causal odds ratios (ORs) with 95% confidence intervals (CIs) from adjusted models (crude model results not included here), the direction of association (increase, decrease, or no change), whether the results are statistically significant, and an interpretation of the findings.

Statistical Approach	***Effect Estimate (adjusted model)***	***Direction of Association***	***Significant?***	***Interpretation***
Pre- & Post-Analysis	OR: 0.906 (95% CI: 0.899, 0.913)	↓	Yes	Policy implementation was associated with a decrease in pre-term birth rates.
2x2 DiD	OR (GMC vs. CTRL): 0.995 (95% CI: 0.985, 1.005)	↓	No	No significant difference in pre-term birth rates between policy-exposed and control areas.
ITS Analysis	OR: 0.973 (95% CI: 0.958, 0.988)	↓	Yes	Slisght bu significant decline in pre-term birth rates post-policy, based on pre-trend projections.
Generalized DiD	OR (averaged): 1.028 (95% CI: 0.984, 1.075)	↑	No	Findings reinforce the lack of a policy effect on No strong evidence of policy impact on pre-term birth rates across areas.

Summary and Discussion

This study evaluated the impact of goods movement policies on low birth weight (LBW) and pre-term birth rates using multiple statistical approaches, including Pre-Post Analysis, 2x2 Difference-in-Difference (DiD), Interrupted Time-Series (ITS), and Controlled Interrupted Time-Series (Generalized DiD). It was hypothesized that reductions in air pollution due to ERPPGM policies would lead to improvements in birth outcomes. However, the results indicate limited and mixed effects, with a slight but statistically significant increase in LBW rates post-policy and some evidence of a modest decline in pre-term birth rates in certain models. The Pre-Post Analysis showed a small but statistically significant increase in LBW rates post-policy, while pre-term birth rates exhibited a slight decline. The DiD models, which compare trends between policy-affected and control regions, found no strong evidence that the policy had a differential impact on either outcome. However, the ITS analysis did detect a statistically significant decline in pre-term birth rates over time, suggesting a potential gradual improvement rather than an immediate post-policy effect. Despite this finding, the estimated policy effects remained small, and confidence intervals suggest the changes may not be clinically meaningful. One possible explanation for these findings is that the policy's effect size was too small to detect, particularly given the relatively short post-policy observation period (2008–2011). Although the ITS models suggested a gradual reduction in pre-term birth rates, the confidence intervals indicate that the change was modest. Additionally, while LBW rates showed a slight increase, the underlying reasons remain unclear and may be influenced by unmeasured factors rather than the policy itself. If the policy had any long-term benefits, they may not have fully manifested within the study period. Without a longer follow-up, potential delayed effects on birth outcomes could have gone undetected. Future research with a longer follow-up period, larger sample sizes, and improved exposure assessment will be essential to determine whether the policy led to delayed but meaningful improvements in birth outcomes. Additionally, ongoing research on $PM_{2.5}$ and birth outcomes may provide stronger evidence regarding the relationship between air pollution reductions and birth outcomes in affected communities. Given the current lack of a strong and consistent relationship between the policy and birth outcomes, these health metrics were not included in the final dashboard.

The results here differed from the earlier HEI study mentioned above where significant beneficial effects of the GM policy were observed in terms of reduced emergency department visits and hospital admissions. The earlier HEI study relied on a cohort of people in poverty who suffered from serious pre-existing conditions. It is likely that this group was more susceptible to the effects of the policy than the mothers who delivered the babies because this group was relatively young, healthy and of higher socioeconomic status because they were patients of the UCLA Health System and did not require government subsidized healthcare.

The study had several strengths, including the use of diverse statistical methods, the integration of control areas to account for broader trends in birth outcomes, and the application of temporal trend analyses to better assess the parallel trends assumption. These methodological considerations enhance the robustness of the findings, even as further research is needed to clarify the policy's long-term impact. However, several methodological limitations should be acknowledged:

1. **Pre-Post Analysis Assumptions**: The pre-post analysis assumes that, after adjusting for covariates, all observed changes in birth outcomes are attributable solely to the policy. This assumption may not fully account for other concurrent factors influencing birth outcomes during the study period, such as changes in healthcare practices, socioeconomic shifts, or environmental influences.
2. **Minimal Temporal Variability in Pre-Post and Difference-in-Difference Models**: The pre-post and difference-in-difference (DID) approaches rely on a limited number of time points, which restricts the ability to assess long-term trends and variations. The DID analysis further assumes that control areas selected for comparison follow parallel trends with the policy-affected areas, an assumption that cannot be tested directly.
3. **Statistical Power and Effect Size**: The observed changes in LBW rates were minimal, with only slight increases post-policy. Although statistically significant, the effect sizes were small, raising concerns about whether the changes reflect meaningful clinical differences. Similarly, some of the estimated odds ratios in the DID models were close to 1.0, suggesting limited practical impact.
4. **Linearity Assumption in Interrupted Time-Series (ITS) Analysis**: The ITS models assume a linear temporal trend in birth outcomes before and after policy implementation.

If birth outcomes followed non-linear patterns, the estimated policy effects might be biased. Additionally, the reliance on a short post-policy observation period could limit the ability to detect longer-term trends.

5. **Lack of a True Counterfactual in Some Models**: The uncontrolled ITS and pre-post analyses do not include a true counterfactual scenario, making it difficult to isolate the policy's impact from other underlying trends. While the controlled ITS approach attempts to address this by incorporating control areas, it depends on the assumption that trends in the control and policy-exposed areas would have been similar in the absence of the intervention.
6. **Potential Residual Confounding**: Although adjusted models incorporate known confounders, there remains the possibility of unmeasured or residual confounding. Factors such as individual maternal characteristics, changes in prenatal care access, or neighborhood-level stressors could have influenced birth outcomes independently of the policy.
7. **Generalizability**: The findings are specific to the study regions (GMC, NGMC, and CTRL areas) and may not be directly applicable to other geographic areas with different population characteristics, healthcare systems, or environmental exposures. Additionally, the effects observed within this policy context may not generalize to other policy interventions targeting similar health outcomes.
8. **Short Follow-Up Period**: The study primarily examines birth outcomes within a few years post-policy. Longer-term evaluations could provide a clearer picture of sustained effects, particularly in assessing potential lagged impacts on birth outcomes.

Challenges with the AB 617 Program and Alternative Approach

Originally, the researchers aimed to evaluate AB 617 programs as a test case. However, after reviewing the emission reduction plans across AB 617 communities, no suitable interventions were identified for evaluation (Task 1, Subtask 3). To guide the selection process, the team established six key criteria for identifying viable health interventions:

1. The intervention was implemented within a consistent and well-defined timeframe.
2. It affected a sufficiently large population to enable statistical modeling and meaningful analysis.
3. It had been active long enough to yield measurable health benefits.
4. The intervention's implementation allowed for clear identification of both an "intervention" and a "control" group.
5. It was deemed relevant and valuable by both the community and the California Air Resources Board (CARB) through stakeholder consultation.
6. The intervention's effects were not confounded by the impacts of COVID-19.

Many of the interventions considered—both by the research team and through community consultations—failed to meet these criteria. A common challenge was that policy implementation was too diffuse over time, making it difficult to establish a clear exposure window for evaluation. Additionally, several interventions under consideration had not been in place long enough to demonstrate measurable health effects, limiting the ability to detect changes in health outcomes.

Finally, in many cases, expected air pollution reductions were minimal, making it unlikely that the interventions would produce detectable health improvements.

Efforts to identify alternative interventions through collaboration with project partners were also unsuccessful. Programs such as school flag warnings and indoor air filtration systems were considered, but the absence of symptom reporting data from school nurses made it difficult to establish a reliable dataset for analysis. While emergency room (ER) visits could have served as a potential metric, it was determined that this measure would likely not be sensitive enough to detect meaningful changes attributable to the flag programs or air filtration systems. As a result, the research team shifted focus to an alternative approach specified as a fallback in the original contract: assessing the impact of goods movement policies on birth outcomes. Previous research has demonstrated significant declines in air pollution near goods movement corridors and port facilities (Su et al., 2016; 2020). Additionally, a preliminary examination of birth outcome data suggested a notable reduction in pre-term births around 2007, coinciding with the implementation of California's "Emission Reduction Plan for Ports and Goods Movement" (ERPPGM).

Summary

This project highlights the potential for developing interactive tools, in collaboration with community members, agencies, and key stakeholders, to track and address the health impacts of air pollution in California's most affected communities. The CalHealthMap dashboard**,** created as a pilot tool, represents a major step toward democratizing access to zipcode-level health data for communities burdened by pollution. While our analysis of environmental interventions and birth outcomes produced mixed and non-statistically significant results—underscoring the challenges of using advanced statistical modeling to assess policy impacts—we have developed a framework for continued research in this area as additional data become available.

Community-Centered Approach

The project emphasized community engagement throughout its development, integrating feedback from community members, agency stakeholders, and CBOs. This iterative process ensured that the selected health metrics, dashboard design, and overall project priorities aligned with the lived experiences and needs of the targeted populations. The workshops and focus groups demonstrated that communities value tools that not only provide data but also contextualize it in ways that support advocacy and education. However, the project also revealed persistent barriers to achieving full participation from targeted groups. Limited capacities (aligning schedules), language barriers, and historical distrust in institutional data collection efforts and agencies were recurring challenges. Addressing these barriers through sustained community partnerships and ongoing capacity-building will be essential for the success and scalability of tools like CalHealthMap.

Addressing Data Gaps and Limitations

A major challenge encountered in Part 1 of the project was significant data gaps, particularly for health metrics with long latency periods (e.g., cancers), outcomes not systematically collected (e.g., ER data), and cross-border health impacts. These gaps limit the tool's ability to fully capture the range of potential health effects and the nuances of community-specific health conditions. While these exclusions reduce the tool's comprehensiveness, they could be addressed in future iterations with additional resources. Similarly, the absence of key social determinants of health, such as economic hardship, housing quality, and healthcare access, restricts the tool's ability to assess health inequities related to air pollution. Expanding these metrics could enhance the tool's capacity to provide a more holistic understanding of environmental health impacts.

The statistical models used in Part 2, while rigorous, rely on assumptions that may not fully account for unmeasured confounders or geographic variability, potentially affecting result interpretation. Limited time points restrict the assessment of long-term trends, and interrupted time-series (ITS) models assume linearity, which may not fully capture policy effects. Some models lack a true counterfactual, making it difficult to isolate the policy's impact. The use of quasi-experimental methods assumes parallel trends between treatment and control groups, which may not fully account for unobserved confounders or pre-existing differences. Additionally, reliance on relative risks may oversimplify causal relationships between air pollution and health, potentially leading to under- or over-estimation of intervention impacts. Future research should incorporate machine learning, longer-term datasets, and refined statistical approaches to better capture complex causal relationships. Given the current lack of a strong and consistent association between the policy and birth outcomes, these health metrics were not included in the final dashboard (Part 1).

Sustainability and Future Directions

Ensuring the sustainability of the CalHealthMap dashboard requires a multifaceted approach that integrates technical maintenance, user engagement, and institutional support. Regular updates to data sources are critical to maintaining the tool's relevance and accuracy. This necessitates the establishment of clear governance structures and partnerships between Tracking California, UCLA, and CARB to coordinate ongoing data integration and system enhancements. User training and capacity-building efforts are equally vital, particularly for communities most burdened by air pollution to empower residents and stakeholders to effectively utilize the tool for advocacy and decision-making. The dashboard's sustainability also hinges on its adaptability to evolving user needs, such as incorporating additional health and environmental metrics, multilingual support, and features that reflect community priorities. Moreover, financial support through grants or institutional funding will be necessary to sustain technical operations, data curation, and stakeholder engagement over time. By addressing these dimensions, the CalHealthMap dashboard can remain a robust, accessible, and impactful resource for promoting environmental health equity.

For Part 2 of the current project, future research with a longer follow-up period, larger sample sizes, and improved exposure assessment will be crucial in determining whether the ERPPGM policy led to delayed but meaningful improvements in birth outcomes. Additionally, continued investigations into the relationship between PM2.5 reductions and birth outcomes may provide stronger evidence of air pollution's impact on affected communities. Given the current lack of a strong and consistent association between the policy and birth outcomes identified in Part 2 of the current work, birth outcomes were not included in the final dashboard. However, they may be incorporated into future iterations if meaningful causal effects are identified.

Appendix

Appendix 1. Flyer developed by CCV and IV Equity in collaboration with the AIRE Collaborative to promote virtual community workshops on California's Air Quality and Health Equity Dashboard. The flyer provides details for sessions aimed at community residents, local groups, and state agency staff, with dates, times, and RSVP instructions in English. Key workshop goals include helping attendees understand how the dashboard can support advocacy efforts, discuss air quality issues with city leaders, and strengthen grant applications. The flyer also features a QR code for RSVP and additional contact information to facilitate participation, ensuring accessibility for diverse audiences.

Appendix 2. Flyer developed by CCV and IV Equity in collaboration with the AIRE Collaborative to promote virtual community workshops on California's Air Quality and Health Equity Dashboard. The flyer provides details for sessions aimed at community residents, local groups, and state agency staff, with dates, times, and RSVP instructions in Spanish. Key workshop goals include helping attendees understand how the dashboard can support advocacy efforts, discuss air quality issues with city leaders, and strengthen grant applications. The flyer also features a QR code for RSVP and additional contact information to facilitate participation, ensuring accessibility for diverse audiences.

Appendix 3. Screenshot of an online workshop registration form for regional workshops aimed at gathering community feedback on the Air Quality and Health Equity Dashboard. The form invites community residents and groups to participate in virtual workshops held on June 25 and June 27, with sessions offered in English and Spanish. It includes instructions for registration via text or phone, along with a brief overview of the workshop's purpose: to ensure the dashboard meets the needs of communities by addressing air quality and health equity concerns.

You're Invited! Share Your Voice on a Air Quality and Health Equity Dashboard

To those who care about air quality, health equity, environmental justice, and data tools: Join an upcoming virtual workshop to share your feedback on a draft web-based air quality and health equity mapping tool that will track how air pollution affects the health of communities like yours across California.

For Community Residents & Community Groups (English & Spanish)

- Tuesday, June 25, 6:00 - 7:30 PM
- Thursday, June 27, 6:00 - 7:30 PM

Register now by completing this form or text/call 760-618-1651 to receive a confirmation with instructions to join online or by phone.

The Allies in Reducing Emissions (AIRE) Collaborative is partnering with UCLA Public Health researchers and environmental justice groups on this Air Quality and Health Equity Map and Dashboard. We need your input to make sure it truly serves the needs of residents and organizations working to improve air quality and public health in California neighborhoods. This effort is funded by the California Air Resources Board (CARB) to support the AB 617 work happening in communities statewide.

Here's how the dashboard could benefit you:

- Get data to back up your advocacy efforts for cleaner air
- Understand and discuss health/air quality issues with your city leaders
- Access information to strengthen grant applications
- Better serve your community by seeing the impacts of pollution

Don't miss this opportunity to ensure the new dashboard uplifts the voices and priorities of communities on the frontlines of pollution. Your lived experiences will make it a truly useful tool for all.

Appendix 4. Detailed Statistical Analyses of Policy Impact on Low Birth Weight (LBW) and Pre-Term Birth.This appendix presents a detailed statistical analysis of the policy's impact on Low Birth Weight (LBW) and pre-term birth outcomes across multiple analytical approaches. The results are summarized in various tables and figures, each providing insights into different methodological frameworks applied in the study. The Pre-Post Analysis compares LBW and pre-term birth rates in the Goods Movement Corridors (GMC) area before and after policy implementation. The Controlled Pre-Post (2×2 Difference-in-Differences, DiD) Analysis compares changes in LBW and pre-term birth rates in the GMC area against those in the near-GMC (NGMC) and control (CTRL) areas. This approach accounts for fixed confounders but assumes parallel trends across areas. The Interrupted Time Series (ITS) Analysis examines trends in LBW and pre-term birth rates within the GMC area before and after policy implementation. By comparing predicted versus observed post-policy trends, this approach leverages temporal variability. The Controlled Interrupted Time Series (Generalized Difference-in-Differences, DiD) Analysis further explores temporal trends in LBW and pre-term birth rates across the GMC, NGMC, and CTRL areas, controlling for space- and time-fixed confounders.

Low-Birthweight (LBW) Results

Pre-Post Analysis. This analysis compares Low Birth Weight (LBW) rates within the GMC area, before and after the policy implementation. The advantage of this approach is that it avoids the need to select a control area. However, a limitation is that it leverages minimal information regarding temporal variability. Additionally, it assumes that, after adjusting for covariates, all observed changes in outcomes post-policy are attributable solely to the policy.

Table 12 presents Low Birth Weight (LBW) rates (per 1,000 births) in the GMC area during the pre-policy (2004-2007) and post-policy (2008-2011) periods. In the pre-policy period, the LBW rate was 64.52 per 1,000 births, increasing slightly to 65.40 per 1,000 births in the post-policy period.

Table 12. Pre- and post-policy low birthweight rates in the exposure area within the GMC region. The table compares low birthweight rates before the policy implementation (2004–2007), which were 64.52 total LBW cases per 1,000 births, to the rates after the policy implementation (2008–2011), which increased slightly to 65.40 total LBW cases per 1,000 births. This data highlights changes in birthweight outcomes associated with the policy's timeframes.

	LBW Cases (per 1,000 births) in GMC area
Pre-policy (2004-2007)	64.52
Post-policy (2008-2011)	65.40

While the difference of the values in the above table is minimal, this pre-post comparison provides an initial exploration of the potential impact of the policy on birth outcomes in the affected areas.

To estimate the effect of the policy implementation on Low Birth Weight (LBW), two logistic regression models were applied. The first model, a crude model, examined the relationship between LBW and the policy period, represented by an indicator variable (i.PERIOD), without adjustment for confounding variables. The second model, an adjusted model, included potential confounders in addition to the policy period to account for other factors that may influence birth outcomes.

- Crude Model: LBW ~ i.PERIOD
- Adjusted Model: LBW ~ i.PERIOD + confounders

presents the causal odds ratios (OR) for LBW, with 95% confidence intervals for both the crude and adjusted models.

Table 13. Estimate Causal Odds Ratios (OR) for Low Birth Weight (LBW) with 95% Confidence Intervals using Crude and Adjusted Model

Model	Causal OR	Lower 95% CI	Upper 95% CI
Crude	1.014	1.005	1.024
Adjusted	1.019	1.009	1.029

The crude model showed an odds ratio of 1.014 (95% CI: 1.005, 1.024), suggesting a slight increase in the likelihood of LBW in the post-policy period. After adjusting for confounders, the odds ratio increased to 1.019 (95% CI: 1.009, 1.029).

Controlled Pre-Post (2x2 Difference-in-Difference)

The analysis compares changes in Low Birth Weight (LBW) rates before and after the policy implementation in the GMC area, against concurrent changes in the NGMC and CTRL areas. This approach offers the advantage that, if control areas are appropriately selected, covariates that are fixed over time (varying only between areas) or fixed over space (varying only over periods) are automatically accounted for. However, a significant limitation is that this method utilizes minimal information regarding temporal variability. Consequently, it is not possible to test or visually assess the "parallel trends" assumption, which is key for unbiased estimation in difference-in-difference analysis. Instead, we must rely on this assumption, which places strong dependence on the careful selection of control areas.

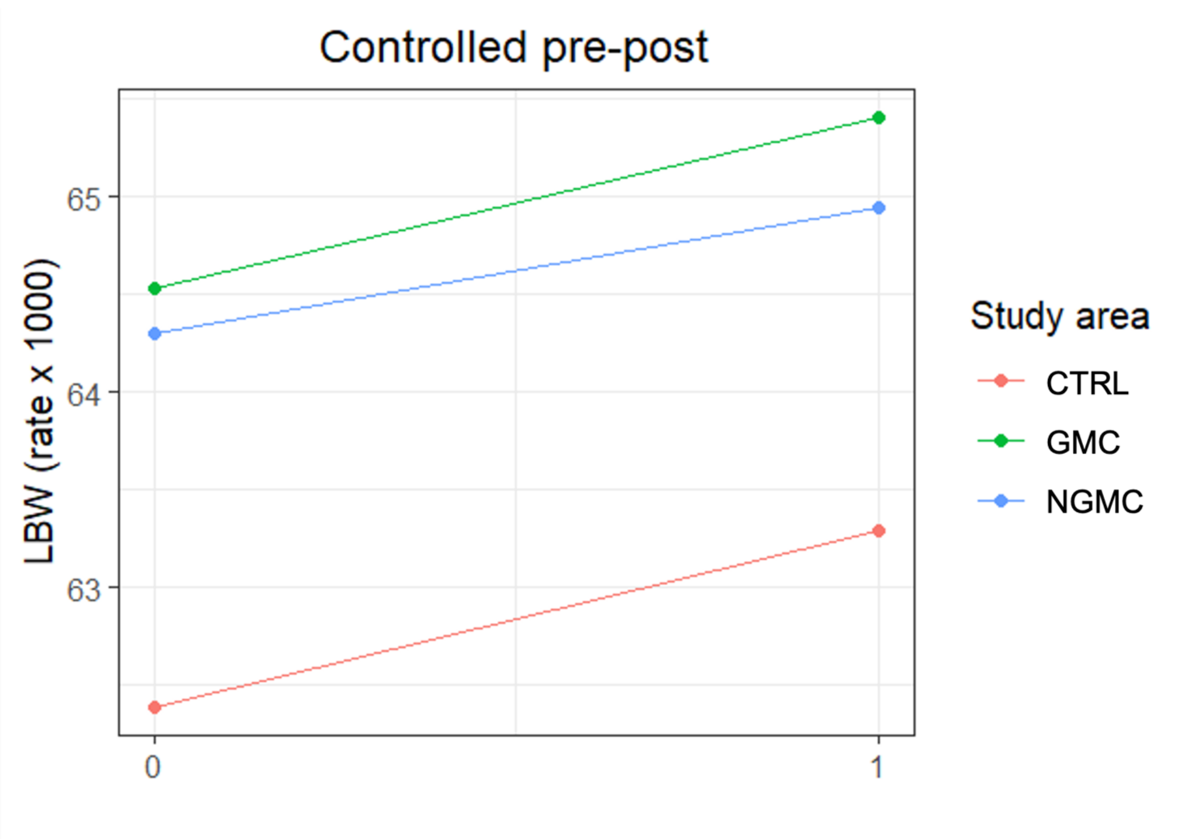
Table 14 summarizes the low birthweight (LBW) rates (per 1,000 births) for the pre-policy (2004-2007) and post-policy (2008 - 2011) periods, across three areas: the control area (CTRL), near policy area (NGMC), and the GMC area. Prior to the policy, the LBW rates in the CTRL, NGMC, and GMC areas were 62.39, 64.30, and 64.52 per 1,000 births, respectively. Post-policy, these rates increased to 63.29, 64.95, and 65.40 per 1,000 births.

Table 14. Low Birth Weight (LBW) Rates (per 1,000 births) Pre- and Post-Policy by Area (Control Region, Near Policy Area, and Goods Movement Corridor)

	CTRL	NGMC	GMC
Pre policy (2004-2007)	62.39	64.30	64.52
Post policy (2008-2011)	63.29	64.95	65.40

The graph below provides a visual comparison of LBW rates over time across the three areas.

Figure 12. Graphical comparison of low-birth-weight rates over time across control region, goods movement corridor (GMC) policy area, and near the GMC policy area (NGMC). The x-axis represents time, where 0 indicates the pre-period and 1 indicates the post-period



Two models were applied to estimate the effects of the policy on LBW rates:

- Crude: LBW ~ i.PERIOD + i.area + <u>i.PERIOD*i.AREA</u>
- Adjusted: LBW ~ i.PERIOD + i.area + <u>i.PERIOD*i.AREA</u> + confounders

The crude model includes the policy period (i.PERIOD), area (i.area), and their interaction term (i.PERIOD * i.area) to assess the impact of the policy and its differential effect across areas. The coefficient of the interaction term is the estimated causal impact of the policy on LBW rates across the different areas (CTRL, NGMC, GMC). Alternatively, the adjusted model builds on the crude model by adjusting for potential confounders that could influence LBW.

Finally, Table 15 below presents the estimated causal odds ratios (OR) for Low Birth Weight (LBW) in the NGMC and GMC areas, relative to the control (CTRL) area, for both crude and adjusted models.

Table 15. Estimated Causal Odds Ratios (OR) for Low Birth Weight (LBW) with 95% Confidence Intervals using Crude and Adjusted 2x2 Difference-in-Difference Models

Model	Contrast	Causal OR	Lower 95% CI	Upper 95% CI
Crude	NGMC vs CTRL	0.995	0.984	1.006
	GMC vs CTRL	0.999	0.986	1.012
Adjusted	NGMC vs CTRL	0.995	0.984	1.007
	GMC vs CTRL	1.000	0.987	1.013

For the **crude model**, the odds ratio for LBW in the NGMC area compared to the control area was 0.995 (95% CI: 0.984, 1.006), indicating no significant difference in LBW rates. Similarly, the odds ratio for the GMC area compared to the control area was 0.999 (95% CI: 0.986, 1.012), suggesting no significant change in LBW rates between these areas as well.

In the **adjusted model**, after controlling for potential confounders, the odds ratios remained largely unchanged. The odds ratio for NGMC vs. CTRL was 0.995 (95% CI: 0.984, 1.007), while for GMC vs. CTRL it was 1.000 (95% CI: 0.987, 1.013). These results indicate no statistically significant difference in LBW rates between the areas post-policy implementation, even after adjusting for confounding factors.

Interrupted Time-Series

For the interrupted time series analysis, we estimated LBW temporal trends in the GMC area post-policy implementation based on the trends observed in the pre-policy period. The predicted versus the observed outcomes post-policy were then compared. A key advantage of this analysis is that it does not rely on a designated control area, allowing for a broader assessment of policy effects. Additionally, while all approaches incorporate temporal variability, this method leverages within-area trends in the outcome over time to evaluate changes without requiring a comparison group. The main limitations are the linearity assumption and the potential lack of power, as most of the inference is done on the period immediately after the policy. For the purposes of the analysis, time trend is fragmented into three-month strata.

Table 16. LBW rates (number per 1,000) by trimester quarter in the exposed area. The trimester quarter refers to the pregnancy trimester that predominantly overlaps with the calendar quarter.

Trimester Quarter (Pre-Period)	LBW rate	Trimester Quarter (Post-Period)	LBW rate
01-2004	65.25	01-2008	68.83
02-2004	63.02	02-2008	64.18
03-2004	62.43	03-2008	62.35
04-2004	62.75	04-2008	64.79
01-2005	64.86	01-2009	64.17
02-2005	66.09	02-2009	65.48
03-2005	66.38	03-2009	64.05
04-2005	62.43	04-2009	67.92
01-2006	67.08	01-2010	65.80
02-2006	65.87	02-2010	66.48
03-2006	63.64	03-2010	64.66
04-2006	62.82	04-2010	67.10
01-2007	65.04	01-2011	67.55
02-2007	65.11	02-2011	64.00
03-2007	65.33	03-2011	65.43
04-2007	64.51	04-2011	64.12

Below are the two interrupted time series models applied to estimate temporal trends in LBW rates in the GMC area post-policy implementation:

- Crude Model: LBW ~ i.PERIOD + i.(TRIMONTH-16) + i.PERIOD*i.(TRIMONTH-16)
- Adjusted Model: LBW ~ i.PERIOD + i.(TRIMONTH-16) + i.PERIOD*i.(TRIMONTH-16) + confounders

Table 17 displays the estimated causal odds ratios obtained when using the crude and adjusted interrupted time series models.

Table 17. Estimated Causal Odds Ratios (OR) for Low Birth Weight (LBW) with 95% Confidence Intervals for Crude and Adjusted Time Series Models

Model	Causal OR	Lower 95% CI	Upper 95% CI
Crude	1.004	0.985	1.023
Adjusted	0.992	0.973	1.011

Controlled Interrupted Time Series (Generalized DID)

In this controlled interrupted time series analysis, we compare temporal trends in low birth weight (LBW) rates before and after the policy implementation across three areas: the Goods Movement Corridors (GMC), the near-GMC (NGMC), and the control (CTRL) areas. We use the differences in pre-policy LBW rates between the CTRL and GMC areas to project expected post-policy rates in the GMC area, assuming a counterfactual scenario where the policy was never implemented. The primary advantage of this approach is the use of temporal variability to test and visualize the parallel trends assumption, while also controlling for space- and time-fixed confounders by design. However, a key limitation lies in the choice of control areas and the potential lack of power to effectively test or visualize parallel trends, particularly when pre-policy periods are short or when outcome rates are rare or unstable across temporal windows.

Figure 13. Temporal Trends in Low Birth Weight (LBW) Rates Across Study Areas Using Controlled Interrupted Time Series (Generalized DiD Analysis) Models. The dotted line indicates the trimester quarter separating the pre- and post-policy periods.

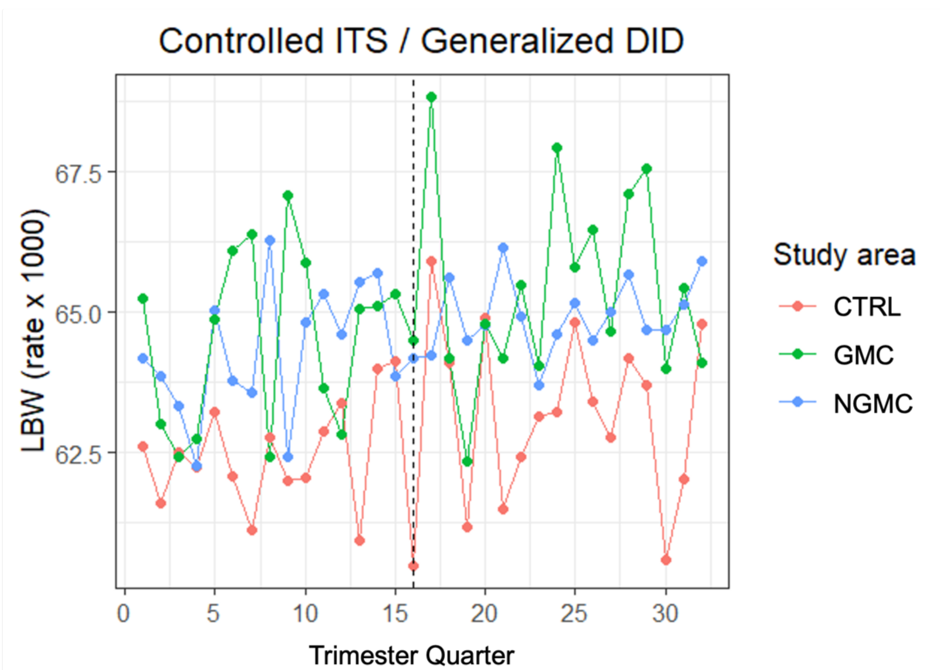


Figure 13 displays the temporal trends in low birth weight (LBW) rates (per 1,000 births) across three areas—control (CTRL), Goods Movement Corridors (GMC), and near-GMC (NGMC)—

over a series of trimesters. The y-axis represents LBW rates, while the x-axis represents the trimesters before and after the policy implementation, with the vertical dashed line indicating the policy intervention point. Each study area is represented by a distinct color: red for the CTRL area, green for the GMC area, and blue for the NGMC area. Figure 13 illustrates how LBW rates fluctuated over time in each area, with the GMC area showing a generally higher and more variable LBW rate post-policy compared to the CTRL and NGMC areas. It also allows for visual inspection of the parallel trends assumption and changes in LBW rates after the policy implementation.

Presented below are the two controlled interrupted time series models applied to compare temporal trends in low birth weight (LBW) rates before and after the policy implementation across the Goods Movement Corridors (GMC), the near-GMC (NGMC), and the control (CTRL) regions.

- Crude: LBW ~ i. TRIMONTH + i.AREA + i. TRIMONTH *i.(AREA)
- Adjusted: LBW ~ i. TRIMONTH + i.AREA + i. TRIMONTH *i.(AREA) + confounders

Table 18 below displays the results of the adjusted model, when comparing the Goods Movement Corridor (GMC) area with the control region.

Table 18. Estimated Causal Odds Ratios (OR) for Low Birth Weight (LBW) with 95% Confidence Intervals for Crude and Adjusted Controlled Interrupted Time Series Models

Reference	Month	Causal OR	Lower 95% CI	Upper 95% CI
2004-1	2004-2	0.984	0.930	1.040
2004-1	2004-3	0.962	0.911	1.015
2004-1	2004-4	0.973	0.921	1.028
2004-1	2005-1	0.985	0.932	1.041
2004-1	2005-2	1.027	0.972	1.085
2004-1	2005-3	1.051	0.997	1.109
2004-1	2005-4	0.954	0.904	1.008
2004-1	2006-1	1.040	0.985	1.098
2004-1	2006-2	1.018	0.964	1.074
2004-1	2006-3	0.972	0.921	1.025
2004-1	2006-4	0.954	0.904	1.006
2004-1	2007-1	1.024	0.970	1.082
2004-1	2007-2	0.972	0.921	1.027
2004-1	2007-3	0.983	0.932	1.036
2004-1	2007-4	1.030	0.976	1.087
2004-1	2008-1	1.004	0.952	1.059
2004-1	2008-2	0.963	0.913	1.016
2004-1	2008-3	0.979	0.928	1.032
2004-1	2008-4	0.961	0.911	1.014
2004-1	2009-1	1.001	0.947	1.057

2004-1	2009-2	1.011	0.957	1.067
2004-1	2009-3	0.974	0.923	1.027
2004-1	2009-4	1.037	0.983	1.094
2004-1	2010-1	0.975	0.923	1.029
2004-1	2010-2	1.012	0.959	1.069
2004-1	2010-3	0.995	0.943	1.050
2004-1	2010-4	1.009	0.956	1.065
2004-1	2011-1	1.024	0.969	1.081
2004-1	2011-2	1.014	0.959	1.071
2004-1	2011-3	1.012	0.959	1.068
2004-1	2011-4	0.951	0.901	1.004

Pre-Term Birth Results

Pre-Post Analysis

This analysis compares pre-term birth rates within the GMC area, before and after the policy implementation.

Table 19 below presents pre-term birth rates (per 1,000 births) in the GMC area during the pre-policy (2004-2007) and post-policy (2008-2011) periods. In the pre-policy period, the pre-term birth rate was 116.75 per 1,000 births, decreasing slightly to 105.52 per 1,000 births in the post-policy period.

Table 19. Pre- and post-policy pre-term birth rates in the exposure area within the GMC region. The table compares per-term birth rates before the policy implementation (2004–2007), which were 116.75 total pre-term birth cases per 1,000 births, to the rates after the policy implementation (2008–2011), which decreased to 105.52 total pre-term birth cases per 1,000 births.

	Pre-term Birth Cases (per 1,000 births) in GMC area
Pre policy (2004-2007)	116.75
Post policy (2008-2011)	105.52

The table above shows the pre-policy and post-policy pre-term birth rates for the exposed (GMC) area and providing an initial exploration of the potential impact of the policy on birth outcomes in the affected areas.

The following models were used to compare pre-term birth rates in the GMC area before and after the policy implementation.

- Crude: PRETERM ~ i.PERIOD
- Adjusted: PRETERM ~ i.PERIOD + confounders

The outcomes of the analyses using these models are shown in Table 20 below:

Table 20. Estimated Causal Odds Ratios (OR) for Pre-Term Birth with 95% Confidence Intervals for Crude and Adjusted Time Series Models

Model	**Causal OR**	**Lower 95% CI**	**Upper 95% CI**
Crude	0.892	0.886	0.899
Adjusted	0.906	0.899	0.913

a. Controlled Pre-Post (2x2 Difference-in-Difference)

The analysis compares changes in pre-term birth rates before and after the policy implementation in the GMC area, against concurrent changes in the NGMC and CTRL areas.

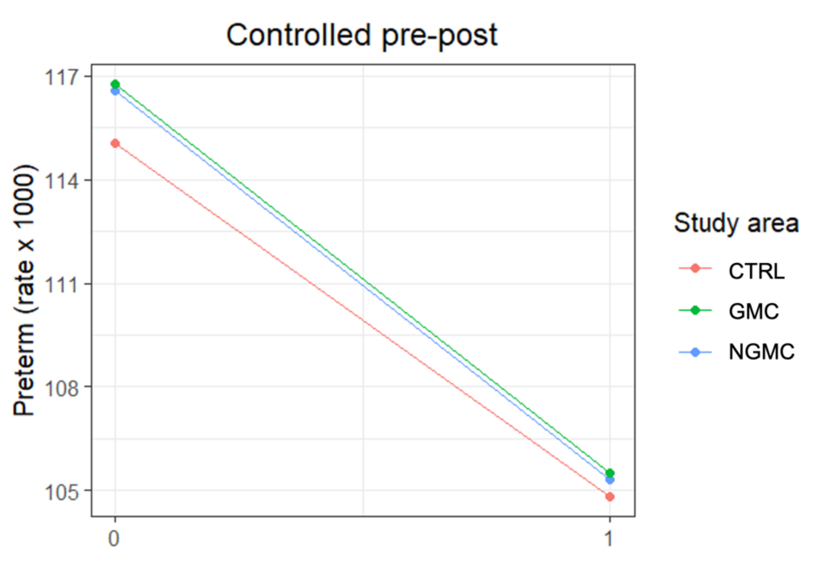
Table 21 below summarizes the pre-term birth rates (per 1,000 births) for the pre-policy (2004-2007) and post-policy (2008-2011) periods, across three areas: the control area (CTRL), near policy area (NGMC), and the GMC area. Prior to the policy, the pre-term rates in the CTRL, NGMC, and GMC areas were 115.05, 116.56 and 116.75 per 1,000 births, respectively. Post-policy, these rates decreased to 104.84, 105.31, and 105.52 per 1,000 births.

Table 21. Pre-Term Birth Rates (per 1,000 births) Pre- and Post-Policy by Area (Control Region, Near Policy Area, and Goods Movement Corridor)

	CTRL	NGMC	GMC
Pre policy (2004-2007)	115.05	116.56	116.75
Post policy (2008-2011)	104.84	105.31	105.52

The graph below provides a visual comparison of pre-term birth rates over time across the three areas.

Figure 14. Graphical Comparison of Pre-Term Birth Rates Over Time Across Control, Near Policy Area, and GMC Movement Corridor



The following two models were applied to estimate the effects of the policy on LBW rates:

- Crude: PRETERM ~ i.PERIOD + i.area + <u>i.PERIOD*i.AREA</u>
- Adjusted: PRETERM ~ i.PERIOD + i.area + <u>i.PERIOD*i.AREA</u> + confounders

The crude model includes the policy period (i.PERIOD), area (i.area), and their interaction term (i.PERIOD * i.area) to assess the impact of the policy and its differential effect across areas. The coefficient of the interaction term is the estimated causal impact of the policy on pre-term rates across the different areas (CTRL, NGMC, GMC). On the other hand, the adjusted model builds on the crude model by adjusting for potential confounders that could influence pre-term. The results of the analysis with the models are presented below:

Table 22. Estimated Causal Odds Ratios (OR) for Pre-Term Birth with 95% Confidence Intervals using Crude and Adjusted 2x2 Difference-in-Difference Models

Model	Contrast	Causal OR	Lower 95% CI	Upper 95% CI
Crude	NGMC vs CTRL	0.990	0.981	0.999
	GMC vs CTRL	0.991	0.980	1.001
Adjusted	NGMC vs CTRL	0.990	0.982	0.999
	GMC vs CTRL	0.995	0.985	1.005

Interrupted Time-Series

For the interrupted time series analysis, we estimated pre-term birth temporal trends in the GMC area post-policy implementation based on the trends observed in the pre-policy period. The predicted versus the observed outcomes post-policy were then compared.

Table 23. Pre-term birth rates (number per 1,000) by trimester in the exposed area

Trimester	Preterm birth rate	Month	Preterm birth rate
01-2004	117.65	01-2008	116.51
02-2004	119.59	02-2008	113.50
03-2004	107.91	03-2008	104.69
04-2004	118.16	04-2008	110.88
01-2005	128.60	01-2009	111.30
02-2005	123.49	02-2009	109.29
03-2005	114.90	03-2009	101.98
04-2005	115.07	04-2009	107.02
01-2006	120.81	01-2010	104.91
02-2006	120.80	02-2010	102.50
03-2006	109.45	03-2010	99.36
04-2006	115.69	04-2010	103.86
01-2007	117.51	01-2011	104.23
02-2007	116.23	02-2011	101.18
03-2007	113.55	03-2011	97.92
04-2007	111.57	04-2011	98.70

Below are the two interrupted time series models applied to estimate temporal trends in pre-term birth rates in the GMC area post-policy implementation:

- Crude: PRETERM ~ i.PERIOD + i.(TRIMONTH-16) + i.PERIOD*i.(TRIMONTH-16)
- Adj: PRETERM ~ i.PERIOD + i.(TRIMONTH-16) + i.PERIOD*i.(TRIMONTH-16) + confounders

Table 24 below displays the estimated causal odds ratios obtained when using the crude and adjusted interrupted time series models.

Table 24. Estimated Causal Odds Ratios (OR) for Pre-Term Birth with 95% Confidence Intervals for Crude and Adjusted Time Series Models

Model	Causal OR	Lower 95% CI	Upper 95% CI
Crude	0.996	0.981	1.012
Adjusted	0.973	0.958	0.988

Controlled Interrupted Time Series (Generalized DID)

In this controlled interrupted time series analysis, we compare temporal trends in pre-term birth rates before and after the policy implementation across three areas: the Goods Movement Corridors (GMC), the near-GMC (NGMC), and the control (CTRL) areas. We use the differences in pre-policy pre-term birth rates between the CTRL and GMC areas to project expected post-policy rates in the GMC area, assuming a counterfactual scenario where the policy was never implemented.

Figure 15. Temporal Trends in Pre-Term Birth Rates Across Study Areas Using Controlled Interrupted Time Series (Generalized DiD Analysis) Models

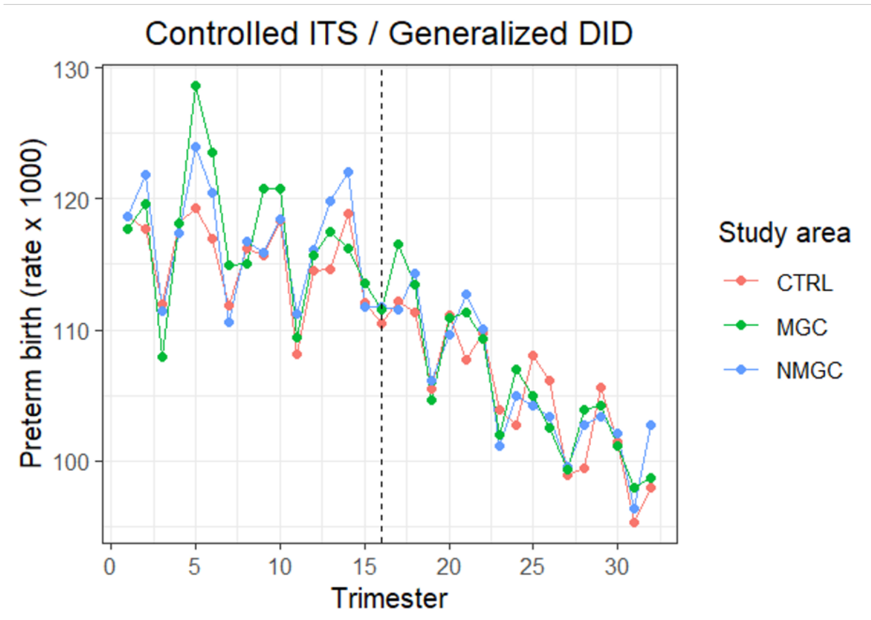


Figure 15 displays the temporal trends in pre-term birth rates (per 1,000 births) across three areas—control (CTRL), Goods Movement Corridors (GMC), and near-GMC (NGMC)—over a series of trimesters. The y-axis represents pre-term rates, while the x-axis represents the trimesters before and after the policy implementation, with the vertical dashed line indicating the policy intervention point. Each study area is represented by a distinct color: red for the CTRL area, green for the GMC area, and blue for the NGMC area. The figure (Figure 15) illustrates how pre-term rates fluctuated over time in each area. It also allows for visual inspection of the parallel trends assumption and changes in pre-term rates after the policy implementation.

Presented below are the two controlled interrupted time series models applied to compare temporal trends in pre-term birth rates before and after the policy implementation across the Goods Movement Corridors (GMC), the near-GMC (NGMC), and the control (CTRL) regions.

- Crude: PRETERM ~ i. TRIMONTH + i.AREA + <u>i. TRIMONTH *i.(AREA)</u>
- Adjusted: PRETERM ~ i. TRIMONTH + i.AREA + <u>i. TRIMONTH *i.(AREA)</u> + confounders

Table 25 displays the results of the adjusted model, when comparing the Goods Movement Corridor (GMC) area with the control region.

Table 25. Estimated Causal Odds Ratios (OR) for Pre-Term Birth with 95% Confidence Intervals for Crude and Adjusted Controlled Interrupted Time Series Models

reference	month	Causal OR	Lower 95% CI	Upper 95% CI
2004-1	2004-2	1.029	0.986	1.075
2004-1	2004-3	0.974	0.933	1.016
2004-1	2004-4	1.014	0.972	1.058
2004-1	2005-1	1.104	1.058	1.152
2004-1	2005-2	1.075	1.030	1.122
2004-1	2005-3	1.045	1.002	1.090
2004-1	2005-4	1.004	0.963	1.048
2004-1	2006-1	1.065	1.020	1.111
2004-1	2006-2	1.036	0.993	1.080
2004-1	2006-3	1.027	0.985	1.071
2004-1	2006-4	1.031	0.989	1.075
2004-1	2007-1	1.050	1.006	1.096
2004-1	2007-2	0.993	0.952	1.037
2004-1	2007-3	1.039	0.996	1.083
2004-1	2007-4	1.039	0.996	1.084
2004-1	2008-1	1.066	1.022	1.112
2004-1	2008-2	1.041	0.998	1.086
2004-1	2008-3	1.012	0.970	1.056
2004-1	2008-4	1.019	0.977	1.063
2004-1	2009-1	1.058	1.014	1.105
2004-1	2009-2	1.013	0.971	1.058
2004-1	2009-3	1.000	0.958	1.044
2004-1	2009-4	1.067	1.022	1.114
2004-1	2010-1	0.987	0.945	1.031
2004-1	2010-2	0.984	0.941	1.028
2004-1	2010-3	1.026	0.983	1.071
2004-1	2010-4	1.071	1.026	1.119
2004-1	2011-1	1.005	0.961	1.050
2004-1	2011-2	1.012	0.968	1.058
2004-1	2011-3	1.049	1.004	1.096
2004-1	2011-4	1.028	0.984	1.075

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