Bay Area Air Quality Management District

Woodsmoke White Paper

Regulatory Analysis and Recommendations to Further Mitigate Woodsmoke Impacts Through Potential Amendments to Regulation 6, Rule 3: Wood-Burning Devices

Prepared By
Julia Luongo, PhD – Senior Air Quality Engineer
Laura Cackette – Senior Air Quality Specialist

November 2024

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Acknowledgements

The development of this white paper was guided by many contributors, including:

Aaron Richardson, Senior Public Information Officer, Communications
Annie Allen, Air Quality Specialist, Engineering
Brian Butler, Senior Air Quality Engineer, Community Engagement
Charley Knoderer, Manager, Meteorology & Measurement
Daniel Alrick, Principal Air & Meteorological Monitoring Specialist, Meteorology & Measurement
David Holstius, Senior Advanced Projects Advisor, Assessment, Inventory & Modeling
David Joe, Manager, Rules & Strategic Policy
Eric Pop, Air Quality Specialist, Compliance & Enforcement
Grace Leung, Air Quality Specialist, Compliance & Enforcement
Gregory Nudd, Deputy Executive Officer, Science & Policy
Jeff Gove, Director, Compliance & Enforcement
Jennifer Lam, Assistant Manager, Rules & Strategic Policy
Jessica DePrimo, Supervising Staff Specialist, Strategic Incentives
Judy Cutino, Public Health Officer, Public Health
Katherine Hoag, Assistant Manager, Meteorology & Measurement
Mark Tang, Assistant Manager, Planning & Climate Protection
Michael Flagg, Principal Air Quality Specialist, Meteorology & Measurement
Omonigho Oiyemhonlan, Assistant Counsel, Legal
Robert Cave, Senior Air Quality Engineer, Rules & Strategic Policy
Saffet Tanrikulu, Manager, Assessment, Inventory & Modeling
Sharon Burchik, Staff Specialist, Legal
Song Bai, Director, Assessment, Inventory & Modeling
Victor Douglas, Director, Rules & Strategic Policy
Yuanyuan Fang, Statistician, Assessment, Inventory & Modeling

Abbreviations and Acronyms

AB 617 – Assembly Bill 617

Air District – Bay Area Air Quality Management District

AQI – Air Quality Index

BC – Black Carbon

BenMAP – Environmental Benefits Mapping and Analysis Program

CARB – California Air Resources Board

Clean HEET Program – Clean Heating Efficiently with Electric Technology Program

CO – Carbon Monoxide

EPA – U.S. Environmental Protection Agency

$\mu g/m^3$ – Micrograms per cubic meter

NAAQS – National Ambient Air Quality Standard

NOV – Notice of Violation

NSPS – New Source Performance Standards

PAHs – polycyclic aromatic hydrocarbons

$PM_{2.5}$ – Fine particulate matter (particulate matter that is 2.5 microns or less in diameter)

Rule 6-3 – Regulation 6, Rule 3: Wood-burning Devices

SCAQMD – South Coast Air Quality Management District

SMAQMD – Sacramento Metropolitan Air Quality Management District

SVJAPCD – San Joaquin Valley Air Pollution Control District

STA – Spare the Air

Executive Summary

In response to growing concerns about air quality and public health impacts related to woodsmoke emissions, the Bay Area Air Quality Management District (Air District) has developed this white paper detailing our current understanding of wood burning in the Bay Area, the state of the regulatory landscape, data gaps, and potential opportunities to adjust our programs or policies to further mitigate woodsmoke health impacts. Air District Staff (Staff) consider wood burning as an important source to evaluate as it represents over 10 percent of the fine particulate matter ($PM_{2.5}$) emissions in the region on an annual basis with an even greater impact during the winter. The Air District has also committed to explore woodsmoke mitigation options through concerns identified in Assembly Bill (AB) 617 communities.[1]

The regulatory landscape governing woodsmoke emissions is complex, involving federal, state, and local jurisdictions. Various approaches of regulation are utilized, including restricting when wood burning is allowed, emissions standards and requirements for wood stoves and other devices, and requirements for firewood sales. In addition, voluntary device change out incentives and public health outreach initiatives can complement regulatory approaches. The Air District administers various regulatory and non-regulatory woodsmoke programs aimed at reducing emissions and protecting public health. Air District Regulation 6, Rule 3: Wood-burning Devices (Rule 6-3) regulates emissions from wood-burning devices.

This paper explores a range of potential strategies for woodsmoke mitigation, including further restriction of when people can burn wood (burn curtailment), expansion of device regulatory requirements, and incentivizing transitions to cleaner alternatives. Potential outreach strategies emphasize education, awareness, and targeted support to reduce woodsmoke emissions.

In compiling data to support consideration of potential strategies, Staff identified specific gaps. These include our inventory of woodsmoke emissions from cooking and outdoor recreational wood burning, our understanding of how many people burn wood as the sole source of heat in their household, as well as our understanding of households that currently rely on "free" indoor heating by burning wood cleared from their property as part of vegetation management. The extent of further study and data collection required will be contingent on the policy direction the Air District chooses to pursue.

Given the significance of the source and the known health impacts, Staff recommend developing policies to further minimize woodsmoke emissions and exposures, focused on wood burning for the purposes of ambiance or aesthetics (not as a primary source of heat). These policies should utilize a combination of mechanisms to target both reduction in short-term peak exposures and long-term exposures. This includes strengthening the Air District's burn curtailment program and accelerating the disabling and turnover of dirtier wood-burning devices in homes with alternative heating options. Both policies would have both short-term and long-term public health benefits. Staff is seeking input from the Board and public stakeholders on the level of stringency and mechanism for these proposed policy changes.

[1] AB 617 communities refer to communities partnered with the Air District under the Community Air Protection Program developing and implementing strategic plans called Community Emissions Reduction Programs (CERPs) and identifying strategies that reduce air emissions in these communities.

Impetus

This white paper examines the impacts of residential wood combustion, also referred to as wood burning or woodsmoke, on Bay Area residents and introduces possible policy opportunities to lessen these effects. Woodsmoke is one of the main contributors of $PM_{2.5}$ emissions in the Bay Area on an annual basis with an even greater impact during the winter. Negative health effects from exposure to woodsmoke include heart impacts (risk of heart attack, irregular heartbeat, heart failure, stroke, and early death) and lung impacts (triggered asthma attacks, aggravated lung disease, and damage to children's lungs). The health risks associated with woodsmoke are exacerbated in winter months, in communities with older, unrenovated homes, and in areas with frequent wood burning activity.

There is no identified safe threshold for exposure to fine particulate matter,[2] and research suggests that even modest reductions in particulate matter can yield health benefits, particularly for vulnerable populations facing disproportionate impacts. Therefore, the Air District is actively exploring potential rule development initiatives to further mitigate exposure to particulate matter and the health risks associated with woodsmoke exposure. This pursuit is underscored by concerns raised in Assembly Bill (AB) 617 communities. In West Oakland, apprehensions about backyard burning were voiced in the West Oakland Community Action Plan,[3] which proposed a strategy to "explore the possibility of amending Rule 6-3 to restrict recreational fires." Additionally, the Richmond, North Richmond, and San Pablo "Path to Clean Air" Community Emissions Reduction Plan[4] includes measures to reduce exposure to wood burning through incentive programs and evaluation of possible regulatory initiatives.

In addition to meeting commitments in AB 617 community plans, the Air District is responsible for ensuring that the National Ambient Air Quality Standards (NAAQS) are met in the Bay Area. The NAAQS are health-based standards set by the U.S. Environmental Protection Agency (EPA) to limit the amount of pollutants in the air that are harmful to public health and the environment. On February 7, 2024, the EPA revised the NAAQS for particulate matter by lowering the primary annual $PM_{2.5}$ standard from 12.0 to 9.0 micrograms per cubic meter ($\mu g/m^3$). While ambient levels of $PM_{2.5}$ can vary seasonally, we see little improvement in the trends of annual average $PM_{2.5}$ concentrations over the past decade despite our ongoing mitigation efforts. Additional reductions may be required to meet and maintain the revised $PM_{2.5}$ NAAQS of 9.0 $\mu g/m^3$.

1 Background

1.1 Wood Burning in the Bay Area

Wood burning is a widespread practice in the San Francisco Bay Area and includes the use of various devices like fireplaces, firepits, wood stoves, manufactured pellet stoves, and recreational

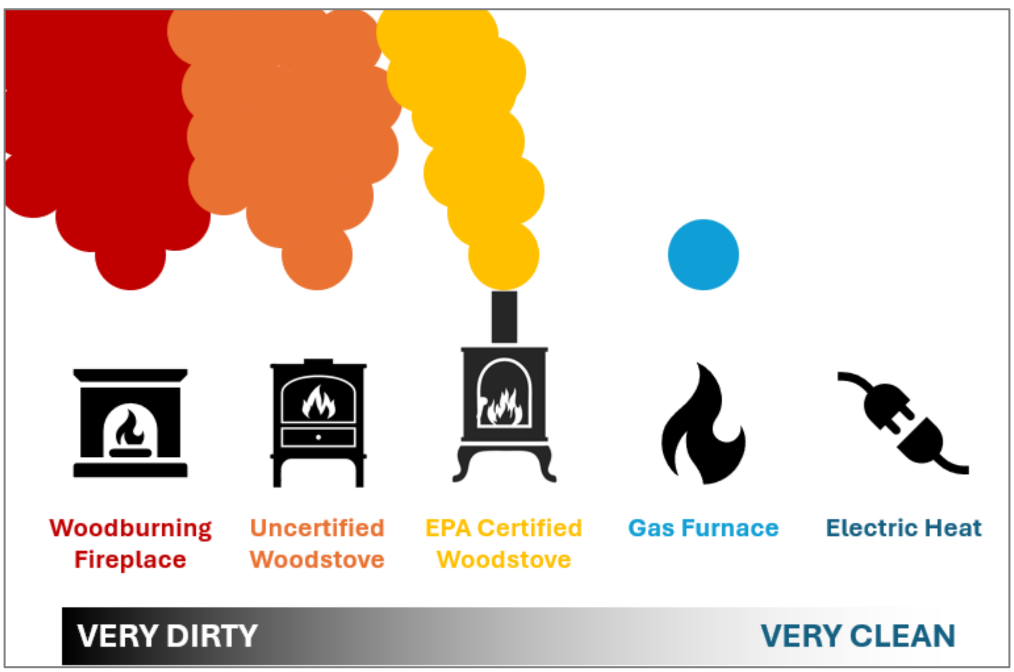
[2] https://www.lung.org/clean-air/outdoors/what-makes-air-unhealthy/particle-pollution
[3] https://www.baaqmd.gov/~/media/files/ab617-community-health/west-oakland/100219-files/final-plan-vol-1-100219-pdf.pdf?rev=77062b14b6e64f1196ec7c9aa870d82d&sc_lang=en
[4] https://www.baaqmd.gov/~/media/files/ab617-community-health/richmond/2024/03252024-draft-final-plan-files/draft-final-ptca-plan-pdf.pdf?rev=290927ece4d64392be5331154929d111&sc_lang=en

fires such as campfires and bonfires. In 2020, there were an estimated one million indoor wood-burning devices installed in homes across the Bay Area. Based on Spare the Air winter survey modeling, slightly over one-third of these (37 percent) were in active use. Of those in use, about three-fourths (76 percent) were wood-burning fireplaces.

Although a primary concern with wood burning is the release of particulate matter during combustion, woodsmoke also contains toxic air contaminants (TACs) including benzene, formaldehyde, acrolein, and polycyclic aromatic hydrocarbons (PAHs). Exposure to fine particulate matter and TACs from woodsmoke, even at low levels, is harmful to human health and is associated with a variety of adverse health effects, including respiratory and cardiovascular diseases.[2]

Most wood heaters (a wood-burning device intended as a primary source of heat) release far more air pollution, indoors and out, than heaters using other fuels (Figure 1). Burning wood indoors using stoves or fireplaces causes high levels of indoor air pollution, even when using a chimney.[5] Generally, fireplaces and old (non-certified) wood stoves are inefficient, expensive heaters. Most fireplaces rob a house of heat because they draw air from the room and send it up the chimney. You may be warmed if you sit within six feet of the fire, but the rest of your house is getting colder as outdoor air leaks in to replace the hot air going up the chimney. Additionally, most fireplaces waste wood because of unrestricted airflow.[6]

Figure 1. Relative emissions of fine particulate matter for various heating devices. Infographic adapted from EPA Burn Wise.[7]



[5] https://www.epa.gov/burnwise/burn-wise-facts-figures-health-and-safety-tips
[6] https://ww2.arb.ca.gov/resources/documents/woodburning-handbook
[7] https://19january2017snapshot.epa.gov/burnwise/burn-wise-energy-efficiency_.html

Woodsmoke currently accounts for about 14 percent of the direct $PM_{2.5}$ annual emission inventory for the Bay Area.[8] From December through January, on average, about one third (34 percent) of direct $PM_{2.5}$ emissions is due to woodsmoke—although this can vary from place to place and day to day.[9] On cold, calm days, woodsmoke tends to get trapped near the ground due to a weather phenomenon called an inversion layer. A layer of warmer air acts like a lid over a colder layer, preventing the dispersion of pollutants and leading to increased concentrations. However, significant woodsmoke exposure can occur under a variety of conditions, even in the absence of an inversion layer. Elevated exposure can occur if you are close to and downwind where wood is burning, if you are in a valley where dispersion is limited by hills, or if you are in an enclosed or indoor space near wood burning.

Further discussion of emissions, long-term exposures, and resulting health impacts can be found in the Understanding Wood Burning in the Bay Area section of this paper. The next section of this paper describes various programs the Air District utilizes to address wood burning and woodsmoke impacts.

1.2 Air District Woodsmoke Programs

1.2.1 Current Regulations on Wood-Burning Devices

Regulation 6, Rule 3: Wood-burning Devices

In the San Francisco Bay Area, Air District Rule 6-3 addresses emissions from wood-burning devices used for primary heat, supplemental heat, or ambiance. This rule prohibits the use of wood-burning devices like fireplaces, woodstoves, or pellet stoves for space heating or aesthetics purposes during a Mandatory Burn Ban. A Mandatory Burn Ban (also referred to as a wood burning ban) is issued when fine particulate pollution in the ambient air is forecast to exceed the federal health standard of 35 $\mu g/m^3$ averaged over a 24-hour period, and a Spare the Air Alert is called (more information on the Spare the Air Program can be found in the Outreach Program section).

In addition to periodic wood burning bans Rule 6-3 also: 1) places restrictions on excessive smoke during permissible burning periods; 2) prohibits the burning of garbage, plastics, and other toxic materials; 3) sets requirements for wood-burning device manufacturers and retailers for the sale or installation of wood-burning devices; and 4) mandates labeling on firewood and other solid fuels sold in the Bay Area. Rule 6-3 also contains exemptions where certain rule requirements do not apply under specific conditions. For example, Mandatory Burn Bans announced through Spare the Air alerts do not apply to those whose sole source of heat is an EPA-certified wood burning device and who do not have a permanently installed natural gas, propane, or electric heating device. Registration with the Air District is required to qualify for this sole source exemption. There are also exemptions for instances when a permanently installed heater is non-functional and in need of repair, or when there is a loss of natural gas or electric power and there is no alternate form of heat other than burning wood. Qualification for exemption is subject to verification.

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[8] Wildfire emissions are excluded from this calculation.

[9] Please see Appendix B for model-based estimates of: month-to-month variation in regional emissions (Figure B1.5); 1 km scale variation in winter emissions (Figure B1.7); city-scale variation in annual average emissions per capita (Figure B1.8); and 1 km scale variation in annual average emissions (Figure B1.9).

The current rule prohibits the installation of wood-burning devices, including fireplaces, EPA-certified wood-burning devices, and pellet-fueled devices in newly constructed buildings in the Bay Area. Fireplace and chimney remodels costing more than $15,000 and requiring a local building permit must install a gas-fueled, electric, or EPA-certified wood-burning device. Additionally, as of November 1, 2018, rental properties in areas with natural gas service must provide a permanently installed form of heat that does not burn solid fuel, such as wood or pellets.

Rule 6-3 was last amended in 2019 along with Regulation 5: Open Burning (see below). As a result, beginning in 2020, the wood burning ban extends year-round to include any day for which a Spare the Air Alert has been called due to high levels of fine particulate pollution. This allows the Air District to implement burn bans on non-winter days that are of concern due to air pollution events such as wildfires or fireworks.

Regulation 5: Open Burning

Another Air District regulation governing wood-burning activity is Regulation 5: Open Burning. This regulation aims to minimize the harmful air pollution caused by open burning activities while allowing for necessary exemptions (under certain conditions) for activities such as agricultural burning, disposal of hazardous materials, fire training, and range, forest, and wildlife management. While recreational outdoor fires are not subject to the administrative requirements of Regulation 5, they must comply with the Mandatory Burn Ban requirements of Rule 6-3, described above.

This white paper focuses on emissions, impacts, and policy initiatives associated with Rule 6-3. The Air District has received public comments interested in amendments to Regulation 5 and, while outside the scope of this document, Staff is considering their potential impacts.

1.2.2 Woodsmoke Reduction Incentives Programs

Incentive programs and voluntary change-out initiatives encourage the replacement of older, more polluting wood-burning devices with cleaner and more efficient alternatives. These programs aim to improve air quality, reduce particulate matter emissions, and promote the use of cleaner heating technologies.

In 2008, as a complement to the recently adopted Rule 6-3, the Air District began implementing incentive programs to curb wood smoke from residential homes. The initial program, spanning 2008–2009, awarded around $336,000 for 665 projects. Gas and EPA-certified wood and pellet stoves were replacement options for uncertified wood burning devices. All Bay Area residents were eligible to receive funding during this early phase.

Between 2016–2019, a new funding round allocated nearly $3 million to approximately 1,000 projects. This initiative focused on replacing wood-burning devices with gas or electric alternatives or decommissioning them without replacement. Priority funding and additional "plus-up" funding were directed to low-income residents and residents in identified impacted communities.

Appendix A – Incentives Program Information contains additional information on previous funding rounds including average project costs, summaries of project types, and summaries of project location by county.

The Air District recently launched the next generation of wood smoke incentives in Spring 2024. The Clean Heating Efficiently with Electric Technology (Clean HEET) Program aims to award $2 million to approximately 270 homeowners. The focus is on reducing costs for replacing wood stoves and fireplace inserts with electric heat pumps, emphasizing impacted communities and low-income residents. Specifically, 60 percent or more of the funding is earmarked for priority communities, including AB 617 and disadvantaged communities, with additional plus-up funding support for low-income participants.

1.2.3 Outreach Program

Effective public communication is essential to reducing emissions and exposure associated with wood burning, since these devices are primarily operated and maintained by individual households. The Air District has developed a robust outreach system and continues to expand its efforts to reach previously underserved communities and neighborhoods where wood burning occurs more frequently.

Spare the Air Program

The Air District created the Spare the Air Program in 1991 to alert residents when air quality is forecast to be unhealthy, to share information on ways to reduce air pollution, and to encourage clean air choices. Since 2008, the Spare the Air program has also informed Bay Area residents when a wood-burning ban is in place due to forecasted high concentrations of fine particle pollution. The Spare the Air program is known regionwide and is a trusted source of air quality information in the Bay Area.

The Spare the Air program tailors messaging based on the season and pollutant of concern. During summer months, ozone pollution (also known as smog) can become a health problem in the Bay Area. The Air District issues Spare the Air Alerts on days when air quality is forecast to be unhealthy and urges residents to drive less and reduce the use of ozone-forming pollutants. During winter months, or during wildfire events throughout the year, particulate matter pollution can reach unhealthy levels in the Bay Area. On these days when particulate matter levels are forecast to be high, the Air District issues a Spare the Air Alert, making wood burning illegal throughout the Bay Area. On these days, residents are advised to limit their time outdoors, especially those sensitive to unhealthy air. Residents can file a wood smoke complaint online or by calling 1-877-4NO-BURN (466-2876).

The 2023-2024 Spare the Air winter outreach campaign focused on the localized health impacts from woodsmoke as well as indoor air quality impacts from wood burning. The campaign reduces the impact of wood burning on air quality by encouraging the public to not burn wood even on non-Spare the Air days and to permanently replace their wood-burning fireplaces and stoves with cleaner alternatives. Spare the Air winter advertising campaigns run on TV, radio, digital media, outdoor banners, as well as social media, throughout the Bay Area. The ads also run in multiple languages (English, Spanish, Mandarin, Cantonese, Vietnamese and Tagalog).

Every winter (since 2008), the Air District has conducted door-to-door outreach in various communities around the Bay Area. Door hangers are left at homes with information about the health impacts of wood smoke and how to sign up for Spare the Air Alerts. The door-to-door neighborhood locations are chosen based on the number of complaints the Air District receives, neighborhoods that have older homes with fireplaces and jurisdictions that allow canvassing. The Air District also printed extra door hangers for community groups, Air District's Community Advisory Council Members and interested Board members for distribution in their communities.

Every year (since 2001), randomly selected residents within the Air District's boundaries complete a phone or online survey during winter months on the topics of wood burning and the Spare the Air Alert program. This white paper refers to these interviews as the "Spare the Air survey." For the 2023–2024 Spare the Air survey, interviews were conducted in English, Spanish, and Cantonese. Households were surveyed on one of the 82 randomly selected days that surveys were conducted throughout the winter season.

2 Knowledge Assessment

Woodsmoke currently accounts for about 14 percent of the annual $PM_{2.5}$ emission inventory in the Bay Area, and about one-third (34 percent) of direct $PM_{2.5}$ emissions during December and January. Understanding and reducing emissions from woodsmoke is important to achieve and maintain the ambient air quality standards for $PM_{2.5}$. Additionally, since woodsmoke contains gaseous toxic air contaminants such as benzene in addition to $PM_{2.5}$, reducing these emissions is crucial for protecting the health of Bay Area residents. Assessing these impacts presents unique challenges due to the variety of devices used to burn wood, the seasonal nature of wood burning activities, the difficulty in characterizing the spatial distribution of woodsmoke emissions, and other factors.

2.1 Health Impacts from Woodsmoke Exposure

Woodsmoke is a mixture of aerosols that include solids, gases, and liquids. Much like cigarette smoke, woodsmoke contains hundreds of air pollutants that can cause cancer and other health problems. The pollutant of most concern is fine particulate matter or $PM_{2.5}$. The particles in smoke are tiny bits of solids and liquids made of partially burned wood. When you breathe air containing woodsmoke, you inhale the fine particles deeply into your lungs.[10] $PM_{2.5}$ can pass through the nasal passage and enter the lungs, leading to serious health effects associated with the heart and lungs. The particles contain toxic substances that can remain in your lungs for months, causing changes that lead to diseases and structural damage.[11] Studies have shown that fine particulate matter from woodsmoke, even at low levels, is harmful to human health and is associated with a variety of adverse health effects, including respiratory and cardiovascular diseases.[12] Although anyone can have health effects from woodsmoke, those most likely to be affected, even at low levels, are

[10] Environmental Protection Agency, n.d. Particulate Matter (PM) Basics. Accessed December 5, 2023: https://www.epa.gov/pm-pollution/particulate-matter-pm-basics
[11] How Wood Smoke Harms Your Health. Publication #91-br-023 (revised July 2012). https://apps.ecology.wa.gov/publications/publications/91br023.pdf
[12] Naeher, Luke P., et al. "Woodsmoke health effects: a review." *Inhalation toxicology* 19.1 (2007): 67-106.

sensitive populations including infants and children,[13,14,15] the elderly, and adults with existing heart or lung conditions. Healthy individuals can also experience acute effects from exposure to elevated levels of particulate matter in addition to these more serious health issues.

A study of wintertime air pollution and emergency room visits for asthma in Santa Clara County during the winters of 1986–1987 through 1991–1992 found an association between ambient wintertime PM_{10} and exacerbations of asthma in an area where one of the principal sources of PM_{10} was residential wood combustion.[16]

The Air District's Advisory Council published a Particulate Matter Reduction Strategy Report[17] in late 2020 that "recognized that particulate matter is a major driver of health risks from Bay Area air quality."[18] The Advisory Council also recognized "there is no known threshold for harmful $PM_{2.5}$ health effects" and recommended further actions to reduce PM exposure and achieve additional health benefits. To understand what is meant by "no known threshold for harmful $PM_{2.5}$ health effects," we can make an analogy with lead. There is also no known level of exposure to lead that will not result in potential health impacts, yet we still develop health protective levels to ensure we are below them to protect people from harmful effects of lead exposure. However, no one wishes for themselves or their families to have any exposure to lead whatsoever, regardless of the health protective level. Exposure to $PM_{2.5}$ should be thought of in a similar manner. While we have short-term and long-term ambient air quality standards for $PM_{2.5}$ to protect public health, there are benefits to reducing exposures below those standards.

2.2 Understanding Wood Burning in the Bay Area

The sections below provide more information on what we know about wood burning across the Bay Area and the level of detail at which we can currently quantify devices, woodsmoke complaints, emissions, and exposures. The information provided in this knowledge assessment comes from a variety of sources, including census data, Spare the Air surveys, air monitoring data, and compliance data such as woodsmoke complaint data or device exemption applications.

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[13] Honicky, R. E., Osborne, J. S., 3rd, and Akpom, C. A. (1985). Symptoms of respiratory illness in young children and the use of wood-burning stoves for indoor heating. *Pediatrics* 75, 587–593.

[14] Johnson, K. G., Gideon, R. A., and Loftsgaarden, D. O. (1990). Montana air pollution study: Children's health effects. *J. Official Stat*. 5, 391–408.

[15] Larson, T. V., and Koenig, J. Q. (1994). Wood smoke: emissions and noncancer respiratory effects. *Annu. Rev. Public Health* 15, 133–156.

[16] Lipsett, Michael, Susan Hurley, and Bart Ostro. "Air pollution and emergency room visits for asthma in Santa Clara County, California." *Environmental Health Perspectives* 105.2 (1997): 216-222. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1469790/pdf/envhper00315-0066.pdf

[17] https://www.baaqmd.gov/~/media/files/board-of-directors/advisory-council/2020/ac_particulate_matter_reduction_strategy_report.pdf?la=en&rev=570867c8b25e4ca0b2f93f80c4c1ef02

[18] BAAQMD, 2020. Particulate Matter: Spotlight on Health Protection. *Advisory Council Particulate Matter Reduction Strategy Report*. Available at: https://www.baaqmd.gov/%7E/media/files/board-of-directors/advisory-council/2020/ac_particulate_matter_reduction_strategy_report.pdf?la=en&rev=570867c8b25e4ca0b2f93f80c4c1ef02

2.2.1 Wood-Burning Device Population and Emissions Inventory

The emissions inventory is based on detailed information on wood-burning device population data estimates for the region (using inputs such as surveys). Emissions are estimated using that data. With respect to establishing a wood-burning device population, the Air District's Rule 6-3 defines wood-burning devices as "any wood heater, fireplace, or any indoor permanently installed device used to burn any solid fuel for space-heating or aesthetic purposes."

How many wood-burning devices are there in the Bay Area?

In 2020, Staff estimated there were about 1 million indoor wood-burning devices installed in homes across the Bay Area. Based on Spare the Air winter survey modeling, slightly over one-third of these (37 percent) were in active use. Of those in use, about three-fourths (76 percent) were wood-burning fireplaces. While there is a wide range of wood-burning device types,[19] Spare the Air survey questions only differentiate amongst three different wood burning device types: 1) wood-burning fireplace; 2) pellet stoves; or 3) wood stoves and wood stove inserts. An important differentiation between fireplaces and wood stoves is that fireplaces burn wood in an open hearth and are not typically the primary source of heat, whereas wood stoves and pellet stoves are enclosed wood heaters that can be used as a primary source of heat. Wood stoves are certified by the EPA and subject to emissions standards as wood heaters. Fireplaces are not considered heaters and are not subject to EPA standards.

Staff estimated the number of devices present in the Bay Area during any particular year and for any ZIP code. Trends evident in the results show a decline in wood-burning devices and a rise in natural gas fireplaces over the past decade. The overall number of devices, when natural-gas fireplaces are included, has stayed essentially unchanged, while the number of occupied housing units has grown by about seven percent. More details on device populations, activity, and emissions can be found in Appendix B – Emissions Inventory, Air Modeling, and Estimated Health Impacts.

How do woodsmoke emissions compare to other air pollution sources in the Bay Area?

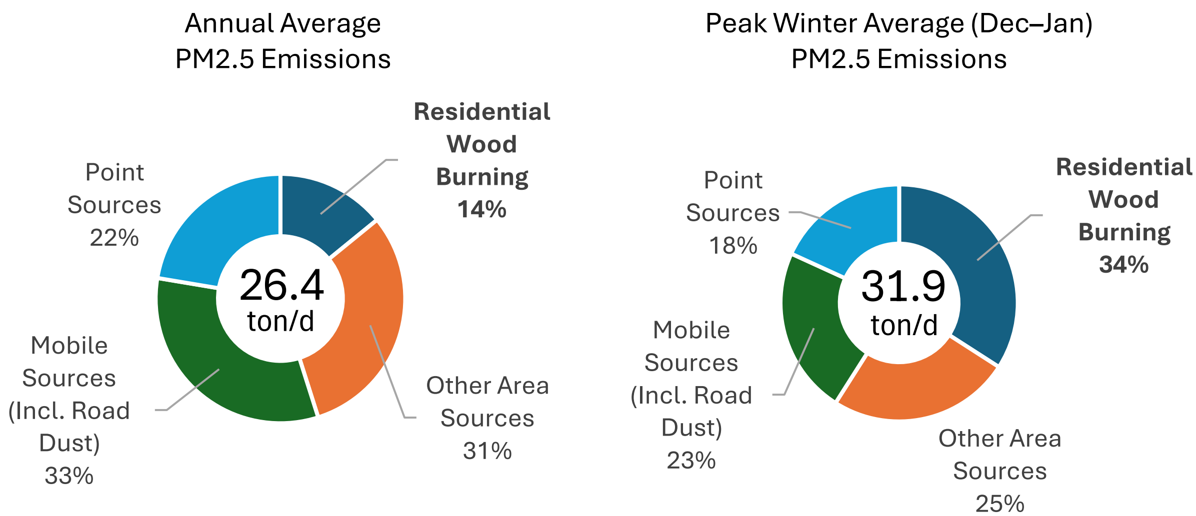
Staff estimates that indoor residential wood-burning devices in the Bay Area directly emit about 1,360 tons of $PM_{2.5}$ per year (3.7 tons per day, averaged across all months). This accounts for 14 percent of estimated direct $PM_{2.5}$ emissions from anthropogenic (human driven) sources in the Bay Area (Figure 2). In this figure, point sources are permitted facilities, such as refineries or other industrial facilities, where exact locations of each source are known. Area sources are generally un-permitted, widespread, geographically distributed, where exact locations of each source are not precisely known, but can be estimated based on other demographic or land-use data. Residential building appliances and fugitive dust are examples of area sources. Mobile sources include onroad and offroad mobile sources, such as emissions from passenger cars, marine vessels, and construction equipment. Road dust is included in the mobile sources category.

Depending on the season, monthly average rates can be significantly higher or lower. December and January emission rates for residential wood burning may reach nearly 11 tons of $PM_{2.5}$ per day

[19] https://www.epa.gov/burnwise/choosing-wood-burning-appliances

on average. This would account for about one-third of the Bay Area's total fine particulate matter emissions during those peak months.

Figure 2. Bay Area $PM_{2.5}$ Modeled Emissions for 2020. Left panel: Modeled $PM_{2.5}$ emissions by source sector for an entire year. Right panel: Modeled $PM_{2.5}$ emissions during peak wood burning months (December and January).



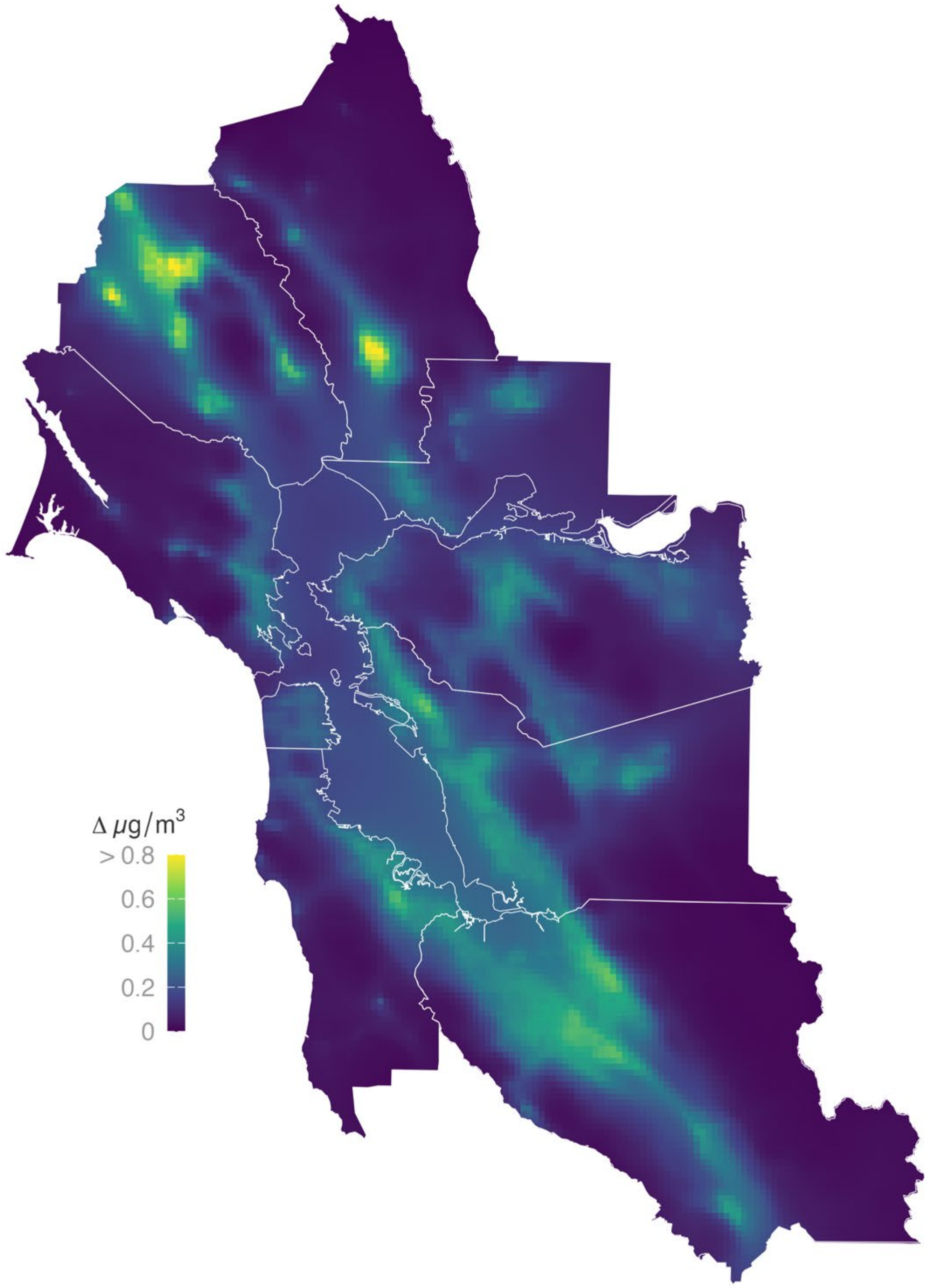
Where in the Bay Area are modeled emissions highest and where in the Bay Area are modeled concentrations highest?

There is a wide variability in wood burning activity across the Bay Area, and even within the same county. For example, fireplaces in Alameda County are predicted to be used about twice as intensively (in terms of fuel use per week per active device) across ZIP code 94586, a largely rural region containing the San Antonio reservoir, compared to ZIP code 94612, an urban area in Oakland.

Dense urban areas, especially San Francisco, had the lowest predicted emissions per capita. The highest emissions per capita were generally found scattered across rural areas, which were mostly north of the Carquinez Strait. More information and figures from this study can be found in Appendix B – Emissions Inventory, Air Modeling, and Estimated Health Impacts.

Modeled annual average $PM_{2.5}$ contributions from residential wood burning varied from near zero to 0.85 μg/m^3 across the Bay Area. The highest contributions (between 0.6 μg/m^3 and 0.8 μg/m^3) were located in the counties of Sonoma and Napa, in and around the cities of Santa Rosa, Sebastopol, Rohnert Park and Napa. Woodsmoke added between 0.5 μg/m^3 and 0.6 μg/m^3 to the $PM_{2.5}$ level in some areas in Sonoma and Napa counties as well as elsewhere in the cities of Oakland, San Jose and Redwood City (Figure 3).

Figure 3. Modeled contributions from residential wood burning to annual average $PM_{2.5}$ concentrations across the Bay Area.



2.2.2 Estimated Health Impacts

To gain a more comprehensive understanding of the air quality and health impacts of $PM_{2.5}$ emissions from wood burning, the Air District has also utilized air quality modeling. Air quality modeling uses computer programs to simulate the flow and transformation of pollutants in the atmosphere. Models estimate the impacts on outdoor air quality based on emissions information and typical meteorology. Annual average exposures are then computed using the modeled impacts on outdoor air quality to the population.

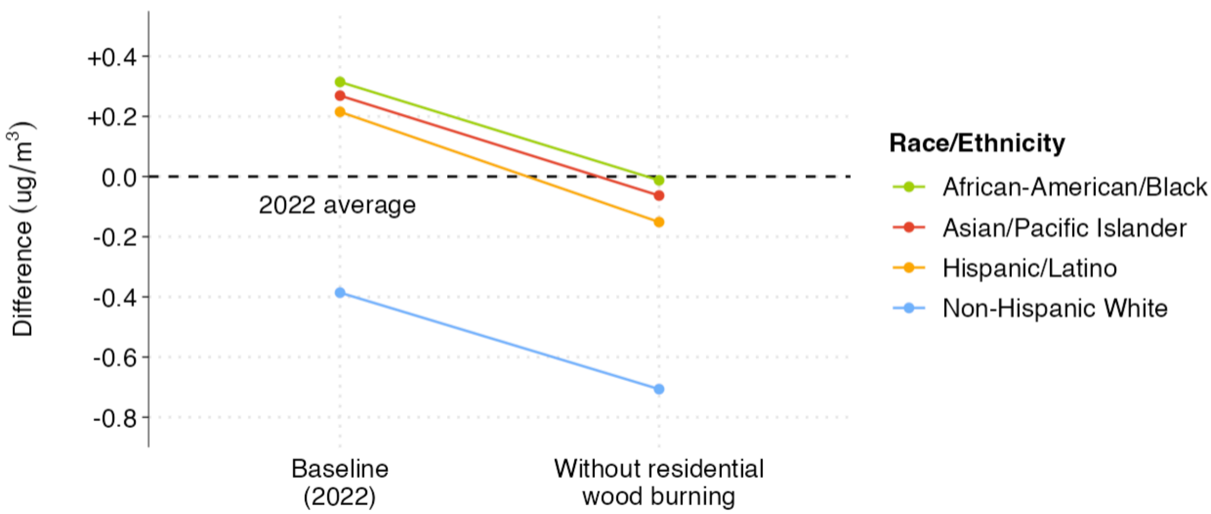
Based on this modeling approach, what are the implications for exposure disparities?

To evaluate the impacts of wood burning on exposure disparities and health impacts, the Air District conducted two simulations: (1) a baseline scenario that included the District's latest wood burning emissions estimates; and (2) a control scenario that eliminated wood burning emissions from all indoor devices in the Bay Area.[20] To analyze exposure disparities, staff considered four major racial/ethnic groups: Hispanic/Latino; non-Hispanic White; African-American/Black; and Asian/Pacific Islander. Modeled populations were for the year 2020. The air quality simulations and the modeled populations were at 1 km^2 resolution.

In the baseline scenario, people of color in the Bay Area were exposed to between 0.6 and 0.7 $\mu g/m^3$ more total $PM_{2.5}$ than non-Hispanic white residents, on average (Figure 4, left side). This baseline exposure disparity results from the combination of all sources of $PM_{2.5}$ in the world as it exists today.

Figure 4 also indicates (right side) that the magnitude of this disparity would remain essentially unchanged after the removal of wood burning. The average reduction in annual exposure, across the entire population, would be 0.34 $\mu g/m^3$ $PM_{2.5}$, with similar reductions for all four racial/ethnic groups (Table B3.2 in Appendix B). The disparity between the most-exposed group (African-American/Black) and the least-exposed (non-Hispanic White) would remain the same (0.7 $\mu g/m^3$).

Figure 4. Differences in modeled annual average $PM_{2.5}$ exposures (annual average ambient concentrations, weighted by residential population).



What are the health impacts from woodsmoke and how does it compare to health impacts from other air pollution sources in the Bay Area?

In the Bay Area, approximately 94 to 210 premature deaths per year were attributed, via modeling, to the impacts of residential wood burning on annual average $PM_{2.5}$ levels. To perform this analysis, staff relied on the US EPA's BenMAP platform, which was previously used to evaluate health impacts from refinery fluidized catalytic cracking units (for amendments to Rule 6-5) and from natural gas-fueled appliances (for amendments to Rules 9-4 and 9-6). For comparison, modeled

[20] Wood burning emissions from outdoor devices (which could not be adequately quantified), and wood burning emissions originating outside the Air District's jurisdiction, were not removed.

benefits of eliminating primary and secondary $PM_{2.5}$ from natural gas-fired building appliances targeted by amendments to Rules 9-4 and 9-6 included avoiding 37 to 85 premature deaths per year.

What do these health impacts estimates represent and what is missing from the analysis?

While modeling provides valuable insights into woodsmoke emissions and their potential health impacts, it leaves gaps in understanding, particularly regarding localized peak exposures. The health impacts presented here estimate changes in human health due to changes in annual average ambient air quality due to woodsmoke for specific populations. A notable limitation of the modeling approach utilized—especially in the context of residential wood burning—is that it will not capture variability in peak exposures, as might be experienced during wintertime (for example, maximum 24-hour exposures, or number of days exceeding a certain level), when emissions are higher and meteorological conditions are more conducive to local accumulations of $PM_{2.5}$. This study is only modeling total $PM_{2.5}$ and does not estimate impacts from the numerous toxic air pollutants also present in woodsmoke. Additionally, it is important to remember that this study is only representing health impact estimates from woodsmoke, which is a fraction of a person's total exposure to PM or other pollutants, or cumulative impact. Some populations are experiencing a larger total exposure than others, and that is not captured in this analysis.

Apparent "hot spots" in maps of modeled activity and emissions (such as in Figure 3 or other figures found in Appendix B) should be interpreted with caution. These are estimates, not observations or measurements. Maps of modeled estimates will imperfectly reflect true differences due to data and modeling limitations.

Apart from differences in population density, these maps mainly reflect variation in the surveyed distributions of active devices, typical winter burning frequencies, and typical amounts of wood burned during winter months. Unmeasured or unmodeled factors, such as differences in the predominant types and qualities of wood, could result in additional geographical variation.

Appendix B – Emissions Inventory, Air Modeling contains detailed information on methodologies and results from the Air District's emissions and air modeling assessment of woodsmoke. This appendix also includes discussion of model limitations.

2.2.3 Air Quality Monitoring Data

In contrast to the estimation approach of an emissions inventory combined with air quality modeling, air quality monitoring is an observed approach that tells us the real picture of what pollutants are in the air at a given time and location. Monitoring is an important tool that can help answer a number of questions regarding woodsmoke patterns and exposure (such as those presented below). Unlike the modeling approach in the previous section, monitoring can capture variability in peak exposures and episodic woodsmoke episodes. Monitoring is also capable of capturing very localized exposures that can be challenging to estimate using the modeling methods previously employed. Air monitoring can also check that our model results make sense and highlight where models are not doing a good job predicting air pollutant behavior. Especially for a source like wood burning that is so widespread, episodic, and subject to individuals' behavior, air quality monitoring is an important tool to fill in gaps in our understanding and provide a clearer picture of real-world exposures. However, air monitoring has its limitations as well. For example, monitors can measure total $PM_{2.5}$ but cannot always differentiate the source or type of source. Furthermore, monitors cannot be located everywhere, and thus geographical coverage is often limited.

The following section provides some key takeaways from air quality monitoring data based on the types of questions raised by Board members during the November 2023 Stationary Source Committee meeting. This section is further supported by Appendix C – Air Monitoring Information, which provides additional information and supporting figures.

How are $PM_{2.5}$ concentrations changing over time in the Bay Area?

Long-term annual and 24-hour $PM_{2.5}$ trends show little improvement over the last 10 years and elevated daily $PM_{2.5}$ concentrations above 20 $\mu g/m^3$ continue to be measured at all monitoring sites in the Bay Area in recent years. Additional reductions may be required to meet and maintain the revised PM NAAQS of 9.0 $\mu g/m^3$ (Figure C1 in Appendix C).

How large are the impacts on $PM_{2.5}$ concentrations from residential woodsmoke emissions based on monitoring data?

Air monitoring data showing elevated and episodic black carbon levels can indicate $PM_{2.5}$ from wood burning sources. Black carbon is a component of $PM_{2.5}$, primarily produced by the combustion of fossil fuels (primarily diesel), wood, or other materials. Like $PM_{2.5}$ as a whole, it is also associated with health issues such as asthma, respiratory problems, low birth rates, heart attacks, and lung cancer.[21]

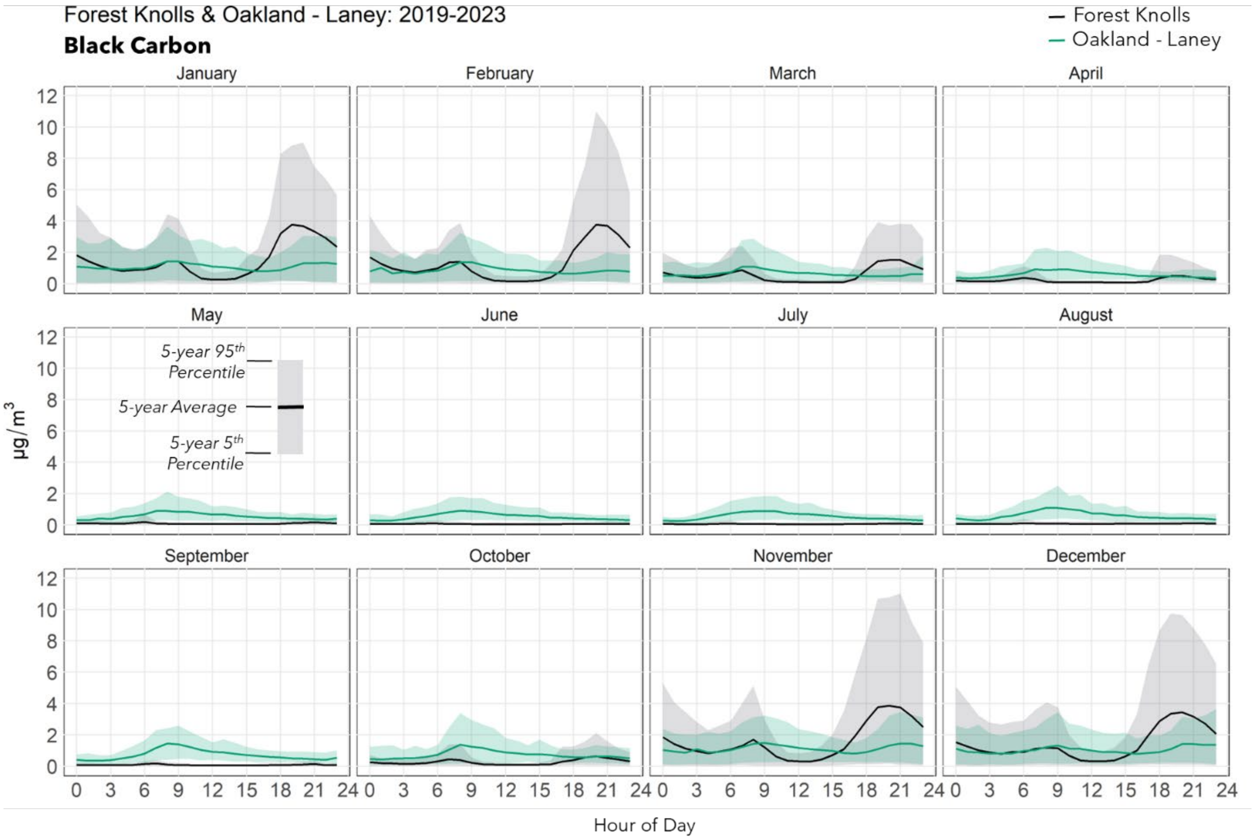
The Forest Knolls monitoring site in Marin County currently measures the most significant increases in black carbon in the monitoring network that are associated with woodsmoke emissions. This monitoring site is likely representative of many other locations in the Bay Area (particularly inland valleys) with similar wood burning activities and emissions impacts. This data from the Forest Knolls monitoring site indicates how measured black carbon concentrations are affected by woodsmoke emissions and provides insights into the seasonal patterns of woodsmoke impacts since there are few other contributing sources nearby. The figures provided in Appendix C suggest that:

- Peak daily black carbon concentrations during woodsmoke episodes at Forest Knolls are comparable and, in some instances, higher than black carbon concentrations measured during the 2020 wildfire episodes (see Figure C3 in Appendix C).
- Peak hourly black carbon concentrations at Forest Knolls are **much higher** than at near-road monitoring sites (Oakland – Laney) during the months of October through April (Figure 5).
- Woodsmoke emissions are likely contributing to elevated $PM_{2.5}$ concentrations on days that fall outside of the historical winter woodsmoke “season” from November to February. Indicators suggest that woodsmoke emissions are contributing to elevated $PM_{2.5}$

[21] https://www.epa.gov/sites/default/files/2013-12/documents/black-carbon-fact-sheet_0.pdf

concentrations from October through April, though peak contributions are still November to February (see Figure 5 below and Figure C3 in Appendix C).

Figure 5. Diurnal Profiles of Hourly Black Carbon by Month at Forest Knolls



***Detailed Description**: The plots above show hourly black carbon concentrations averaged over the last 5-years by hour of day. The averaged data and associated 5th and 95th percentiles shown as black lines and gray shading were calculated after removing data that may have been affected by wildfire and represent largely anthropogenic black carbon concentrations. The plots compare different hourly averaged profiles by month for Forest Knolls (located in a rural area in western Marin County) and Oakland – Laney (located adjacent to the eastern side of the 880 in East Oakland). A comparison of these two sites shows the differences in how average hourly black carbon concentrations change throughout the day for each month at locations that represent substantively different mix of sources.*

Where are these impacts occurring?

The Air District developed a 5-year dataset of all PurpleAir sensors in the Bay Area from 2018-2022. Processing of $PM_{2.5}$ data included multiple quality control checks on the raw, hourly, and daily data to provide a consistent dataset for use for various purposes, including evaluation of spatial patterns in hourly or daily $PM_{2.5}$ across the Bay Area. $PM_{2.5}$ data were also corrected using EPA's U.S.-Wide correction factor for PurpleAir $PM_{2.5}$ sensors that was developed to consider the influence of relative humidity and the level of $PM_{2.5}$ during wildfire smoke-impacted events.[22] A preliminary review of these data included identifying candidate days in recent years that may be affected by woodsmoke by evaluating day-specific concentrations to a number of biomass burning indicators: black carbon, brown carbon, and $PM_{2.5}$/CO enhancement ratios. Candidate days were flagged if black or brown carbon concentrations were greater than the 5-year non-wildfire 98th percentile or if $PM_{2.5}$/CO enhancement ratios were elevated above values typical for non-biomass burning urban air pollution. Diurnal profiles of hourly $PM_{2.5}$ were also reviewed to confirm that increases in $PM_{2.5}$ during these days were occuring in the evening and early morning consistent with typical woodsmoke emissions. This preliminary review of PurpleAir sensor network $PM_{2.5}$ data suggests that spatial variability during woodsmoke episodes changes from day-to-day and can affect different areas throughout the Bay Area depending on a number of factors. Three examples of the candidate days meeting these criteria as shown in Figure C4 in Appendix C.

How often do relatively high 24-hour $PM_{2.5}$ concentrations occur outside of wildfire smoke?

Currently, Spare the Air alerts for $PM_{2.5}$ are issued when 24-hour average $PM_{2.5}$ concentrations are forecast to be above 35 μg/m^3. However, in recent years (2018-2022), measured 24-hour average $PM_{2.5}$ concentrations have only exceeded 35 μg/m^3 on about two days per year outside of wildfire smoke periods (note that some Spare the Air alerts are called on days that are forecasted to have, but do not result in, concentrations above 35 μg/m^3). Days with $PM_{2.5}$ concentrations above a lower threshold of 25 μg/m^3 were also relatively uncommon, with an average of about 10 days per year. The San Jose – Jackson, San Jose – Knox, Vallejo, Oakland – West, Oakland – Laney, and San Pablo monitoring sites recorded more days with relatively higher levels of $PM_{2.5}$ (24-hour averages above 25 μg/m^3 or above 35 μg/m^3) as compared to other monitoring sites (Table C1 in Appendix C).

General Takeaways from Air Monitoring Data:

Given the episodic nature of residential woodsmoke emissions and the resulting impacts, annual average concentration analysis from measurements or modeling will tend to underestimate peak impacts and could show a different spatial pattern of where short-term residential woodsmoke impacts are most significant. This highlights the importance of burn curtailment for lessening short term peak exposure impacts.

Since days above 35 μg/m^3 now occur so infrequently outside wildfire smoke periods (largely due to overall reductions in woodsmoke and other emissions that contribute to $PM_{2.5}$ since the time the rule was first implemented), moving to a lower $PM_{2.5}$ threshold for initiating burn curtailment would further reduce woodsmoke emissions. An assessment of operational and resource impacts incurred by lowering the threshold during wildfire periods will be performed prior to the proposal of rule amendments.

The revised annual $PM_{2.5}$ NAAQS and changes to the Air Quality Index (AQI) for the moderate category place additional emphasis on the importance of reducing daily concentrations ranging from 9 μg/m^3 - 35 μg/m^3 for protecting public health. Daily concentrations near or above the moderate breakpoint of 9 μg/m^3 occur regularly at all sites in the Bay Area and continue to be a

[22] Details on data processing methodology and quality control checks can be found on the Bay Air Center website: Air Sensor Dataset FAQ.

public health concern. While understanding peak impacts from woodsmoke emissions is important, concentrations at these levels should also be given appropriate consideration. Reducing the emissions on days within this range will contribute to the reduction of both peak daily and annual $PM_{2.5}$ concentrations over time.

2.2.4 Woodsmoke Complaint Data and Enforcement

Air District field staff employ various investigative techniques to ensure compliance with the Woodsmoke Rule (Rule 6-3). Woodsmoke patrols are used to maximize area surveillance coverage around known woodsmoke complaints and known woodsmoke impacted neighborhoods. Weekend and holiday patrols are conducted by field staff with two staff members covering each of three coverage areas or zones. Due to field staff resource limitations, a proactive "patrol" approach is employed to patrol areas based upon complaint data rather than dispatching field staff for each individual woodsmoke complaint received. The AB 617 communities are prioritized, as well as recurring and heavy smoke complaints.

For each woodsmoke complaint, the Air District collects relevant information including location, time, whether a wood burning ban is in effect, a description of the odor, smoke density (how much one can see through the smoke), and contact information (if provided). Figure 6 illustrates the total number of woodsmoke complaints received each year, noting some decline over the past six years, with the caveat that the number of complaints is influenced by several factors, including weather conditions.

Figure 6. Total number of woodsmoke complaints by year

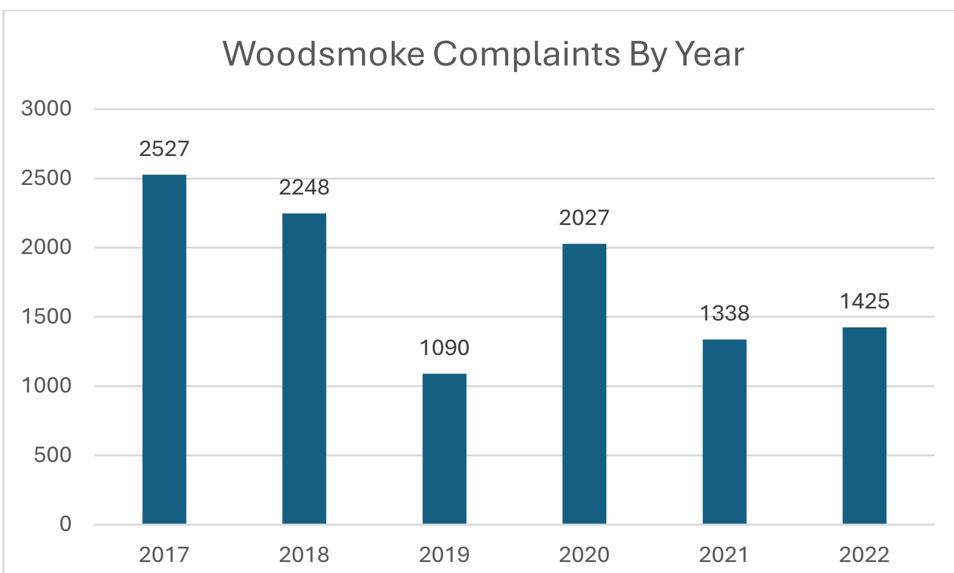
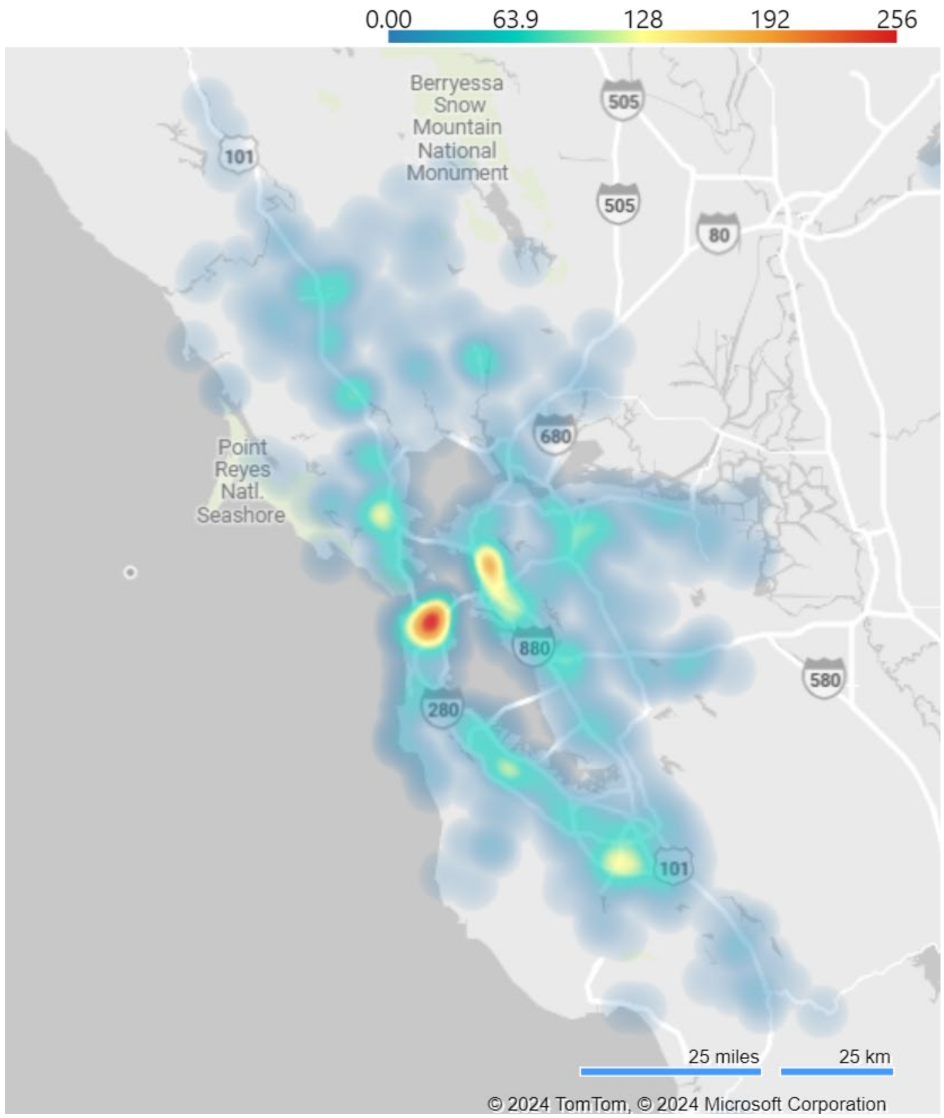


Figure 7 displays woodsmoke complaints received between 2017 and 2023. Note the differences between the map of woodsmoke complaints and the map showing annual average woodsmoke emissions from the Air District's bottom-up air quality model (Figure 3). Complaints are influenced by a number of different factors including people's actions and experiences, not just emissions. This serves as a reminder that real-world situations may not always match what our models predict.

Figure 7. Heatmap of woodsmoke complaints received between 2017 and 2023. "Hotspots" represent higher frequency and geographic concentration of complaints.



Upon receiving a woodsmoke complaint, the Air District mails a woodsmoke information packet to the location of the source reported, providing guidance on cleaner burning practices, the negative health effects of woodsmoke and how to comply with the regulation. The Air District also receives garbage burning complaints and, in those cases, mails a letter notifying of the no garbage burning regulation. If field staff observe a violation of the wood burning ban during a Spare the Air alert, a Notice of Violation (NOV) is issued unless the source is exempt from the wood burning ban. Figure 8 displays the total number of woodsmoke NOVs issued annually. Figure 9 displays the total number of particulate matter Spare the Air Alerts (when wood burning is banned) by year, categorized by days that were impacted by wildfire smoke and days that were not impacted by wildfire smoke. Over the last five years, there has been a general reduction in both complaints and NOVs. Identifying a specific cause for this decline is challenging. The number of NOVs depends on the number of wood-burning bans (generally, more NOVs tend to be issued when there are more wood burning bans), while the number of complaints is influenced by human behavior. A decrease in complaints may suggest a decline in burning activity, but it could also result from complaint fatigue where individuals who have submitted multiple complaints are reluctant to continue submitting complaints.

Figure 8. Total number of woodsmoke notice of violations (NOVs) issued by year.

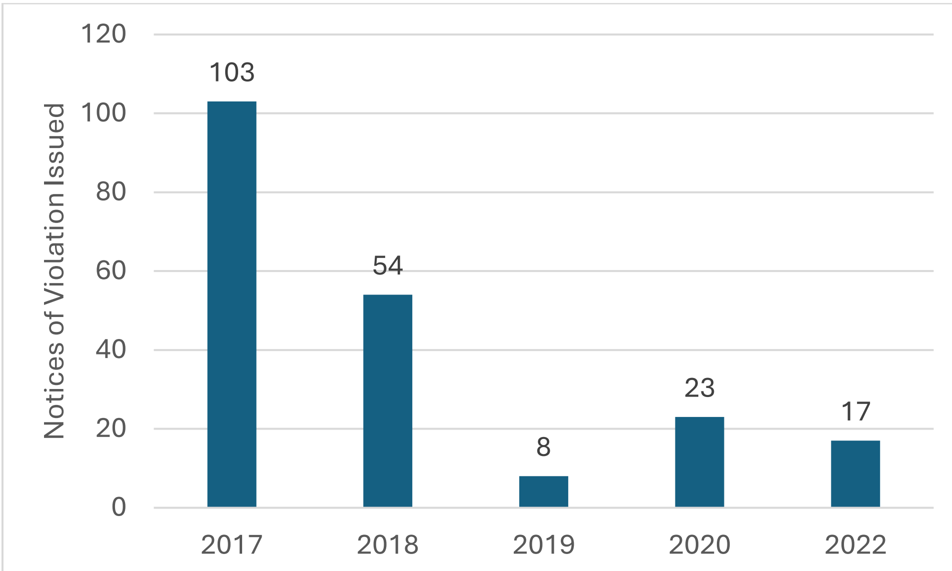
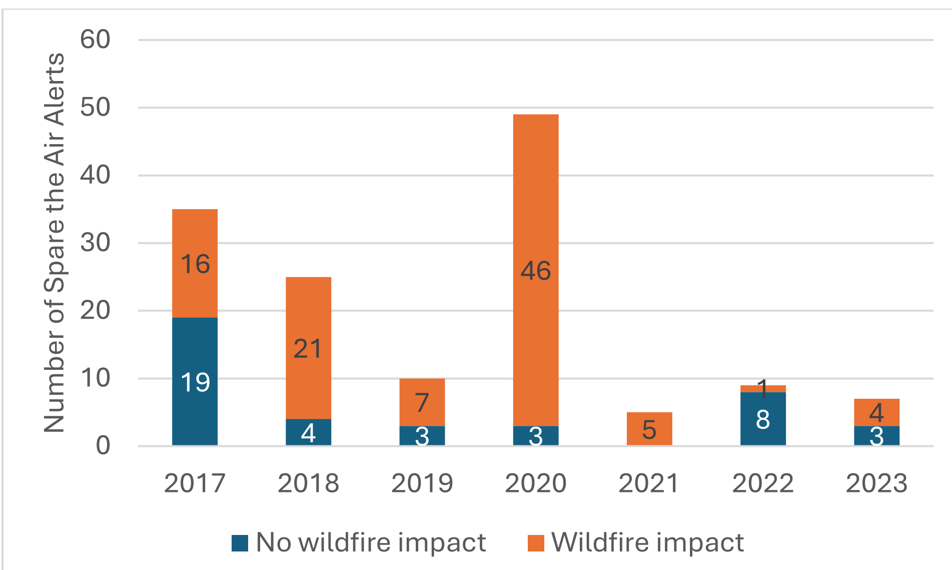


Figure 9. Total number of particulate matter Spare the Air Alerts by year, categorized by days that were impacted by wildfire smoke and days that were not impacted by wildfire smoke.



There was a total of 205 NOVs issued between 2017 and 2022. A small portion of the total NOVs (15 out of 205) were issued to households that qualified for an exemption, but prior to receiving that NOV, may have been unaware of the need to register with the Air District for an exemption. Qualifying exemptions include Permanent and Temporary exemptions. A Permanent exemption denotes a sole source of heat exemption, while a Temporary exemption indicates a nonfunctioning primary heat source which is valid for 30 days. Less than 10 percent of NOVs issued between 2017 and 2022 claimed an exemption, with the majority being first-time violations.

2.3 State of Regulatory Landscape

As previously mentioned, Air District Rule 6-3 addresses emissions from wood burning devices used for primary heat, supplemental heat, or ambiance in the Bay Area. There are various other state and federal regulations as well as those at the local level in other air districts. EPA has compiled a webpage listing examples of some ordinances and regulations for wood-burning appliances.[23]

Emissions from wood-burning devices are regulated at the federal level by the EPA and many state and local jurisdictions have their own regulations often building upon or reinforcing the EPA standards. California air districts have some of the most stringent regulations in the United States concerning wood burning due to concerns about air quality and public health. This section summarizes some of those key regulations related to emissions from wood-burning devices.

2.3.1 EPA Emissions Standards for New Wood Heaters

The EPA establishes emission standards for new residential wood heaters in the New Source Performance Standards (NSPS) Subpart AAA.[24] These standards set limits on the amount of PM, carbon monoxide (CO), and other pollutants that can be emitted from new wood stoves, wood heaters, and pellet stoves. This emissions standard was first proposed in 1987 and promulgated in 1988; standards were updated in 2015, followed by the most recent amendments—finalized in 2020—that set more stringent emission standards, amongst several other actions.[25] All new wood heating appliances subject to the NSPS that are offered for sale in the United States are required to meet these emission limits and obtain certification. The EPA Office of Enforcement and Compliance Assistance certifies and maintains a database of all EPA Certified Wood Heaters.[26]

Various portions of Air District Rule 6-3 reference EPA regulations and certification, including provisions for manufacturers, retailers, sale/resale/transfer, registration, or remodeling of devices reference the use of EPA Certified Wood Heaters and compliance with NSPS requirements. The "Sole Source of Heat" exemption states that Burn Ban provisions do not apply to any person whose sole source of heat is an EPA certified wood-burning device that is registered with the Air District and who does not have available to them a permanently installed natural gas, propane or electric heating device.

2.3.2 South Coast Air Quality Management District Rule 445

South Coast Air Quality Management District (SCAQMD) Rule 445 – Wood-Burning Devices – applies to indoor/outdoor wood-burning devices, most residential fireplaces and wood stoves. The

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[23] https://www.epa.gov/burnwise/ordinances-and-regulations-wood-burning-appliances
[24] https://www.federalregister.gov/documents/2015/03/16/2015-03733/standards-of-performance-for-new-residential-wood-heaters-new-residential-hydronic-heaters-and
[25] https://www.epa.gov/sites/default/files/2020-03/documents/wood_heaters_final_nsps_fact_sheet.pdf
[26] This EPA program is being monitored; the Air District will utilize the most up-to-date information as it becomes available. https://www.epa.gov/compliance/residential-wood-heater-compliance-monitoring-program

rule was adopted in 2008 and last amended in 2020 with the addition of $PM_{2.5}$ and ozone contingency measures that would be implemented in the event that the EPA determines that the South Coast Air Basin had failed to meet a Reasonable Further Progress milestone or attain the applicable National Primary Ambient Air Quality Standard.[27] As of April 7, 2022, the $PM_{2.5}$ contingency measures were approved by the EPA into the California State Implementation Plan.[28]

SCAQMD Rule 445 prohibits the installation of permanent wood-burning devices in new developments and requires that replacement of existing units must be made with the types of devices approved in the rule (such as an EPA-certified wood heater), similar to Air District Rule 6-3. Rule 445 has two separate exemption conditions where a cleaner wood-burning device can be installed in a new development:

- properties 3,000 or more feet in elevation; and
- properties where there is no existing infrastructure for natural gas service within 150 feet of the property line.

The rule also contains a seasoned wood fuel sale provision and a non-wood fuel-burning prohibition (e.g., no trash burning). The rule prohibits wood burning on No Burn Days which are triggered when daily $PM_{2.5}$ is forecast to exceed 29 $\mu g/m^3$ during the wood-burning season (November through February) – a more stringent threshold than Air District Rule 6-3 threshold of 35 $\mu g/m^3$. No Burn Days do not apply to:

- properties where a wood-burning device is the sole source of heat; or
- low-income households; or
- properties where there is no existing infrastructure for natural gas service within 150 feet of the property line; or
- properties located 3,000 or more feet above mean sea level; or
- ceremonial fires exempted under Rule 444 - Open Burning.

2.3.3 San Joaquin Valley Air Pollution Control District Rule 4901

San Joaquin Valley Air Pollution Control District (SJVAPCD) Rule 4901 – Wood Burning Fireplaces and Wood Burning Heaters – was adopted in 1992 and last amended in 2023. The rule applies to manufacturers, sellers, and installers of wood-burning devices and individuals who operate wood-burning devices. The rule requires that:

- No one can sell or transfer residential property that contains a wood-burning heater without first ensuring that the device meets certain requirements
- Any non-certified wood heater must be removed from the property or rendered permanently inoperable prior to the close of escrow
- Anyone operating a wood-burning fireplace or heater must ensure that visible emissions do not exceed 20 percent opacity for more than three minutes in any one hour

[27] https://www.aqmd.gov/docs/default-source/rule-book/Proposed-Rules/445/par445-pdsr-03162021.pdf?sfvrsn=14
[28] https://www.federalregister.gov/documents/2022/03/08/2022-04761/air-plan-approval-california-los-angeles-south-coast-air-basin

The rule also restricts the use of fireplaces and wood stoves on bad air quality days from November through February through a tiered wood-burning curtailment status on a county-level basis. The first tier is called a Level One Episodic Wood Burning Curtailment which prohibits burning unless using a registered clean-burning device. A Level One Curtailment is triggered whenever the potential for a $PM_{2.5}$ concentration is forecast to equal or exceed 12 µg/m^3 in some counties or 20 µg/m^3 in other counties. A Level Two Episodic Wood Burning Curtailment prohibits burning for all residential wood burning devices and is triggered whenever the potential for a $PM_{2.5}$ concentration is forecast to exceed 35 µg/m^3 in some counties, 65 µg/m^3 in other counties, or a PM_{10} concentration equal to or exceeding 135 µg/m^3 in any county.

2.3.4 Sacramento Metropolitan Air Quality Management District Rule 421

Similar to SJVAPCD Rule 4901, Sacramento Metropolitan Air Quality Management District (SMAQMD) Rule 421 restricts wood burning from November through February of each year through a tiered burn day status approach. The rule was adopted in 2007 and last amended in 2009. The first tier is a voluntary curtailment where SMAQMD asks owners of wood-burning devices to voluntarily not burn if the 24-hour average $PM_{2.5}$ concentration may exceed 25 µg/m^3 but is not likely to exceed 31 µg/m^3. A Stage 1 mandatory wood burning curtailment is issued when the 24-hour average $PM_{2.5}$ concentration may exceed 31 µg/m^3 but is not likely to exceed 35 µg/m^3 – this makes it illegal to burn unless you use an EPA-certified fireplace insert, stove, or pellet stove that does not emit visible smoke. A Stage 2 mandatory wood burning curtailment is issued if the 24-hour average $PM_{2.5}$ concentration may exceed 35 µg/m^3, making it illegal to burn any solid fuel, including wood, manufactured fire logs, and pellets, in any device.

2.3.5 Local Ordinances

To support the reduction of localized exposure to woodsmoke, the Air District developed a Model Wood Smoke Ordinance in 2012. The model ordinance includes several options that cities and counties can use to adopt or update ordinances, depending on the needs of the community. Several Bay Area cities and counties adopted provisions from a previous 1990 Air District Wood Smoke Ordinance[29] and some local jurisdictions have their own ordinances that build upon or reinforce EPA and regional standards.

The City of Berkeley has unique woodsmoke rules[30] to encourage mediation of woodsmoke nuisance disputes. If smoke from a resident's non-EPA compliant wood-burning device (including open-hearth fireplaces) is causing a disturbance, the City of Berkeley outlines a complaint process. Complaints must meet criteria such as non-compliant devices, proximity, and lack of physical barriers. If written communication and mediation fail, the next step in the process is to consider arbitration or legal action as a last resort. The process follows specific guidelines outlined in Berkeley Municipal Code 15.16.[31]

[29] https://www.baaqmd.gov/~/media/files/communications-and-outreach/wood-smoke/model-ordinance-matrix_website_final.pdf?rev=b870b75e930b4f7a917ce7b35401f133
[30] https://berkeleyca.gov/cityservices/livable-neighborhoods/wood-smoke-rules
[31] https://berkeley.municipal.codes/BMC/15.16

The City of Oakland reinforces the Air District's requirements through the City of Oakland Code of Ordinances Chapter 8.19 - Wood-Burning Appliances.[32] The ordinance prohibits wood-burning fireplaces and inserts unless exempt (e.g., historic buildings) and requires EPA-certified devices for any installations in existing fireplaces.

2.3.6 Regulatory Landscape Outside of California

In the Pacific northwest, the states of Oregon and Washington have a number of rules in place to reduce woodsmoke pollution. The State of Washington regulates the types of wood stoves and other wood-burning devices allowed for sale, resale, exchange, or that are given away. These devices must meet both Washington and EPA certification and labeling standards.[33] Washington also has a tiered burn ban policy where a Stage 1 burn ban prohibiting the use of uncertified wood stoves, fireplaces, and outdoor wood burning is called when the 24-hour average $PM_{2.5}$ levels are forecasted to reach or exceed 35 μg/m^3 (or 30 μg/m^3 in areas at risk for nonattainment) in the next 48-72 hours. A Stage 2 burn ban prohibiting all burning is called when, generally, the 24-hour average $PM_{2.5}$ levels have already reached 25 μg/m^3 or are rising rapidly (amongst several other possible triggers).[34]

Oregon law requires removal and destruction of uncertified wood stoves and fireplace inserts when a home is sold.[35] Multnomah County, Oregon (where the City of Portland is located) has a wood burning curtailment ordinance whereby wood burning cannot occur when the air quality is forecasted to be unhealthy for sensitive groups, unhealthy for all groups, very unhealthy, or hazardous on the AQI scale. There are exceptions for those who must use wood to heat their homes, those with limited income, and during emergencies such as a power outage. Households with an exception must apply for an exemption each year.[36]

Other areas across the United States with cold temperatures and wintertime inversions like Colorado, Alaska, Utah, New York, and Massachusetts also have similar burn curtailment rules and certified stove requirements in place to reduce woodsmoke pollution. As one of the most polluted U.S. cities, Fairbanks, Alaska was reclassified as a "serious" nonattainment area by the Environmental Protection Agency (EPA) in 2017 for its fine particulate matter pollution, of which woodsmoke is the highest contributor of $PM_{2.5}$ emissions.[37]

In the United Kingdom, there are legally defined areas designated as "smoke control areas" where one cannot emit smoke from a chimney and can only burn authorized "smokeless" fuels such as anthracite, natural gas, or low volatile steam coal unless you are using a Defra-approved appliance (similar to an EPA-certified device in the United States). This means that wood cannot be burned in an open fireplace within a smoke control area; only authorized "smokeless" fuels are allowed.

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[32] https://library.municode.com/ca/oakland/codes/code_of_ordinances?nodeId=TIT8HESA_CH8.19WORNAP
[33] https://ecology.wa.gov/Air-Climate/Air-quality/Smoke-fire/wood-stove-info
[34] https://apps.leg.wa.gov/wac/default.aspx?cite=173-433-140
[35] https://www.oregon.gov/deq/Residential/Pages/woodstovesFAQ.aspx
[36] https://www.multco.us/health/staying-healthy/wood-burning-restrictions
[37] Wang, Yungang, and Philip K. Hopke. "Is Alaska truly the great escape from air pollution?-long term source apportionment of fine particulate matter in Fairbanks, Alaska." *Aerosol and Air Quality Research* 14.7 (2014): 1875-1882. https://aaqr.org/articles/aaqr-14-03-oa-0047

Most urban areas, including most London boroughs, are designated smoke control areas where some less centrally located boroughs have partial restrictions. This rule is one of the most stringent rules that Staff reviewed. Smoke control area enforcement is done by local authorities.

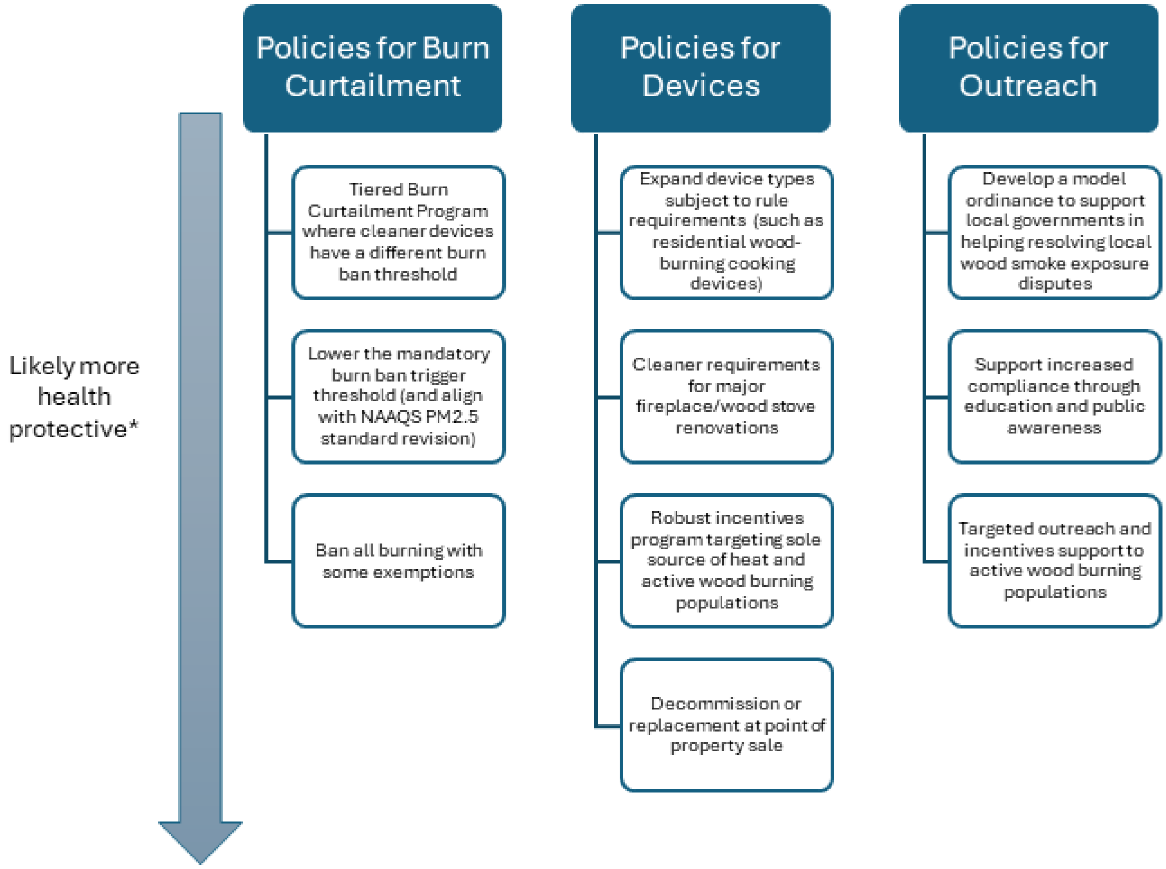
3 Decision-making Context

3.1 Spectrum of Potential Policies Towards Mitigating Woodsmoke Impacts

The following section outlines a range of woodsmoke impact mitigation policies. The impacts and required resources to support the policy options presented below have not yet been fully evaluated – those analyses would be accomplished later in the rule development process once the desired policy direction has been more clearly defined. Staff recognize that the following section is not an exhaustive list of all potential regulatory changes and that other ideas may be considered throughout any future stakeholder engagement and rule development process.

In addressing woodsmoke emissions in the Bay Area, the overarching strategies involve either minimizing the act of wood burning or transitioning to alternatives. This includes the replacement of wood-burning devices with non-wood alternatives or the decommissioning of wood-burning devices altogether. These objectives can be realized through a spectrum of mechanisms, broadly falling into three categories: (1) Policies targeting the act of wood burning, (2) policies directed at the devices engaged in wood burning, (3) and policies designed to encourage and promote voluntary reductions or cleaner alternatives to wood burning. The subsequent sections explore policy opportunities structured within these categories, offering different methods to reduce woodsmoke emissions and mitigate associated health impacts in the Bay Area (Figure 10).

Figure 10. Summary of the range of policies available to minimize or eliminate woodsmoke impacts.



*Health protectiveness has not been quantified but is being qualitatively ordered relative to the other policies within the category based on Air District staff expert opinion

3.1.1 Policies for Burn Curtailment

The Air District currently implements a burn curtailment program that issues a wood burning ban on high PM days. Possible strategies to further minimize the act of wood burning may include:

- Switching to a tiered burn curtailment program
- Lowering the wood burning ban trigger threshold of our current burn curtailment program
- Banning all residential wood burning with some exemptions

A tiered burn curtailment program places multiple stages of burn curtailment for different device types. As an example, see the description of the burn curtailment program in the San Joaquin Valley Air Pollution Control District described previously on page 32. While this type of program may incentivize transition to cleaner burning devices, Staff does not recommend this policy due to its complexity and implementation challenges.

Within the Air District's current burn curtailment program, there are opportunities for public health benefits through reduction of both short term and long term $PM_{2.5}$ exposures through a lowering of the wood burning ban threshold. The current threshold of 35 µg/m^3 is aligned with the EPA federal 24-hour $PM_{2.5}$ standard. Although retained during the recent revision to the NAAQS in February 2024, the current 24-hour standard was noted as not protective against short term exposures by the Clean Air Scientific Advisory Committee (CASAC) advising the EPA. The majority of CASAC members recommended revising the level of the 24-hour standard to 25-30 µg/m^3.[38] Lowering the wood burning ban threshold would strengthen the burn curtailment program to be more health protective.

Finally, the most health protective policy option for burn curtailment would be to ban all residential wood burning in the Bay Area with some exemptions. Exemptions could include burning as the sole source of heat, loss of or lack of utility service, financial hardship, or other possible exemptions. This policy would greatly reduce woodsmoke emissions in the Bay Area by reducing or eliminating burning for the purposes of aesthetics or ambiance.

3.1.2 Policies for Wood-Burning Devices

Another approach for mitigating woodsmoke emissions is to eliminate or transition to cleaner device alternatives. Possible strategies targeting devices include:

- Expanding the device types subject to the Air District's rule requirements
- Requiring cleaner alternatives for major fireplace/wood stove renovations
- Implementing a robust incentives program for voluntary device change outs
- Requiring decommissioning or replacement of devices at the point of real property sale

Expanding the device types subject to the Air District's rule requirements could result in emissions reductions during high PM days by further restricting the types of devices that may burn during a wood burning ban. Like South Coast Air Quality Management Rule 445, the Air District may want to consider the inclusion of wood-burning cooking devices subject to rule requirements. Since cooking with wood-burning devices, such as food smokers and grills, currently falls outside the purview of Air District rules, we lack a robust inventory of emissions from these device types (see Knowledge Gaps and Solutions section for more on this). This data gap would need to be addressed should we pursue this policy.

The Air District's Rule 6-3 contains a requirement that fireplace and chimney remodels costing more than $15,000 and requiring a local building permit can only install a gas-fueled, electric, or EPA-certified device. To support the transition to cleaner alternatives, one possible strategy is to require even cleaner technologies for major fireplace/wood stove renovations. Should this policy be pursued, it would be important to understand the rate at which fireplace and chimney renovations are occurring.

Staff reviewed incentives and change-out programs in other jurisdictions across California air districts and in other states. Programs were found to be similar to the Air District's programs, offering vouchers or rebates for the replacement of uncertified residential wood burning stoves, inserts, and fireplaces used for primary space heating with cleaner, more efficient home heating

[38] https://www.4cleanair.org/wp-content/uploads/EPA-PM-NAAQS-Informational-Presentation-Feb-13-2024.pdf

devices. Many California air districts utilize the California Air Resources Board (CARB) Woodsmoke Reduction Program to fund their programs. The Woodsmoke Reduction Program[39] is part of California Climate Investments, [40] a statewide program that puts billions of Cap-and-Trade dollars to work reducing greenhouse gas emissions, strengthening the economy and improving public health and the environment — particularly in disadvantaged communities.

There has been significant interest generated during the most recent iteration of the Wood Smoke Reduction Incentives Program so there is evidence for the appetite of voluntary change-out to cleaner alternatives. A policy to consider is a robust incentives program that could target specific device types, activity type, or populations.

It is important to highlight the scale and feasible scope of incentive/voluntary change-out programs. Between 2016 and 2019, the Air District completed 1000 projects for a total of $3 million dollars for woodsmoke reduction incentives. There are about 1 million indoor wood-burning devices installed in homes across the Bay Area with slightly over one-third of these devices (37 percent) in active use. The cost and amount of time needed to change out these devices would greatly exceed the amount of incentive funding that the state and region have budgeted for woodsmoke change-outs in the past. For example, assuming an average funding amount of $1,000 towards decommission or change-out of every *active* wood-burning device in the Bay Area would amount to a $370 million incentive program.

Finally, the most health protective policy for devices would be a requirement for decommissioning or replacement of wood-burning devices at the point of real property sale. This policy could also target specific device types, such as devices that are not the primary source of heat.

3.1.3 Policies for Outreach

Various non-regulatory policies are available to educate or encourage cleaner alternatives to wood burning. Possible outreach strategies include:

- Providing local governments with a model ordinance to support woodsmoke reduction and in resolving local woodsmoke disputes
- Support increased rule compliance through education and public awareness
- Targeted outreach and incentives support to active wood burning populations

As discussed earlier in this paper (Local Ordinances section), the Air District previously developed a Model Wood Smoke Ordinance in 2012. The Air District could consider revising this ordinance to support local governments in resolving local woodsmoke disputes, consulting with those who have existing woodsmoke ordinances, such as the City of Berkeley who has wood smoke dispute rules.[41]

Surveys suggest that approximately half of the people in the Bay Area are aware when a wood burning ban is in effect. This suggests there is much to gain through education and public

[39] https://ww2.arb.ca.gov/our-work/programs/residential-woodsmoke-reduction/woodsmoke-reduction-program
[40] https://www.caclimateinvestments.ca.gov/woodsmoke
[41] https://berkeleyca.gov/cityservices/livable-neighborhoods/wood-smoke-rules

awareness efforts to support rule compliance and possibly increase the effectiveness of wood burning bans.

Finally, the Air District could consider targeting outreach and incentives to active wood burning populations. Most of the wood burning devices in the Bay Area are fireplaces which are the dirtiest and most inefficient devices. Finding ways to educate and support more active wood burning populations to consider switching to cleaner alternatives may result in increased emissions reductions.

3.2 Knowledge Gaps and Solutions

In our examination of wood-burning devices, Staff has identified specific gaps in our data or understanding. Each topic below presents a proposed solution to address the knowledge/data gap should a solution or further study be needed to proceed with a policy initiative. Addressing these gaps and answering associated questions would significantly enhance our understanding of this source sector and the potential implications of our policy decisions. The extent of further study required will be contingent on the policy direction the Air District chooses to pursue.

3.2.1 Understanding of Sole Source of Heat Population

The Air District has a few different ways of trying to understand the population of wood-burning devices that are the sole source of heat in a household. Devices seeking the Rule 6-3 “sole source of heat” exemption must register, while a different way to estimate this exempt population is by Census information. A notable difference in estimates from these two approaches reveals an incomplete grasp of this population's size. The Air District's exemption database, with less than 100 entries, contrasts with Census data suggesting around 15,000 households whose most-used heating fuel is wood (Table B1.6, Appendix B). While most-used heating fuel is not the same as the sole source of heat in a household, the magnitude of difference between these two estimates highlights a gap in understanding.

If the Air District were to pursue changes to the burn curtailment program impacting the sole source of heat exemption requirements in Rule 6-3, a more in-depth understanding of this population is crucial. Some proposed solutions to this data gap could involve refining surveys, enhancing outreach to raise awareness of the exemption registration, and implementing targeted incentives to encourage transitioning to cleaner alternatives, thus reducing this population. Should the Air District proceed with a policy initiative that does not make changes to Rule 6-3 exemptions or burn curtailment for this exempt device, impacts to this population would likely be minimal. It is, however, still important to enhance outreach to encourage this population to register with the Air District to claim this exemption.

3.2.2 Inventory of Cooking and Outdoor Recreational Wood Burning

Cooking with wood-burning devices, such as residential food smokers, grills and outdoor options like pizza ovens, currently falls outside the purview of Air District rules. Similarly, outdoor recreational wood burning, like fire pits and campfires, is not covered by Rule 6-3 but is subject to wood-burning bans through Regulation 5: Open Burning. Unfortunately, survey questions prior to

2019 did not gather sufficient information to characterize fuel consumption among outdoor wood-burning devices, impeding a comprehensive understanding of their impact.

Enhancing our understanding of these populations and their associated emissions may be useful for tailoring effective policies to limit woodsmoke emissions and exposures. Addressing this gap is important for equity considerations, especially if the Air District contemplates further indoor wood-burning restrictions, particularly on the devices themselves (versus restriction on when devices can be used). Changes to the wood-burning ban criteria are likely to impact indoor and outdoor burning in similar ways under the current rule structure.

3.2.3 Vegetation Management

The Air District has received concerns regarding the potential effects of policy changes to Rule 6-3 on households that currently rely on "free" indoor heating by burning brush or wood cleared from their property as part of vegetation management.

Our current Spare the Air surveys include only one question about the source of firewood: “Do you typically purchase your wood from a wood supplier, the local store, do you gather your own wood, or other?”

For those who burn wood, gathering one’s own wood is the most likely source of fuel (accounting consistently for over 30 percent of all the fuel sources). Fuel from local stores and wood suppliers are the next two likely fuel sources (account for about 20 percent each). Generally, people with wood stoves are more likely to gather their own wood (more than 45 percent) whereas for people with fireplaces about 30 percent gather their own wood.

While data shows that gathering one’s own wood is an important fuel source for wood-burning devices, we still lack a clear picture of how wood-burning devices contribute to overall residential vegetation management. The discussion excludes agricultural and prescribed burning regulated under Air District's Regulation 5: Open Burning.

While larger branches and trunks might be used for indoor heating, much of the vegetation requiring clearing cannot be burned indoors due to moisture levels and visible emissions. Alternatives to burning include tree removal and chipping services for mulch, composting, natural decomposition, municipal collection sites, or biomass power plants.

Understanding and studying the impacts of regulatory measures on those burning local yard trimmings for heat and vegetation management is important should our policy initiative affect this population. A proposed solution to address this data gap involves surveys or outreach efforts to define this population better, evaluate potential alternatives, and assess associated costs.

3.3 Equity Impacts

Applying an equity lens to our policy decisions is crucial to ensuring that our efforts mitigate woodsmoke emissions without inadvertently exacerbating existing disparities in air pollution burden. By thoroughly investigating the potential consequences of our policies on impacted and vulnerable populations, we aim to develop solutions that not only avoid further harm but also actively work towards repairing and rectifying these long-standing inequities.

The current Rule 6-3 includes several exemptions intended to ensure that vulnerable populations are not unduly impacted by wood burning bans so that people who rely on wood burning for essential heating are not left without a source of warmth during critical times. These exemptions include:

1. **Sole Source of Heat**: If an EPA-certified wood-burning device is the only source of heat for a household, they can apply for an exemption to use it during a Mandatory Burn Ban.
2. **Loss of Utility Service**: Households that experience a loss of gas or electric service, making their regular heating system unusable, can use their wood-burning device during the outage if there is no alternate form of heat.
3. **Temporary Non-Functional Heater**: If the primary heating system is temporarily not working and the household is waiting for repairs, they can use their wood-burning device in the meantime.

While the modeling study presented in this paper (see Estimated Health Impacts) does not indicate that eliminating residential wood burning would substantially affect the persistent gap in exposure between white residents and people of color in the Bay Area, there are several additional equity considerations to investigate prior to the proposal of rule amendments. The modeling study does not characterize peak short-term exposures during wintertime. Potential benefits from woodsmoke mitigation are quantified in terms of exposure reduction by race/ethic group. The study does not address the importance of those benefits for already overburdened groups with high cumulative impacts and/or air pollution sensitivities. Modeled estimates are for woodsmoke only, which is just a fraction of a person's total exposure to air pollution. We must still recognize and consider that some populations' total exposure to air pollution is greater than others and we must therefore prioritize emissions reductions for those disproportionately burdened.

The Air District will investigate and apply equity considerations of any proposed rule amendments to ensure that new policies and regulations advance environmental justice in the Bay Area.

3.3.1 Socioeconomic Impacts

Within Appendix A – Incentives Program Information, we shared data on the costs of alternatives to wood burning (through decommissioning or change-out of devices), drawn from our incentives program. However, should any regulatory changes for further limiting woodsmoke emissions be considered, a comprehensive socioeconomic analysis of potential financial burden and compliance costs of the proposed amendments would be undertaken as required by the California Health and Safety Code. Financial burden and compliance cost includes consideration of fuel costs for heating compared to alternatives and burden based on household income level. Rules in other air districts, such as SCAQMD Rule 445, currently include a low-income household exemption. While this white paper provides foundational information, the detailed economic impact analyses will not be pursued within this document.

4 Recommendations

Staff presented the potential policies contained within this white paper to the Board's Stationary Source Committee and public stakeholders in May 2024 (see Spectrum of Potential Policies Towards Mitigating Woodsmoke Impacts section on page 30). Committee members and public commenters expressed general support for moving forward with mitigation strategies that minimize ambiance wood burning while also considering the importance of wood burning in the case of loss or lack of utility services and for those with financial hardship. Committee members also expressed the importance of rule awareness and compliance through increased outreach efforts.

Given the significance of the source, the known health impacts, and that we see little improvement in the trends of annual average $PM_{2.5}$ concentrations over the past decade, our recommendation is to explore policies to further minimize woodsmoke emissions, focused on targeting wood burning for the purposes of ambiance or aesthetics. Specifically, Staff recommend:

1. Consideration of a lower, more health protective wood burning ban $PM_{2.5}$ concentration trigger threshold while maintaining the existing implementation structure of our burn curtailment program (including current rule exemptions for sole source of heat, loss of utility service, and temporary non-functional heater); and
2. Consideration of a policy that accelerates the disabling and turnover of dirtier wood-burning devices. Staff seeks input from the Board and public stakeholders on the level of stringency and mechanism for this type of policy (e.g., voluntary versus mandatory mechanism).

It is important to note that Staff has not yet extensively evaluated impacts nor the required resources to explore potential policies or rule development efforts due to the wide range of possible mitigation strategies under consideration. An in-depth assessment of these impacts will take place during the development of potential rule amendments, with ample opportunities for stakeholder engagement prior to any proposal for Board consideration. Next steps in this woodsmoke policy initiative will include robust community and stakeholder engagement tailored to the response and public comment received on this white paper and the policy options presented.

Our good friend and work colleague, Eric Pop, passed away on June 6, 2024. He joined the Air District in January 2007 and dedicated 17 years to supporting the agency's mission in the Compliance and Enforcement Division. Eric was passionate in all of his work, including the Woodsmoke Program and Rule 6-3 initiatives, Naturally Occurring Asbestos, Commuter Benefits Program, Portable Equipment Registration Program, Green Business, Ag Engine Program, Flex Your Commute, Language Access Plan, Oil & Gas, Voluntary Compliance Notifications for backup generators, and Innovation Program. Eric wrote the first wood burning rule. His commitment and collective work across the Air District and with our local partners will have a lasting imprint that continues to move the needle in improving air quality. He enjoyed commuting by bike and loved spending time outdoors, hiking, biking and exploring state parks and forests. Eric always had a smile on his face to help brighten the day, and he was always the friend and colleague you could depend on. Eric was a family man and leaves behind his wife, and older sister and brother. He was a great friend and colleague to us at the Air District and he will be greatly missed.

Appendix A – Incentives Program Information

Average change-out or decommissioning costs from the 2016-2019 woodsmoke reduction program round of funding are summarized in Table A1 below.

Table A1. Average Project Costs from 2016-2019 Woodsmoke Reduction Incentive Cycle

Project Type	Number of Projects	Average Cost
Fireplace or Wood-Burning Stove Decommission	62	$3,727
Natural Gas or Propane Freestanding Stove Replacement	22	$6,989
Sealed Natural Gas or Propane Fireplace Insert Replacement	879	$5,552
Electric Heat Pump Replacement	47	$10,963

Data from the 2016-2019 round of funding shows that most applications came from households containing an open-hearth fireplace and most projects elected to install a sealed natural gas or propane-fueled fireplace insert (Figures A1 and A2, respectively). Figure A3 shows the breakdown of project location across Bay Area counties.

Figure A1. Project device from '16-'19 incentive funding

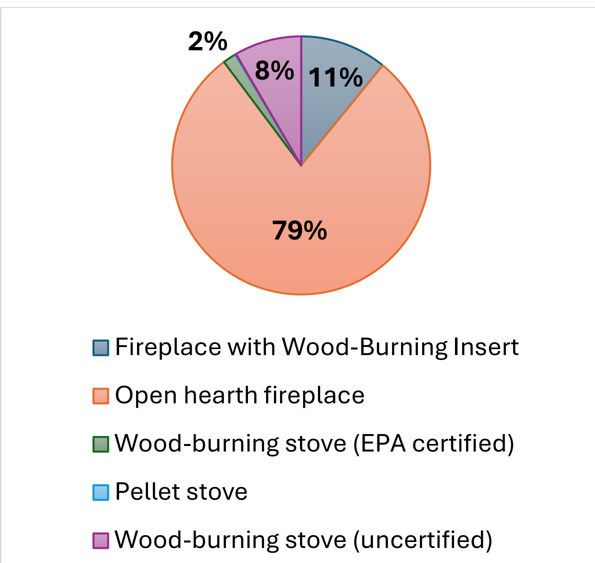


Figure A2. Project option from '16-'19 incentive funding

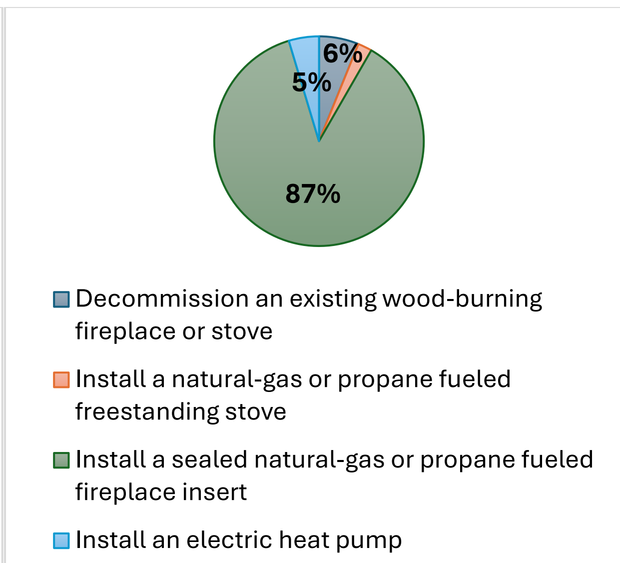
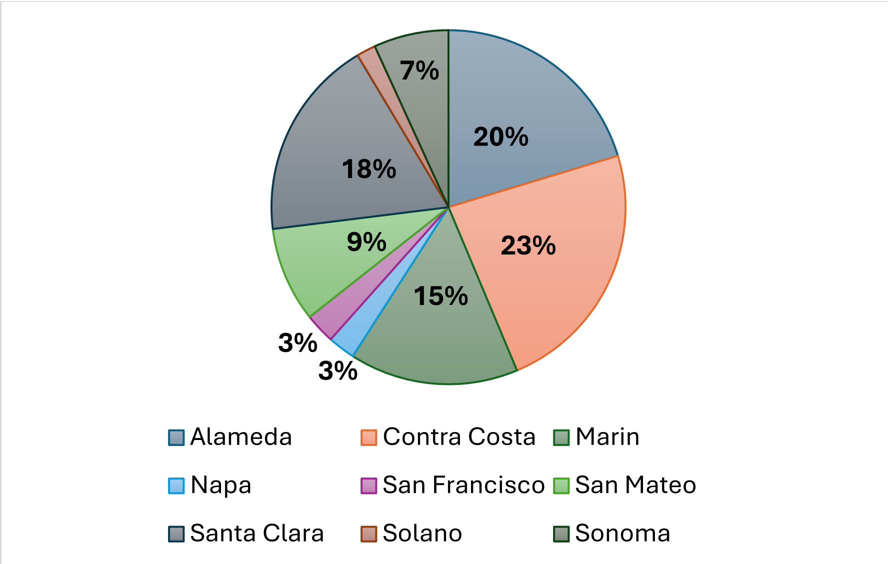


Figure A3. Project location by county for '16-'19 incentives funding



Appendix B – Emissions Inventory, Air Modeling, and Estimated Health Impacts

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Overview

Understanding air quality is like solving a puzzle. Emissions inventories, air quality modeling, air monitoring, and air pollution complaints are all tools that help us piece together the picture. An emissions inventory is like a detailed map of a city, showing the potential sources of pollution that we know about and can try to quantify, like fireplaces. Air quality modeling is like a weather forecast for pollution – it uses information from the emissions inventory and weather data to predict how pollutants will move and react in the atmosphere, giving us a picture of air quality across a wider area and even estimating future scenarios. Air monitors, on the other hand, are like air quality cameras. Some take snapshots of air quality at one moment in time. Other types can take readings continuously. Both can tell us about what pollutants are in the air at that specific location. Air quality complaint data acts like alarms from the public. Residents can report concerns about smoke, helping to identify potential polluters or pollution events that might be missed by other methods.

Here is why all four are important:

- The emissions inventory gives a starting point, a list of potential polluters (i.e., the wood-burning device population, informed by survey data) and associated emissions.
- Air quality modeling helps to understand how pollution spreads and predict future air quality, allowing us to take preventative measures.
- Air monitors can provide information on what's happening in the air we breathe.
- Air pollution complaint statistics provide valuable insights from the community, highlighting specific pollution concerns or things we have missed.

By using all four tools together, we gain a much clearer understanding of air pollution and can develop more effective strategies to keep our air clean or mitigate those impacts.

Emissions inventory and modeling are considered *bottom-up* approaches because they start by gathering detailed information on individual sources of pollution, like fireplaces, and then build up to estimate the total emissions from the population of sources and their impact on air quality. On the other hand, air quality monitoring is a *top-down* approach because it directly measures the levels of pollutants in the air at specific locations, giving a real-world snapshot of the overall air quality (Figure B0.1). Using both approaches together is beneficial because the bottom-up methods provide a detailed understanding of where pollutants come from and how they spread, while the top-down methods offer direct, real-world data on air pollution levels. This combination helps create a more accurate and comprehensive picture of air quality. This paper will describe what insights we can glean from these different approaches and why we may rely on specific approaches for answering certain questions.

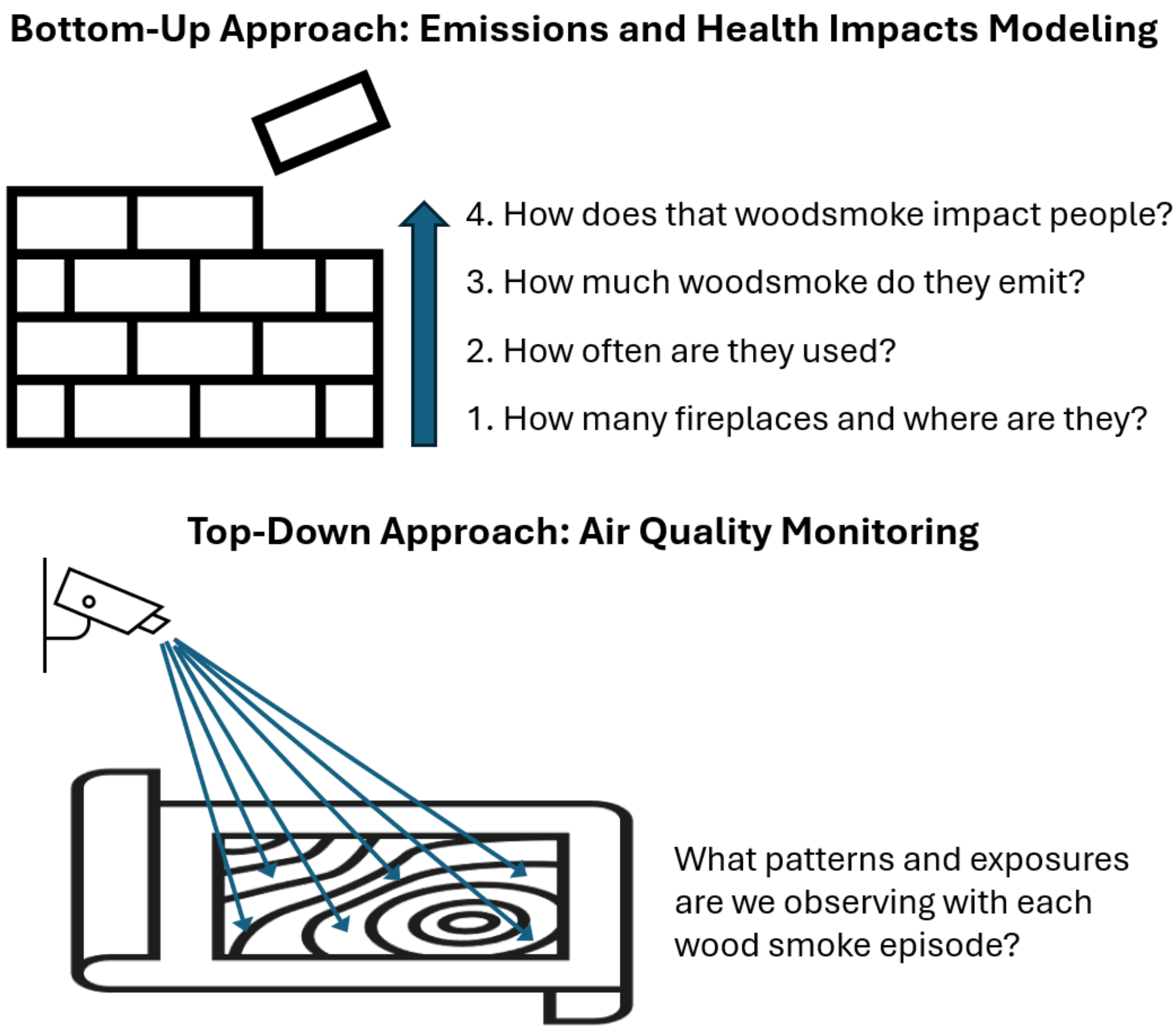


Figure B0.1. Comparison of bottom-up approach and top-down approach

Air District staff prepared an updated inventory of residential wood burning emissions by combining statistical models and data from Spare The Air (STA) surveys conducted during winter months (Nov–Feb) between 2008 and 2023.

In this Appendix, section B1 describes the approach to estimating emissions, and highlights key findings. Estimated emissions specific to the year 2020 were subsequently used to model impacts on ambient $PM_{2.5}$ concentrations, distributions of residential exposure, and selected health endpoints, using an atmospheric chemistry and transport model (CMAQ) and the US EPA's BenMAP-CE platform (sections B2 through B4). Air monitoring information is provided in Appendix C.

B1 Device Populations, Activity, and Emissions

B1.1 Devices In Use

Staff modeled residential wood burning devices installed indoors, including indoor fireplaces, wood stoves and fireplace inserts, and pellet stoves. Pellet stoves, which burn compressed wood pellets, are more efficient and tend to produce lower emissions. Fireplace inserts, installed into existing fireplaces, have operating and combustion characteristics similar to wood stoves.

Staff trained statistical models using STA winter survey data from 2008–2023, and used available Census data on housing stock for 2009–2020 to adjust the results to ensure representativeness. One set of models was trained to estimate the number of devices present in the Bay Area during any particular year and for any ZIP code.[42] Trends evident in the results show a decline in wood-burning devices and a rise in natural gas fireplaces over the past decade (Figure B1.1). The overall number of devices, when natural-gas fireplaces are included, has stayed essentially unchanged, while the number of occupied housing units has grown by about 7 percent. Estimated counts of active (ever used during winter) and total (active + inactive) devices for the year 2020 are reported in Table B1.2.

Santa Clara, Alameda, and Contra Costa counties had the highest number of both active and total wood-burning devices, but this is mainly because they had the largest populations. Adjusting for that, the "prevalence rate" of wood-burning devices was calculated as the average number of devices per household across a given area. At the county level, average prevalence rates of active wood-burning devices were lowest in San Francisco, Alameda, and Contra Costa counties (Figure B1.2), but there were relatively high rates in some of the more rural ZIP codes within the latter two counties (Figure B1.3). The average prevalence rate of actively used wood stoves was highest across Sonoma and Solano; for wood-burning fireplaces, it was highest across Marin.

B1.2 Emission Factors

Burning wood releases various pollutants, including total organic gases (TOG), ammonia (NH_3), sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter ($PM_{2.5}$ and PM_{10}). Emission factors for these pollutants were sourced from CARB (Table B1.1). Emission factors, which are estimates of the amounts of various pollutants released per unit of activity (e.g., pounds of emissions per ton of wood burned), vary depending on fuel types and equipment types. In the Bay Area, staff used survey data to estimate that about 10 percent of fuel burned in wood-burning fireplaces consisted of manufactured logs, which result in more particulate matter emissions than natural wood. Staff also used survey data to estimate that in 2020, approximately one in four wood stoves (not counting pellet stoves) were non-certified.[43] These also tend to be more polluting.

[42] Technical details are documented in a separate document (forthcoming).
[43] Until 2016, the STA Winter Survey asked users of wood stoves whether their stove was EPA-certified. The responses were used to train a statistical model used to forecast the proportion of certified stoves in 2020.

Table B1.1: Emission factors used to model 2020 emissions. Sourced from CARB (2015) except as noted in table footnotes.

	Emission Factor (Pounds Per Ton of Fuel)									
	$PM_{2.5}$	**PM_{10}**	**TOG**	**VOC**	**CH_4**	**NO_X**	**SO_X**	**SO_2**	**CO**	**NH_3**
Wood-Burning Fireplaces										
Natural wood	22.7	23.60	41.60	18.90	21.26	2.60	0.41	0.40	149.0	1.800
Manufactured logs	46.4	48.20	74.40	33.80	38.02	6.50	4.33	4.20	137.0	0.001
Wood Stoves										
Certified	15.7	16.28	28.33	12.87	14.48	2.20	0.41	0.40	130.2	0.900
Conventional	29.5	30.60	116.66	53.00	59.61	2.80	0.41	0.40	230.8	1.700
Bay Area average[1]	19.3	20.01	51.35	23.33	26.24	2.36	0.41	0.40	156.4	1.108
Pellet Stoves										
Pellets	2.9	3.06	0.09	0.04	0.04	3.80	0.33	0.32	15.9	0.300

[1]Weighted mean of conventional (26%) and certified (74%), corresponding to the year 2020.

Consistent with CARB organic profile #549, VOC/TOG = 0.4543 and CH_4/TOG = 0.511.
SO_2/SO_X = 0.97, consistent with SMOKE configuration for modeling (Appendix B2).

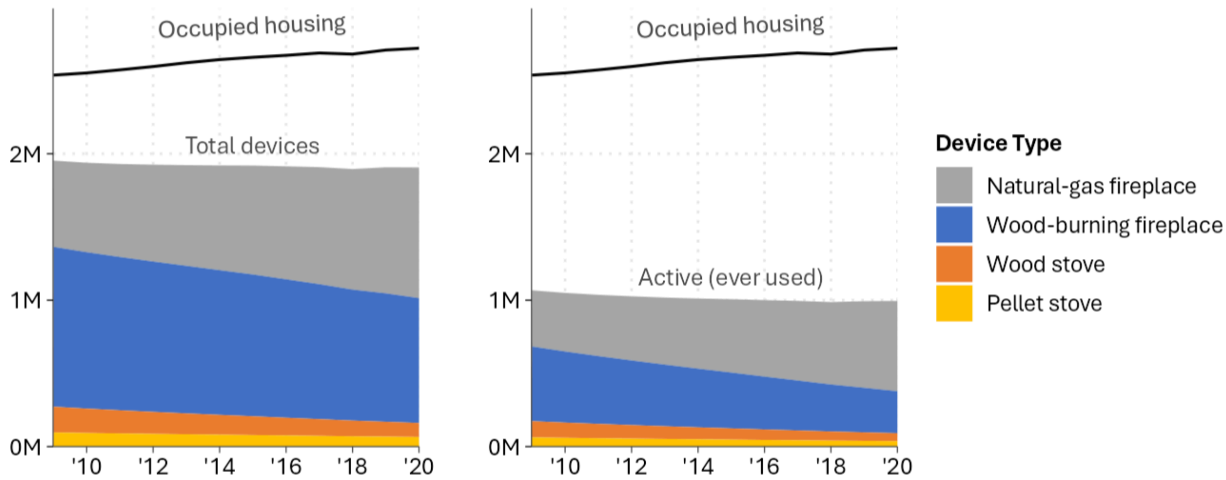


Figure B1.1: Left panel: estimated number of fireplaces, wood stoves, and pellet stoves present in the Bay Area, 2009–2020. Right panel: active devices only (ever used during winter). The trend in occupied housing is shown for reference; it is in terms of "housing units" rather than "devices."

Table B1.2: Estimated numbers of devices in 2020. The fraction that are active (ever used during winter) is based on self-reported intention to use. Counts and fractions are estimated at ZIP code level, and aggregated here to county and regional scale.

	Estimated Number of Devices (Thousands)							
	Natural-Gas Fireplaces		Wood-Burning Fireplaces		Wood Stoves		Pellet Stoves	
County	**Total**	**Active**	**Total**	**Active**	**Total**	**Active**	**Total**	**Active**
Alameda	165.3	112.9 (68%)	178.0	48.9 (27%)	17.6	8.2 (46%)	18.2	9.4 (52%)
Contra Costa	172.8	117.5 (68%)	158.5	60.1 (38%)	14.3	8.4 (58%)	7.9	5.0 (63%)
Marin	41.0	33.2 (81%)	42.6	20.5 (48%)	6.9	4.8 (69%)	2.1	1.5 (73%)
Napa	20.3	16.1 (79%)	15.3	8.1 (53%)	4.5	3.3 (73%)	1.4	1.1 (76%)
San Francisco	70.8	49.2 (69%)	69.0	20.6 (30%)	5.7	2.7 (48%)	9.4	5.1 (55%)
San Mateo	91.0	65.6 (72%)	101.8	37.1 (36%)	8.9	5.1 (57%)	5.6	3.4 (61%)
Santa Clara	231.6	147.2 (64%)	202.3	52.8 (26%)	18.1	8.2 (46%)	14.5	7.2 (49%)
Solano[1]	32.2	24.2 (75%)	40.4	16.5 (41%)	4.3	2.7 (62%)	3.2	2.1 (67%)
Sonoma[1]	67.3	50.3 (75%)	44.9	22.2 (50%)	15.1	10.7 (71%)	3.6	2.6 (73%)
	892.3	616.2 (69%)	852.8	286.8 (34%)	95.4	54.1 (57%)	65.9	37.4 (57%)

[1]Portions outside the BAAQMD boundary are excluded.

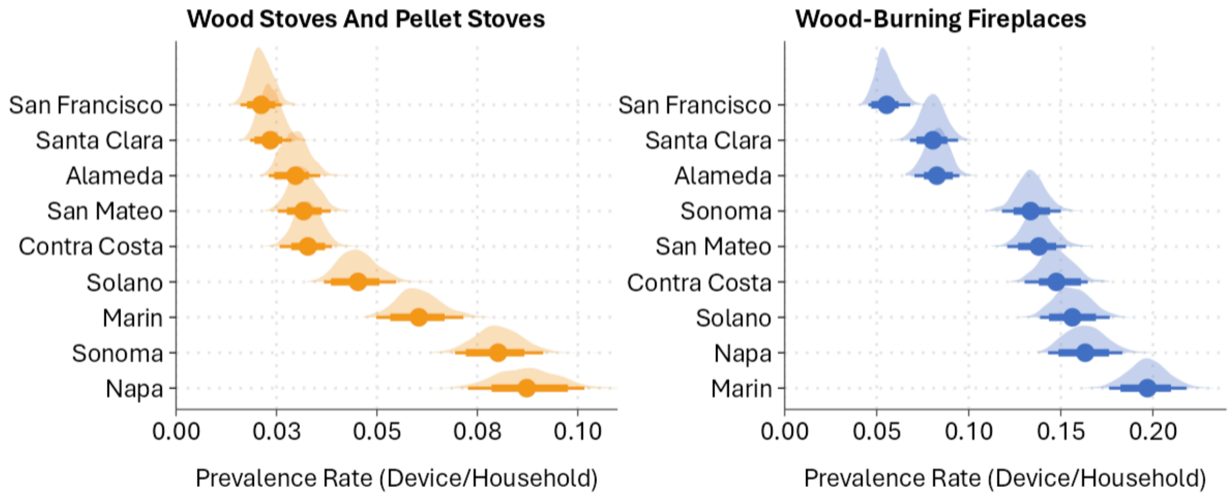


Figure B1.2: Estimated prevalence rates for active devices in 2020, aggregated from ZIP code to county level. Rates are equal to the number of active devices per occupied housing unit in each county. Point estimates (means) and 80% and 95% confidence intervals (highest density) are used to summarize the relative plausibility of different rates, given the survey data and model structure.

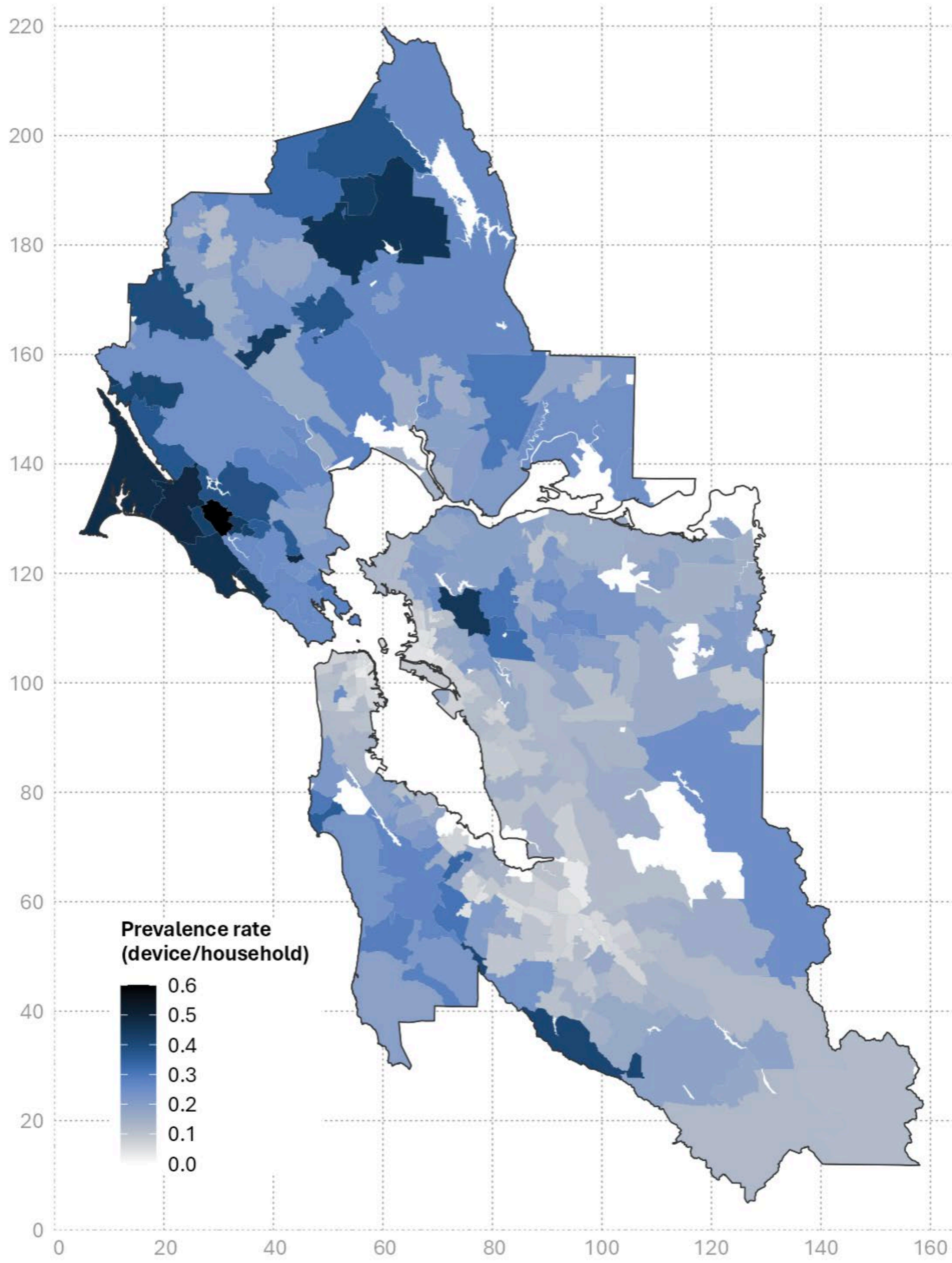


Figure B1.3: Estimated prevalence rate (number of active devices, divided by number of occupied households) for actively used indoor wood-burning devices, including indoor fireplaces, wood stoves, and pellet stoves. Estimates are for the year 2020.

B1.3 Winter Wood Burning Frequency and Fuel Consumption

Staff trained a second set of statistical models to estimate the frequency and intensity of wood burning during winter among active devices at ZIP code level, using the same STA winter survey dataset. These estimates were combined with estimates of prevalence (described in the preceding sections) to yield the average expected mass of fuel burned per winter week for each ZIP code and device type.

The Air District's STA winter surveys measure self-reported "typical" days of wood burning per week during winter. Staff ensured that this data was calibrated using reports of the previous day's behavior to predict average winter wood burning frequency. STA winter surveys also measure self-reported "typical" fuel consumption during days on which the respondent burns wood. Staff combined these with the calibrated frequency estimates, generating predictions for 2020 in terms of the expected average weekly rate of fuel consumption (per active device) during winter months at ZIP code level. These estimates were stratified by device type and housing type, scaled to the expected number of active devices, and converted to mass (5 lb per log). Fuel consumption for fireplaces was apportioned into natural logs and manufactured logs to facilitate the application of fuel-specific emission factors.

Table B1.3 reports county-level and regional summary metrics, created by aggregating ZIP code level estimates across different housing types and/or fuel types. Note that the results in Table B1.3 are for active devices, not total (active + inactive) devices.

TABLE B1.3: Estimated average weekly winter burning frequency and fuel consumption among actively used wood-burning devices in the Bay Area (2020).

	Winter Activity (2020), Active Devices Only				
	Average Per Device				
	Frequency (burn/week)[a]	Amount (lb/burn)[a]	Rate (lb/week)	Devices (thousand)	Fuel (ton/week)
Wood-burning fireplaces					
Alameda	0.96	21.8	20.9	48.9	510
Contra Costa	0.91	22.0	20.0	60.1	600
Marin	1.13	22.9	25.9	20.5	265
Napa	1.44	27.2	39.0	8.1	158
San Francisco	0.75	17.7	13.2	20.6	136
San Mateo	0.97	20.6	19.9	37.1	370
Santa Clara	1.06	21.3	22.7	52.8	598
Solano[1]	1.26	25.6	32.2	16.5	265
Sonoma[1]	1.54	27.5	42.3	22.2	470
(all)	1.04	22.6	23.5	286.8	3,374
Wood stoves					
Alameda	2.87	26.4	75.8	8.2	309
Contra Costa	2.28	26.2	59.8	8.4	250
Marin	2.78	27.5	76.4	4.8	182
Napa	3.21	32.0	102.7	3.3	169
San Francisco	1.58	18.7	29.6	2.7	41
San Mateo	2.25	23.7	53.1	5.1	136
Santa Clara	2.40	26.0	62.3	8.2	257
Solano[1]	2.54	30.8	78.2	2.7	104
Sonoma[1]	3.04	31.0	94.3	10.7	505
(all)	2.61	27.7	72.2	54.1	1,953
Pellet stoves					
Alameda	2.12	13.2	27.9	9.4	131
Contra Costa	1.40	13.0	18.1	5.0	45
Marin	2.35	13.4	31.5	1.5	24
Napa	2.45	15.5	38.0	1.1	20
San Francisco	0.92	10.4	9.6	5.1	25
San Mateo	1.61	11.2	18.1	3.4	31
Santa Clara	1.12	12.8	14.3	7.2	51
Solano[1]	1.89	14.5	27.3	2.1	29
Sonoma[1]	2.15	15.7	33.8	2.6	44
(all)	1.63	13.2	21.4	37.4	400

[a]The unit "burn" here means "a day on which wood is burned."

[1]Portions outside the BAAQMD boundary are excluded.

B1.4 Winter Wood Burning Activity at ZIP Code Level

The Air District often uses spatial surrogates to break down county-level emissions into smaller areas in preparation for modeling their impacts on air quality and health. (See Appendix B2 for more on the preparation of detailed inputs for air quality modeling, which also involve temporal surrogates for, e.g., month-of-year and hour-of-day.) For fireplaces, the most relevant spatial surrogate supplied by CARB is based on the presence or absence of fireplaces at the parcel level. This is obviously a key piece of information, but it is also important to understand differences in the degree to which installed fireplaces are used. Additionally, this surrogate was unavailable for Alameda and Contra Costa counties. These two counties account for one-third of regional $PM_{2.5}$ emissions from this class of device.

Staff found that the ZIP code-level STA winter survey data for the Bay Area was sufficient to estimate meaningful differences in both the prevalence of devices and the average activity rates among the active devices at ZIP code scale. The map shown in Figure B1.3 illustrates the estimated variability in *prevalence* rates (active devices per household) for wood-burning fireplaces at ZIP code level. Figure B1.4 illustrates the degree of remaining variability in *activity*. It shows, for example, that active wood-burning fireplaces in Alameda County are predicted to be used about twice as intensively (in terms of fuel per week per active device) across ZIP 94586, a largely rural region containing the San Antonio reservoir, compared to ZIP 94612, an urban area in Oakland. A similar range is seen across ZIP codes in other counties: for example, ZIP 95113 (downtown San Jose) not only has fewer active fireplaces per household than ZIP (containing Mt. Hamilton), but a lower predicted average rate of fuel consumption among such devices. Of note, the statistical model trained to generate these predictions was deliberately constructed to avoid over-fitting ZIP codes that had relatively few survey responses, so these are likely under-predictions of the true variation across ZIP codes. Nevertheless, they are more informative than assuming all ZIP codes are equal. [44]

Wood stoves and pellet stoves are less common than fireplaces, leading to less data being available for directly predicting ZIP code level variation. To address this, staff took a different approach, refining CARB's surrogate for wood stoves instead. This surrogate was available for all Bay Area counties and is based on the relative distribution of households using wood as their primary heat source, as measured by the US Census. [45] Staff used ZIP code-level Census data on this question and a longer averaging time (2006–2022) to reduce noise in the surrogate, compared to the original. Staff then re-apportioned county-level estimates of wood stove and pellet stove activity to ZIP codes, based on this refined surrogate.

[44] For further discussion and explanation, please see the technical documentation (forthcoming).
[45] The basis is a Census question that asks residents to select the primary fuel used for heat: gas, wood, etc.

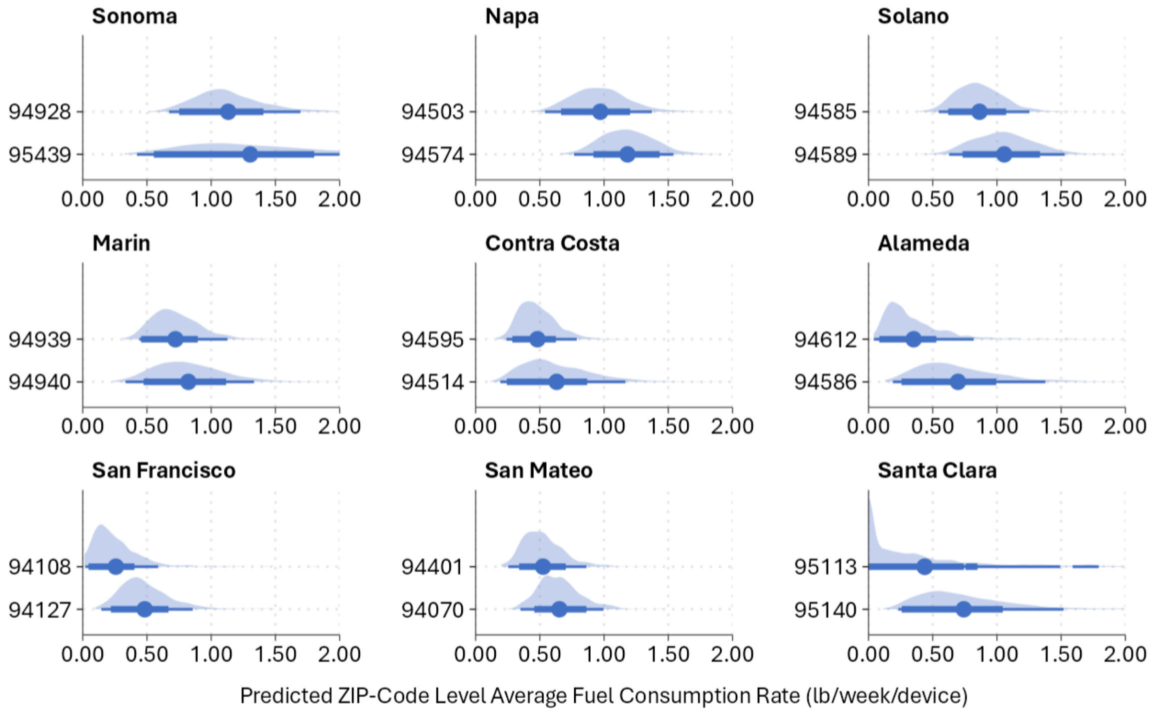


Figure B1.4: Geographic diversity in wood-burning behavior is illustrated using predicted average weekly winter fuel consumption rates, *per active device*, for selected ZIP codes. This stacks on top of variability in *prevalence*. For each county, the two ZIP codes with the (a) highest and (b) lowest predicted rates are shown. Shapes = posterior predictive distributions (PPDs; i.e., plausibility of other possible values for a ZIP code, given the survey data). Points = means; lines = confidence intervals (80% and 95%, highest density).

B1.5 Conversion of Winter Activity to Emission Rates

Staff converted winter activity to winter emissions using the emission factors listed in Table B1.1. This was done separately for: (1a) natural wood burned in fireplaces; (1b) manufactured logs burned in fireplaces; (2) wood burned in wood stoves; and (3) pellet stoves. Results are shown in Table B1.4.

To construct estimates for non-winter months (Mar–Oct), and to construct an annual average, staff used a monthly temporal profile sourced from CARB, reflected in Figure B1.5. Monthly estimates were averaged to produce the annual-average emission rates reported in Table B1.5. After further post-processing, the resulting estimates were used as input to the air quality modeling described in Appendix B2.

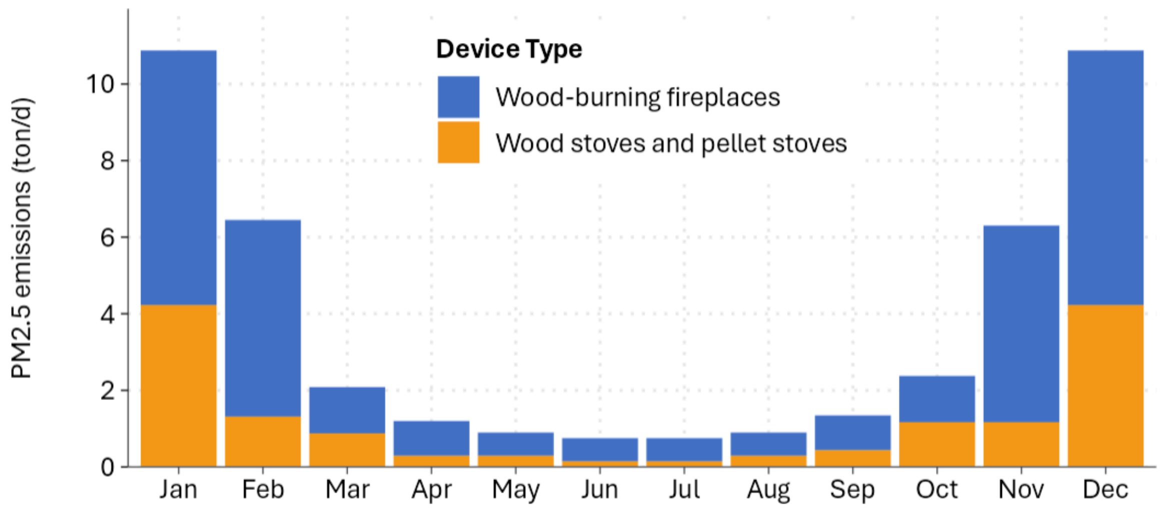


Figure B1.5: Modeled monthly distribution of wood burning emissions in the Bay Area. Pollutants other than $PM_{2.5}$ follow the same monthly profile.

Table B1.4: Winter average (Nov-Feb) emission rates, aggregated to county level.

	Winter Average (Nov-Feb 2020)										
		Emission Rate (ton/d)									
	Fuel (ton/d)	$PM_{2.5}$	PM_{10}	TOG	VOC	CH_4	NO_X	SO_X	SO_2	CO	NH_3
Wood-burning fireplaces											
Alameda	72.8	0.90	0.93	1.61	0.73	0.82	0.106	0.026	0.026	5.39	0.060
Contra Costa	85.7	1.05	1.09	1.89	0.86	0.97	0.124	0.030	0.030	6.35	0.071
Marin	37.9	0.46	0.48	0.83	0.38	0.42	0.054	0.013	0.012	2.81	0.032
Napa	22.6	0.27	0.28	0.49	0.22	0.25	0.031	0.006	0.006	1.68	0.020
San Francisco	19.5	0.25	0.26	0.44	0.20	0.23	0.030	0.009	0.008	1.44	0.015
San Mateo	52.8	0.65	0.68	1.17	0.53	0.60	0.078	0.020	0.019	3.91	0.043
Santa Clara	85.5	1.10	1.15	1.96	0.89	1.00	0.133	0.039	0.038	6.30	0.067
Solano[1]	37.9	0.47	0.49	0.84	0.38	0.43	0.055	0.014	0.014	2.80	0.031
Sonoma[1]	67.2	0.79	0.82	1.43	0.65	0.73	0.092	0.018	0.018	4.99	0.059
(all)	482.0	5.93	6.17	10.67	4.85	5.45	0.703	0.176	0.171	35.67	0.399
Wood stoves and pellet stoves											
Alameda	62.8	0.45	0.47	1.13	0.51	0.58	0.088	0.012	0.012	3.60	0.027
Contra Costa	42.2	0.35	0.37	0.92	0.42	0.47	0.054	0.008	0.008	2.85	0.021
Marin	29.4	0.26	0.27	0.67	0.30	0.34	0.037	0.006	0.006	2.06	0.015
Napa	27.0	0.24	0.25	0.62	0.28	0.32	0.034	0.005	0.005	1.91	0.014
San Francisco	9.3	0.06	0.06	0.15	0.07	0.08	0.014	0.002	0.002	0.48	0.004
San Mateo	23.9	0.19	0.20	0.50	0.23	0.26	0.031	0.005	0.005	1.56	0.011
Santa Clara	44.0	0.36	0.38	0.94	0.43	0.48	0.057	0.009	0.009	2.93	0.021
Solano[1]	19.0	0.15	0.16	0.38	0.17	0.20	0.025	0.004	0.004	1.20	0.009
Sonoma[1]	78.5	0.71	0.73	1.85	0.84	0.95	0.097	0.016	0.015	5.70	0.041
(all)	336.2	2.77	2.88	7.17	3.26	3.66	0.437	0.067	0.065	22.28	0.163
All modeled wood-burning devices											
Alameda	135.7	1.35	1.40	2.74	1.25	1.40	0.194	0.039	0.037	8.99	0.088
Contra Costa	128.0	1.40	1.46	2.81	1.28	1.44	0.179	0.039	0.038	9.20	0.092
Marin	67.3	0.71	0.74	1.50	0.68	0.76	0.091	0.018	0.018	4.87	0.047
Napa	49.6	0.50	0.52	1.10	0.50	0.56	0.065	0.012	0.011	3.59	0.033
San Francisco	28.8	0.31	0.32	0.59	0.27	0.30	0.043	0.010	0.010	1.92	0.019
San Mateo	76.7	0.85	0.88	1.68	0.76	0.86	0.109	0.025	0.024	5.47	0.055
Santa Clara	129.5	1.47	1.52	2.90	1.32	1.48	0.190	0.048	0.047	9.23	0.088
Solano[1]	56.9	0.62	0.64	1.22	0.56	0.62	0.081	0.018	0.017	4.00	0.040
Sonoma[1]	145.7	1.49	1.55	3.29	1.49	1.68	0.189	0.034	0.033	10.69	0.099
(all)	818.2	8.71	9.05	17.83	8.10	9.11	1.140	0.243	0.236	57.95	0.562

[1]Portions outside the BAAQMD boundary are excluded.

Table B1.5: Annual average emission rates, aggregated to county level.

	Annual Average (2020)										
	Fuel (ton/d)	Emission Rate (ton/d)									
		$PM_{2.5}$	PM_{10}	TOG	VOC	CH_4	NO_X	SO_X	SO_2	CO	NH_3
Wood-burning fireplaces											
Alameda	30.8	0.38	0.39	0.68	0.31	0.35	0.045	0.011	0.011	2.28	0.026
Contra Costa	36.3	0.44	0.46	0.80	0.36	0.41	0.053	0.013	0.013	2.69	0.030
Marin	16.0	0.19	0.20	0.35	0.16	0.18	0.023	0.005	0.005	1.19	0.014
Napa	9.6	0.11	0.12	0.21	0.09	0.10	0.013	0.003	0.003	0.71	0.008
San Francisco	8.2	0.11	0.11	0.19	0.09	0.10	0.013	0.004	0.004	0.61	0.007
San Mateo	22.3	0.28	0.29	0.50	0.23	0.25	0.033	0.008	0.008	1.65	0.018
Santa Clara	36.2	0.47	0.48	0.83	0.38	0.42	0.056	0.017	0.016	2.67	0.028
Solano[1]	16.0	0.20	0.21	0.36	0.16	0.18	0.023	0.006	0.006	1.19	0.013
Sonoma[1]	28.4	0.33	0.35	0.61	0.28	0.31	0.039	0.008	0.007	2.11	0.025
(all)	203.9	2.51	2.61	4.51	2.05	2.31	0.297	0.074	0.072	15.09	0.169
Wood stoves and pellet stoves											
Alameda	27.6	0.20	0.21	0.50	0.23	0.25	0.038	0.005	0.005	1.58	0.012
Contra Costa	18.5	0.16	0.16	0.40	0.18	0.21	0.024	0.004	0.004	1.25	0.009
Marin	12.9	0.11	0.12	0.29	0.13	0.15	0.016	0.003	0.003	0.91	0.007
Napa	11.8	0.10	0.11	0.27	0.12	0.14	0.015	0.002	0.002	0.84	0.006
San Francisco	4.1	0.03	0.03	0.07	0.03	0.03	0.006	0.001	0.001	0.21	0.002
San Mateo	10.5	0.09	0.09	0.22	0.10	0.11	0.014	0.002	0.002	0.68	0.005
Santa Clara	19.3	0.16	0.17	0.41	0.19	0.21	0.025	0.004	0.004	1.28	0.009
Solano[1]	8.4	0.07	0.07	0.17	0.08	0.09	0.011	0.002	0.002	0.53	0.004
Sonoma[1]	34.5	0.31	0.32	0.81	0.37	0.42	0.043	0.007	0.007	2.50	0.018
(all)	147.7	1.22	1.26	3.15	1.43	1.61	0.192	0.029	0.029	9.78	0.072
All modeled wood-burning devices											
Alameda	58.4	0.58	0.60	1.18	0.54	0.60	0.083	0.017	0.016	3.86	0.037
Contra Costa	54.8	0.60	0.62	1.20	0.55	0.61	0.076	0.017	0.016	3.94	0.039
Marin	29.0	0.31	0.32	0.64	0.29	0.33	0.039	0.008	0.008	2.09	0.020
Napa	21.4	0.22	0.23	0.48	0.22	0.24	0.028	0.005	0.005	1.55	0.014
San Francisco	12.3	0.13	0.14	0.25	0.12	0.13	0.019	0.004	0.004	0.82	0.008
San Mateo	32.8	0.36	0.38	0.72	0.33	0.37	0.047	0.011	0.010	2.34	0.023
Santa Clara	55.5	0.63	0.65	1.24	0.56	0.64	0.081	0.021	0.020	3.95	0.038
Solano[1]	24.4	0.26	0.27	0.52	0.24	0.27	0.035	0.008	0.007	1.71	0.017
Sonoma[1]	62.9	0.64	0.67	1.42	0.65	0.73	0.081	0.015	0.014	4.61	0.043
(all)	351.6	3.73	3.87	7.66	3.48	3.91	0.489	0.104	0.101	24.88	0.240

[1]Portions outside the BAAQMD boundary are excluded.

B1.6 Apportioning Activity and Emissions to 1 km^2 Scale

In preparation for simulating impacts on air quality and health, staff apportioned ZIP code level estimates to 1 km^2 scale using Census data on occupied housing density.[46] This process accounted for variations in activity based on device type and housing type (single-unit vs. multi-unit). For wood stoves, this hybrid approach noticeably changed the modeling of emissions from small towns, compared to the application of a tract-level surrogate alone.[47]

The overall approach resulted in substantial variation in predicted $PM_{2.5}$ emissions from wood burning per household at 1 km^2 scale. Figures B1.6 and B1.7 are maps of the resulting winter wood burning activity and $PM_{2.5}$ emission rates. See Section B6 for guidance on interpreting these maps.

Figure B1.8 shows the 1 km^2 winter $PM_{2.5}$ emission estimates aggregated to the level of "places," which are based on polygons downloaded from OpenStreetMap. Dense urban areas, especially San Francisco, had the lowest predicted emissions per capita. The highest emissions per capita were generally found scattered across rural areas, which were mostly north of the Carquinez Strait.

[46] STA survey data does not include addresses; ZIP code is the most detailed location data available.
[47] Many rural Census tracts are much larger than 1 km^2. Application of a tract-level surrogate means that emissions are averaged (i.e., diluted) uniformly across that, including sub-areas where homes may not exist.

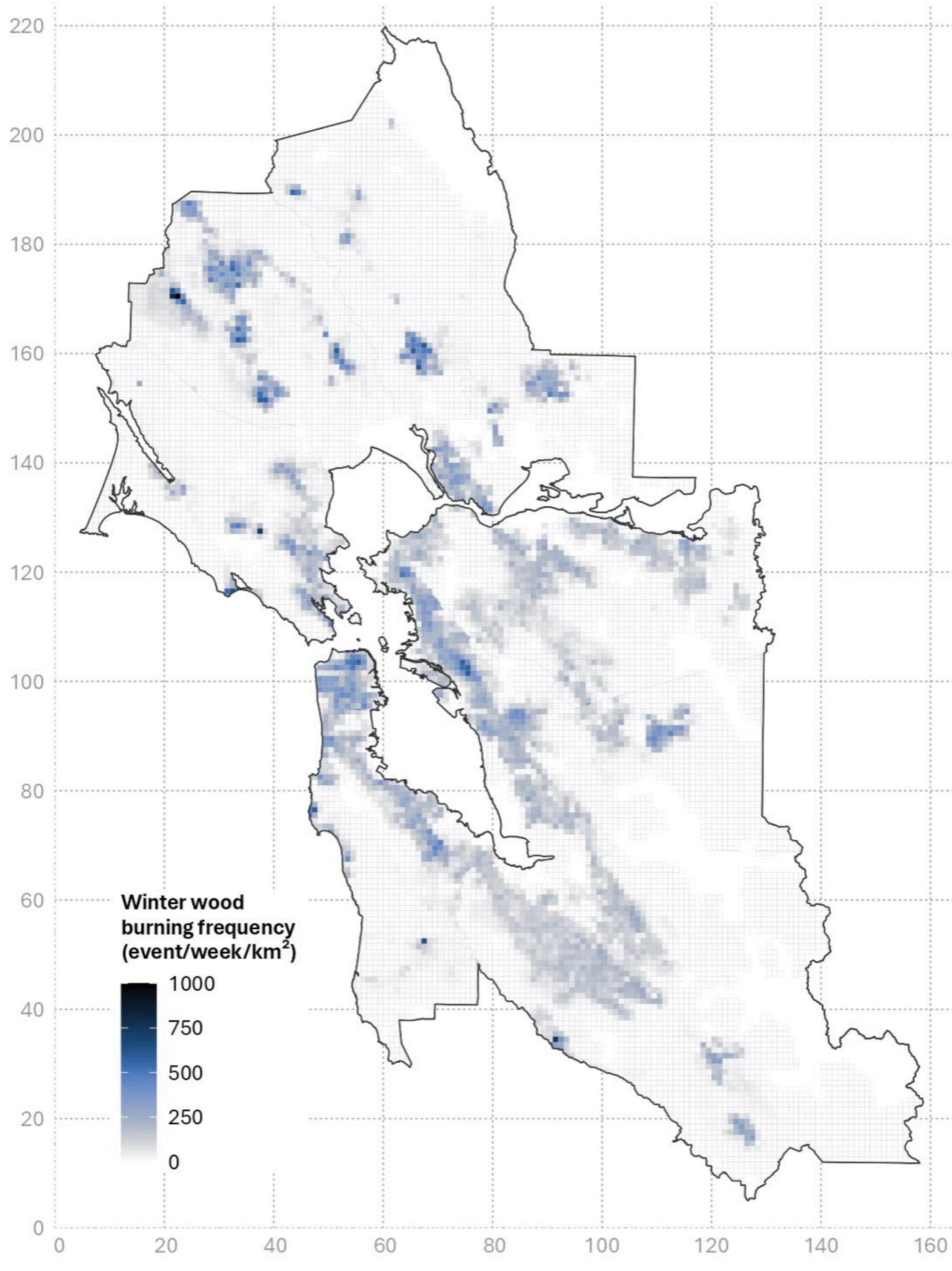


Figure B1.6: Estimated weekly average rate of winter wood burning events across the Bay Area during winter (Nov–Feb) 2020. One thousand events in a grid cell is equivalent to 1,000 devices burning 1 day/week, or 200 devices burning 5 day/week, etc. Please see section B5 for additional guidance on interpreting this map.

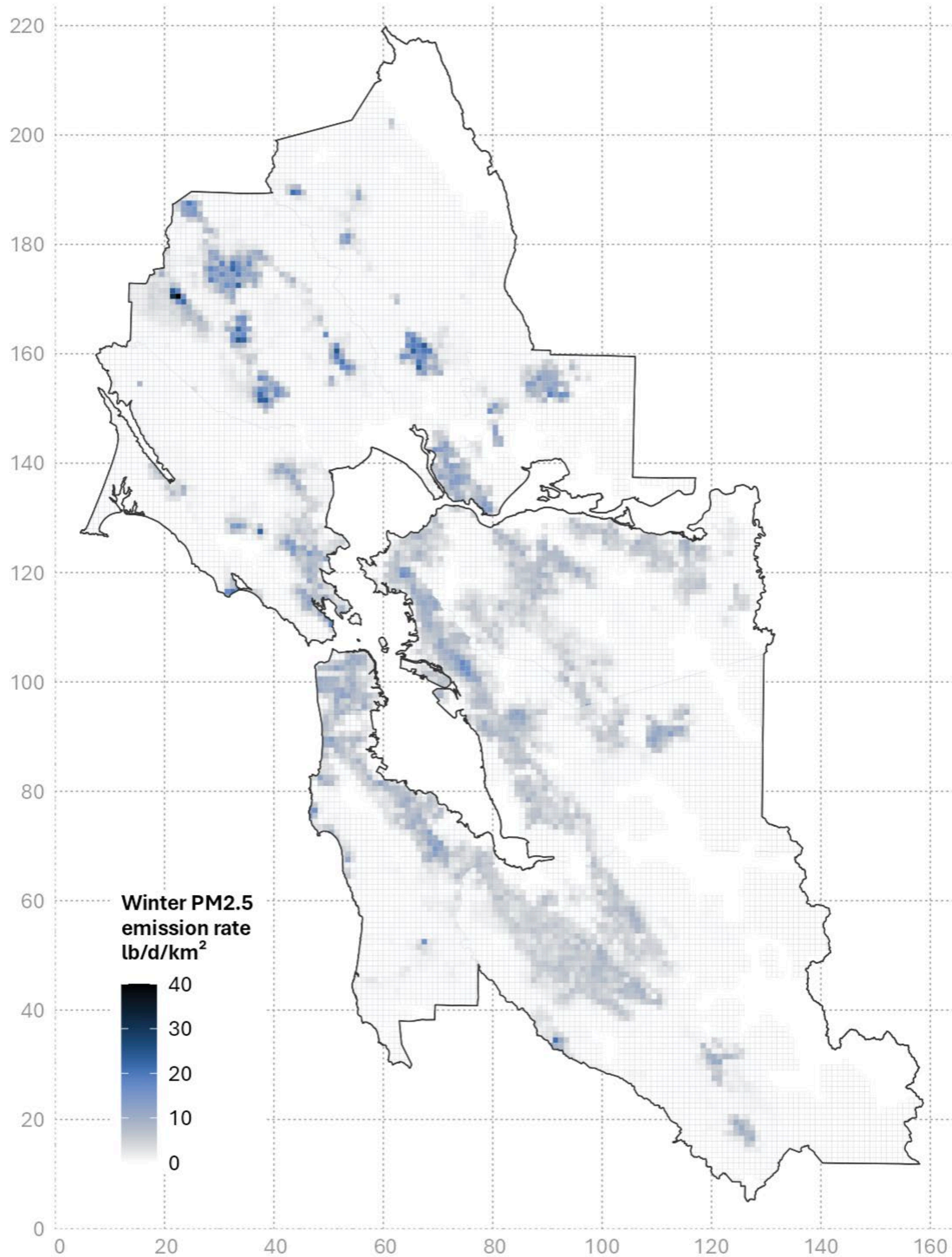


Figure B1.7: Estimated daily average daily $PM_{2.5}$ emissions from wood-burning devices across the Bay Area during winter (Nov–Feb) 2020. Each grid cell is 1 km^2. Compare to Figure B1.6 (events); differences mainly reflect variation in the average amount of fuel burned at a time. Please see section B5 for additional guidance on interpreting this map.

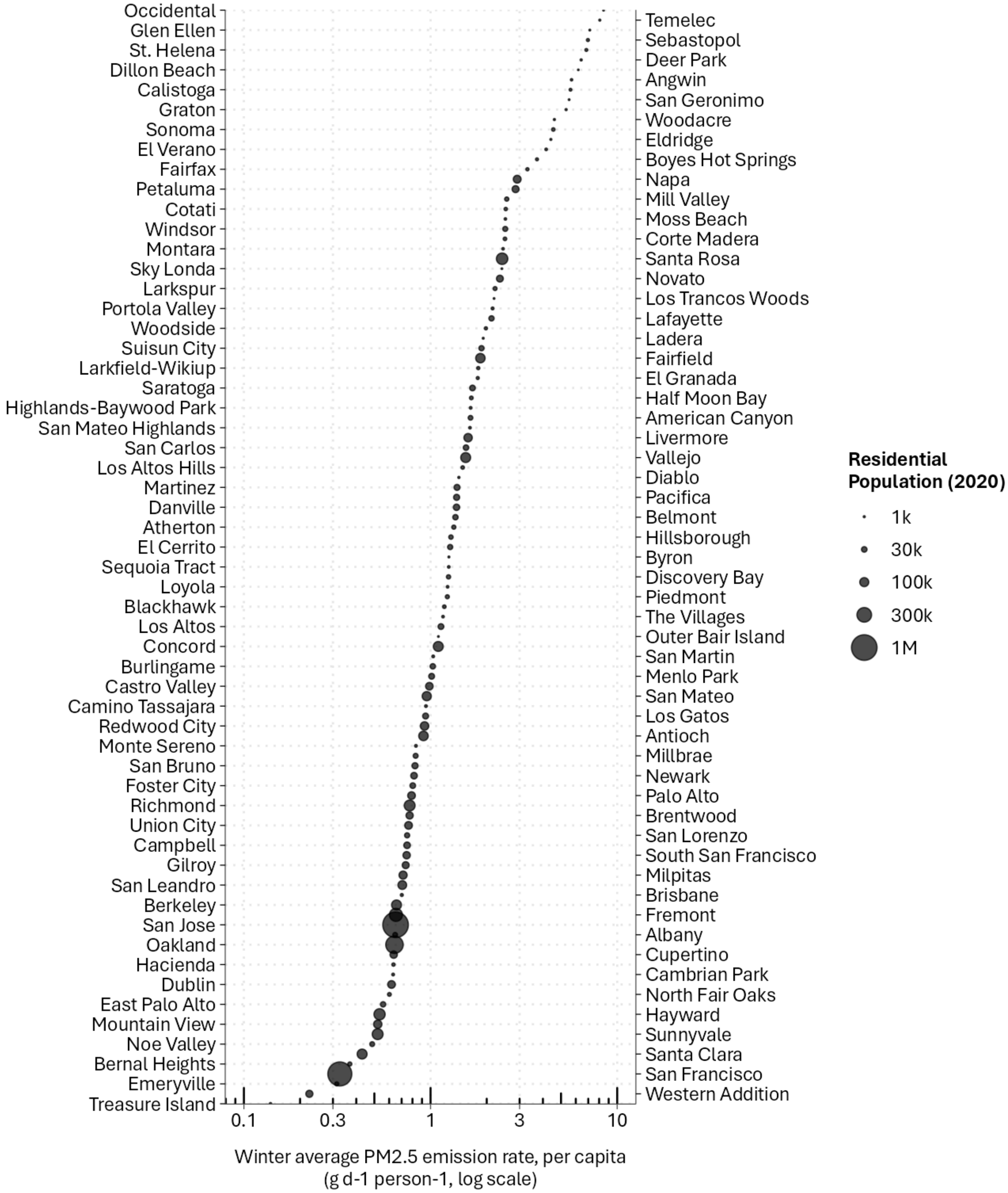


Figure B1.8: Geographic variation in modeled winter average per-capita $PM_{2.5}$ emissions from residential wood burning. Larger dots represent places with larger populations. Places are based on polygons downloaded from OpenStreetMap. Place names are shown on both sides to increase legibility. Note the log scale on the x axis.

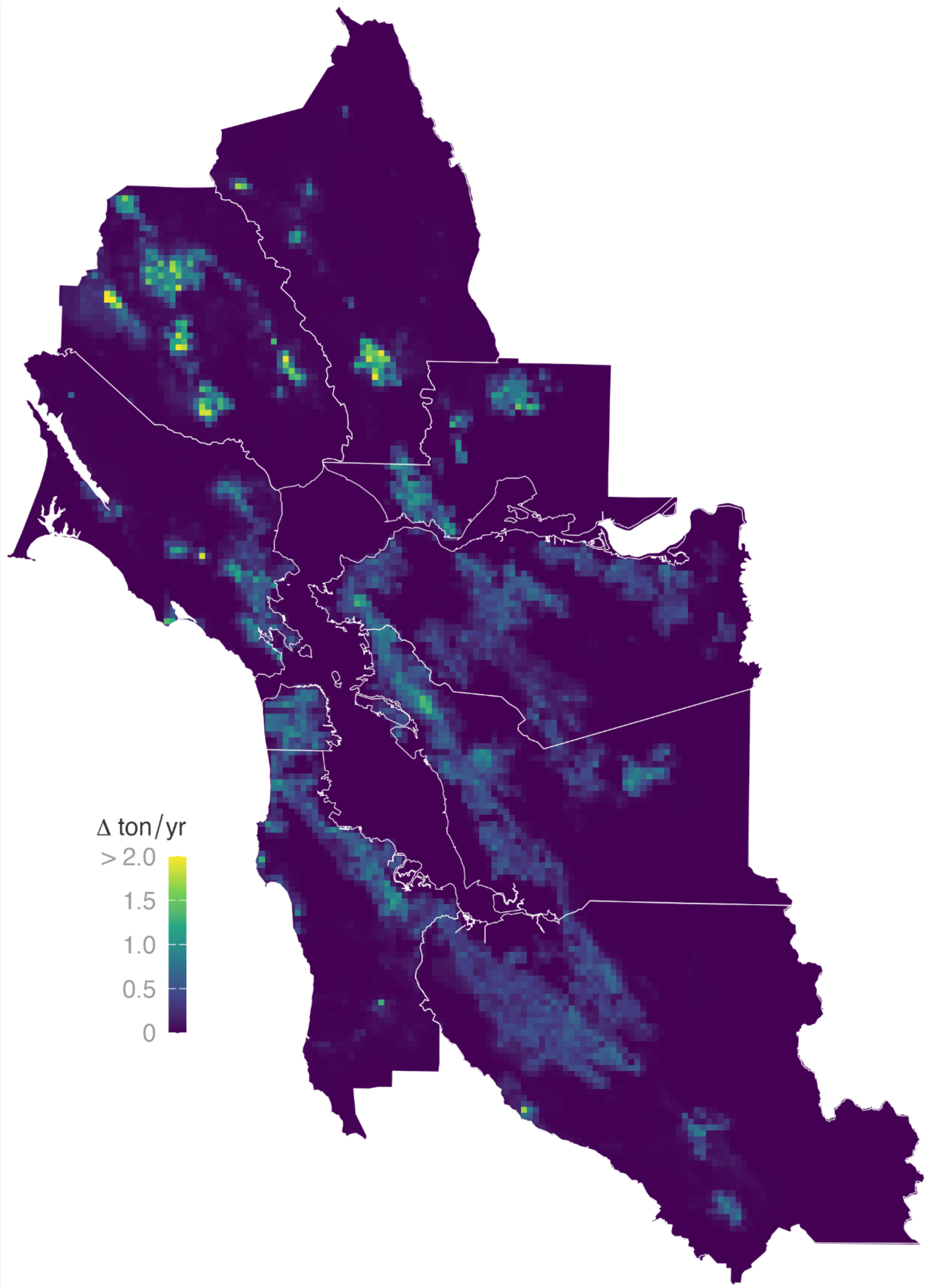


Figure B1.9: Modeled contributions from residential woodburning to annual average $PM_{2.5}$ emissions across the Bay Area. Compare to Figure B2.2 ($PM_{2.5}$ concentrations).

B1.7 Emissions In Context

Taking $PM_{2.5}$ as an example, Figure B1.10 illustrates the approximate proportion of modeled $PM_{2.5}$ emissions that are accounted for by residential wood burning. In the emission inventory constructed for this analysis, on an annual-average basis, it was 14 percent (3.7 ton/d). During the peak winter months of December and January, it accounts for about one-third of modeled $PM_{2.5}$ emissions (10.9 ton/d or 34 percent).

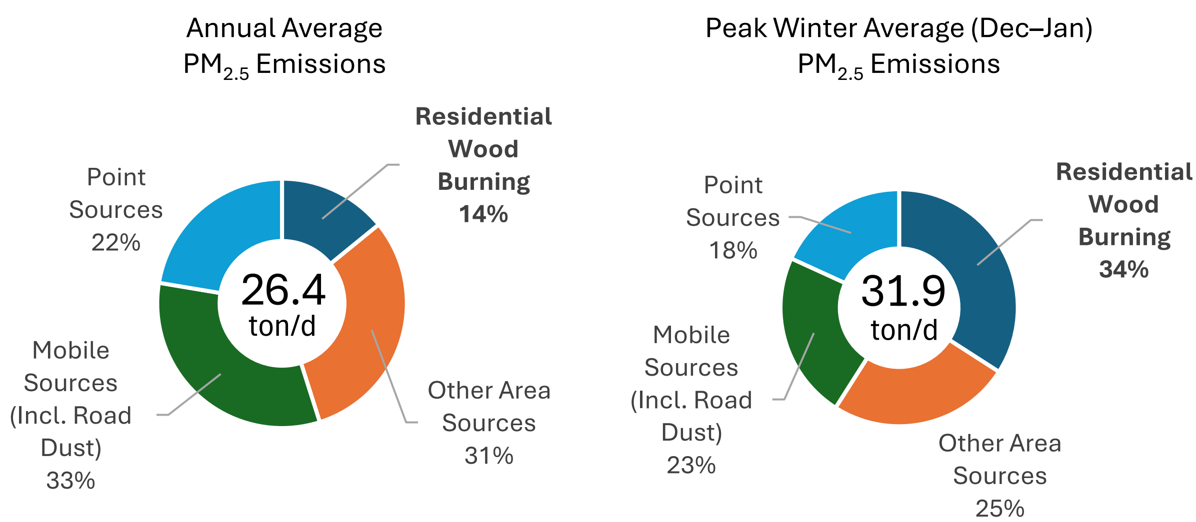


Figure B1.10: Left panel: modeled $PM_{2.5}$ emissions by source sector for an entire year. Right panel: as modeled during peak wood burning months (December and January).

B2 $PM_{2.5}$ Levels from Residential Woodburning Emissions

B2.1 Modeling Method

Staff have been applying the U.S. EPA's Community Multiscale Air Quality (CMAQ) model to estimate regional ambient levels of $PM_{2.5}$ in the Bay Area. The CMAQ model was initially applied to simulate $PM_{2.5}$ levels at a 1-km horizontal resolution over the entire Bay Area for 2016 (Tanrikulu et al., 2019). This work supported the District's activities under Assembly Bill 617 (AB 617), providing assessments of $PM_{2.5}$ levels in the West Oakland AB 617 community. Subsequently, annual simulations were conducted for two additional years (2017–2018) using updated emissions inventories and model improvements. Results from these simulations were used to support the District's ongoing AB 617 and rulemaking efforts.

For this study, employing the same modeling platform, and additional model improvements and updates to emissions, annual simulations were conducted for 2022 to evaluate $PM_{2.5}$ impacts from residential woodburning emissions. This modeling analysis featured two annual simulations for 2022: (1) a base case run that included the District's latest woodburning emissions estimates, and (2) a control case that removed woodburning emissions from devices in the Bay Area. (Wood burning emissions elsewhere were not removed.) Differences between these two simulations provided an estimate of the ambient air quality impacts of this source sector.

The simulated ambient air quality impacts were analyzed for an estimate of $PM_{2.5}$ from residential woodburning emissions. The rest of Appendix B2 describes the study setting, applications of CMAQ and a summary of key findings.

B2.2 Study Setting

Two nested domains were used in the CMAQ simulations. The outer domain covered the Bay Area, San Joaquin Valley, and Sacramento Valley, as well as portions of the Pacific Ocean and the Sierra Nevada Mountains at 4-km horizontal resolution. The inner domain covered the Bay Area and surrounding regions at 1-km horizontal resolution, as shown in Figure B2.1. The outer domain provided initial conditions and hourly boundary conditions to the 1-km domain.

Meteorological inputs to the CMAQ modeling were prepared using the Weather Research and Forecasting (WRF) model. The application and performance of this model were documented by Tanrikulu et al., 2019.

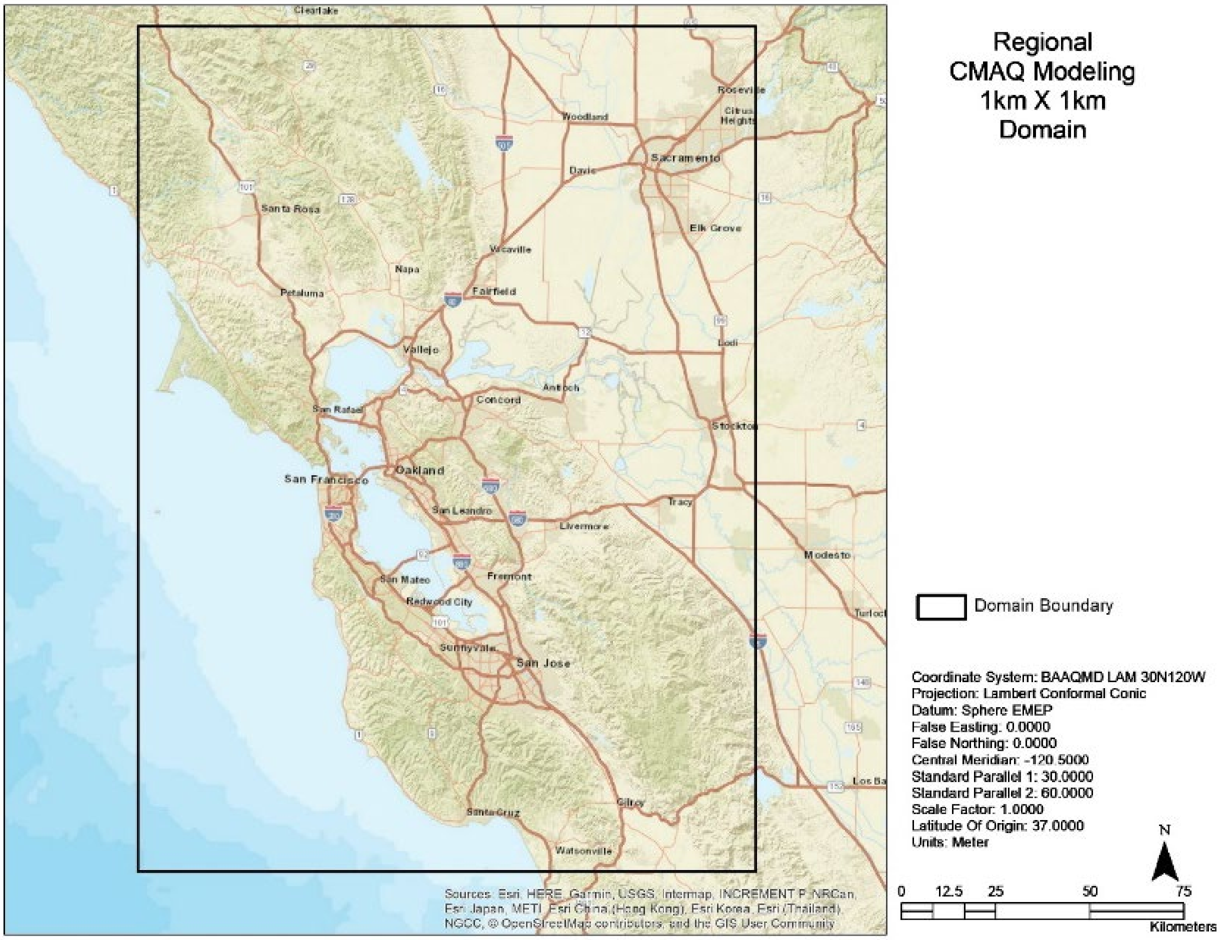


Figure B2.1: The regional 1-km modeling domain used for CMAQ simulations.

B2.3 Simulations

The Air District's current CMAQ modeling platform was configured for the year 2022, and all emissions, except from woodburning, were prepared for this base year. Woodburning emissions estimates presented in Appendix B1 were used in the 2022 model configuration. Residential woodburning emissions for the CMAQ model were prepared separately from other area source categories. This step was taken to facilitate the removal of woodburning emissions for the control case simulation and to allow for future sensitivity runs that investigate the impact of specified changes in wood combustion emissions.

The CMAQ model provides hourly average concentrations, which were used to estimate daily, seasonal, and annual average concentrations. In this study, our analyses focused on annual average concentrations for 1x1 km (1 km^2) horizontal grid cells.

B2.4 Simulated $PM_{2.5}$ Concentrations

In this section, we present the areal distribution of modeled contributions from residential wood burning to annual average $PM_{2.5}$ levels. The contributions estimated for the 1 km^2 grid cells varied from near zero to 0.85 $\mu g/m^3$ in the Bay Area, depending upon cell locations. For the purpose of analysis, we binned these with an increment of 0.1 $\mu g/m^3$ as shown in Figures B2.2 and B3.2 (contour lines).

The largest contributions (between 0.6 $\mu g/m^3$ and 0.8 $\mu g/m^3$) were located in the counties of Sonoma and Napa, in and around the towns of Santa Rosa, Sebastopol, Rohnert Park and Napa. Contributions between 0.5 $\mu g/m^3$ and 0.6 $\mu g/m^3$ were found in Sonoma and Napa counties as well as in the cities of Oakland, San Jose and Redwood City. Contributions between 0.4 $\mu g/m^3$ and 0.5 $\mu g/m^3$ were found in areas surrounding those with contributions above 0.5 $\mu g/m^3$ and in Concord, Livermore, San Leandro, Hayward, San Martien, and Gilroy.

Contributions between 0.2 $\mu g/m^3$ and 0.4 $\mu g/m^3$ were found in areas surrounding those with contributions above 0.4 $\mu g/m^3$ and along the major freeways of the Bay Area. They were also found in residential areas, and downwind of residential areas, in San Francisco, Richmond, Vallejo, Fairfield, Brentwood and other locations of the Bay Area.

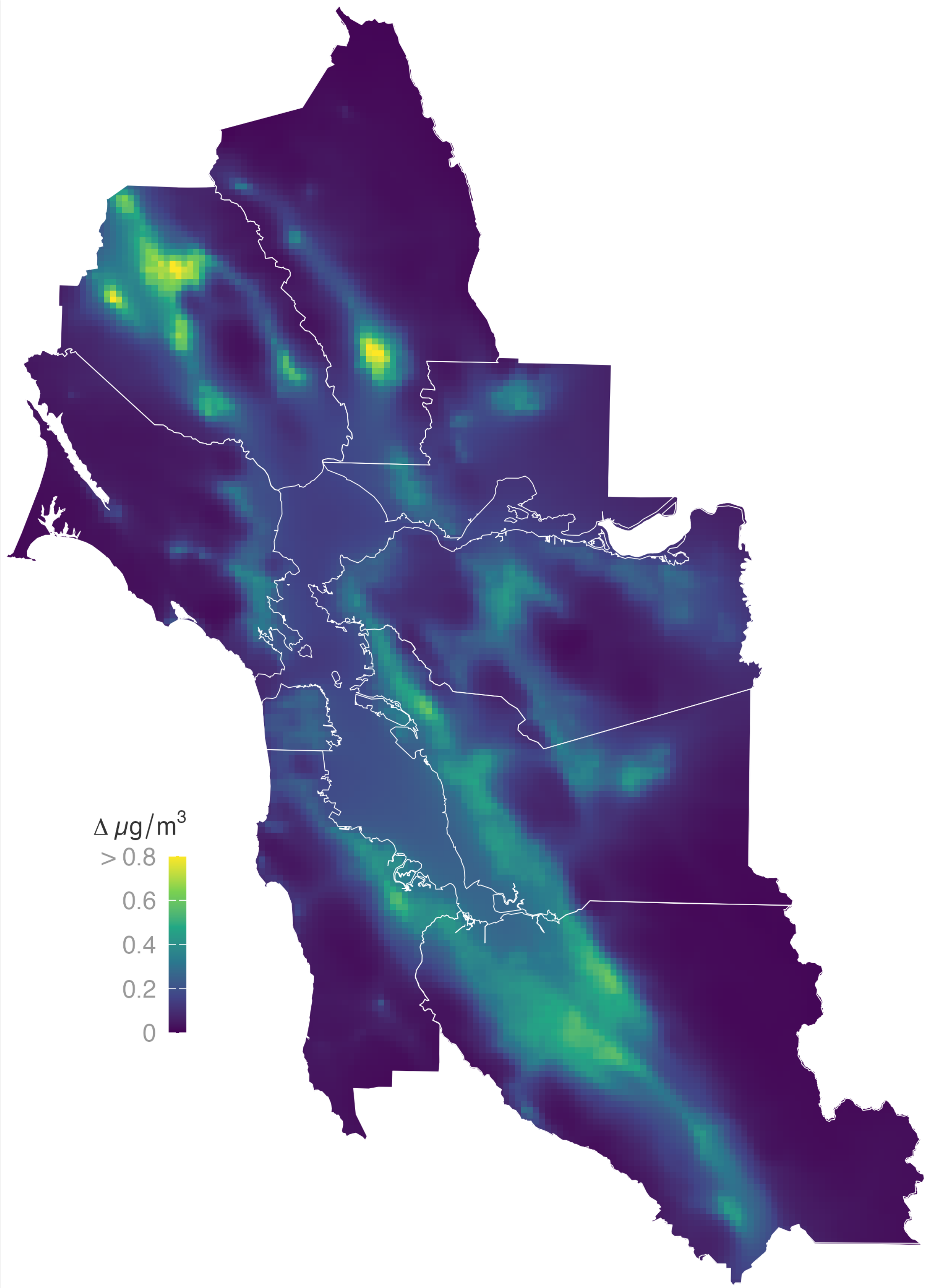


Figure B2.2: Modeled contributions from residential woodburning to annual average $PM_{2.5}$ concentrations across the Bay Area. The same levels are plotted as contours in Figure B3.2. Compare to Figure B1.9 ($PM_{2.5}$ emissions).

B3 Impacts on Annual Average $PM_{2.5}$ Exposure

This section analyzes the levels and distributions of annual average exposures (modeled outdoor concentrations weighted by residential population) attributed to modeled emissions from residential wood burning in the Bay Area. The impacts evaluated in this analysis are taken to be equivalent to the difference between a baseline scenario and a control scenario, in which the latter represents a world where wood is no longer burned in indoor fireplaces or wood stoves. As described in Appendix B1, modeled sources of emissions do not include outdoor wood burning.

B3.1 Modeled Residential Population

The study area included the portions of the 9-county Bay Area that are under the jurisdiction of the Bay Area Air Quality Management District, as illustrated in Figure B3.2. The modeled population is displayed in dot-density form; at a close enough zoom level (not shown), each dot would represent one resident. Dots are colored according to race/ethnicity. Analyses by race/ethnicity are the subject of section B3.3.

The modeled population was projected by BenMAP (PopGrid) for the year 2020, using Census 2010 data as a base year. This population was estimated to be approximately 7.7 million residents. A breakdown by county and race/ethnicity, using categories supplied by BenMAP/PopGrid, is given in Table B3.1. The focus in this section, motivated by the results of the health impact modeling, is on differences in annual average $PM_{2.5}$ impacts for those groups.

Table B3.1: Modeled residential population. Percentages are row-wise; they indicate shares of that county's population. Basis: BenMAP/PopGrid projection from 2010 to 2020.

	Hispanic	**White**	**Asian**	**Black**	**(all)**
Alameda	24.3%	32.1%	32.6%	11.0%	*1,668,288*
Contra Costa	28.7%	43.6%	18.5%	9.2%	*1,180,542*
Marin	18.3%	71.1%	7.4%	3.2%	*266,423*
Napa	36.8%	52.5%	8.5%	2.3%	*147,529*
San Francisco	15.1%	45.1%	34.6%	5.2%	*866,833*
San Mateo	26.6%	39.1%	31.5%	2.7%	*797,392*
Santa Clara	27.7%	31.2%	38.3%	2.8%	*1,991,129*
Solano	27.8%	33.2%	21.7%	17.3%	*311,744*
Sonoma	30.5%	61.7%	5.6%	2.2%	*461,953*
(all)	*25.6%*	*39.4%*	*28.6%*	*6.4%*	*7,691,372*

B3.2 Exposures to $PM_{2.5}$ from Residential Wood Burning

Annual average exposures were computed for this analysis using weighted averages of 1x1 km grid-cell concentrations, with the modeled population (also on the same 1x1 km grid) used for weighting. This is consistent with the approach taken in most large-scale epidemiological studies of outdoor air pollution, and provides a basis for health impact modeling (Appendix B4).

A notable limitation of this approach—especially in the context of residential wood burning—is that it will not capture variability in peak exposures, as might be experienced during wintertime, when emissions are higher and meteorological conditions are more conducive to local accumulations of $PM_{2.5}$.

Figure B3.2 displays contours derived from the modeled $PM_{2.5}$ concentration data shown in Figure B2.2. The outermost contour represents a contribution of 0.1 μg/m^3 from residential wood burning. This amount is on the order of 1% of the population-weighted annual average from all modeled sources, including sources outside the study area.

On average, approximately 0.34 μg/m^3 of annual average $PM_{2.5}$ exposure was attributed to residential wood burning (Table B3.2).

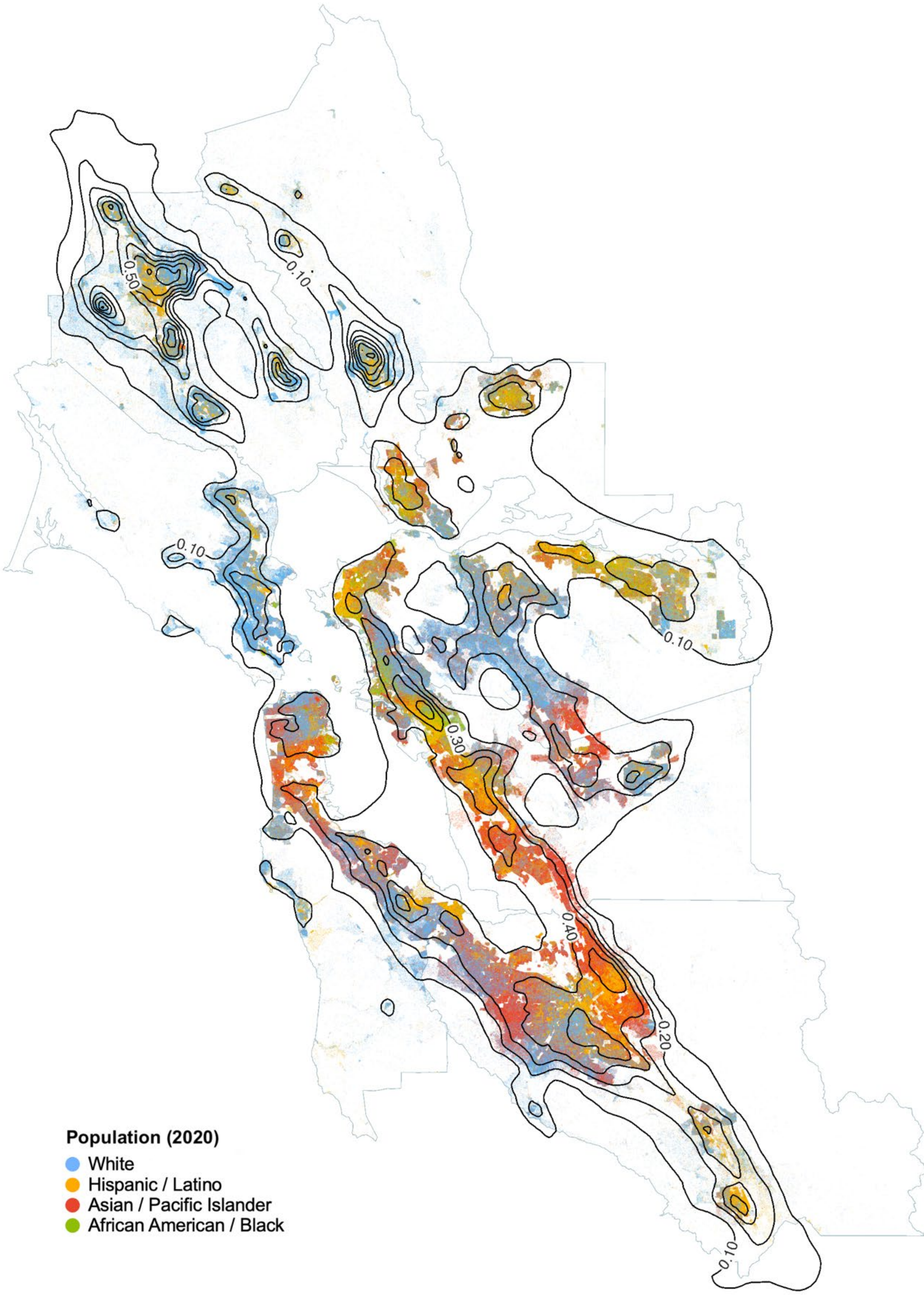


Figure B3.2: Residential wood burning contributions to annual average $PM_{2.5}$ concentrations, overlaid on modeled residential population (colored dots). The lowest contour represents a contribution of +0.1 μg/m^3.

B3.3 Differences Between Racial/Ethnic Groups

If residential wood burning were to be eliminated, the modeling conducted by staff indicates that benefits would accrue to all four modeled racial/ethnic groups. Benefits vary by county and by race/ethnicity, with much more of the variation at this level explained by county rather than race/ethnicity (Table B3.2).

Table B3.2: Modeled contributions of residential wood burning to annual average $PM_{2.5}$ exposure levels (outdoor concentrations, weighted by residential population).

	Hispanic	White	Asian	Black	(average)
$PM_{2.5}$ (Total), µg/m³					
Alameda	0.38	0.34	0.35	0.37	*0.36*
Contra Costa	0.26	0.24	0.24	0.24	*0.25*
Marin	0.27	0.24	0.25	0.24	*0.24*
Napa	0.49	0.43	0.34	0.34	*0.44*
San Francisco	0.24	0.23	0.23	0.24	*0.23*
San Mateo	0.30	0.29	0.25	0.29	*0.28*
Santa Clara	0.44	0.40	0.41	0.43	*0.42*
Solano	0.31	0.28	0.28	0.30	*0.29*
Sonoma	0.53	0.46	0.50	0.52	*0.49*
(average)	*0.37*	*0.32*	*0.33*	*0.33*	0.34

At a regional level, this modeling does not indicate that eliminating residential wood burning would substantially contribute to either narrowing or widening the persistent gap between white residents and people of color in the Bay Area, at least in terms of annual average $PM_{2.5}$ exposure at a regional level. For the baseline scenario (Figure B3.3, left side), there was a spread of 0.6–0.7 µg/m³ between the modeled racial/ethnic groups. With zero wood burning emissions (Figure B3.3, right side), this remained essentially unchanged.

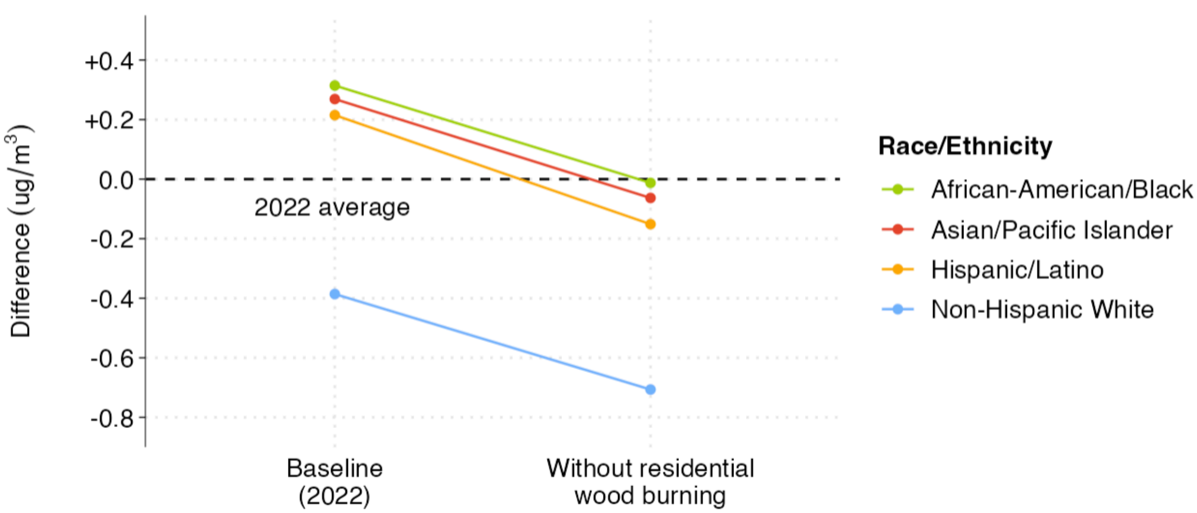


Figure B3.3: Differences in modeled annual average $PM_{2.5}$ exposures (annual average ambient concentrations, weighted by residential population).

B4 Impacts on Selected Health Endpoints

B4.1 Approach to modeling health impacts

BenMAP-CE, version 1.5.8.11 (https://www.epa.gov/benmap), was used to evaluate the health impacts of $PM_{2.5}$ from residential woodburning emissions. BenMAP-CE was designed to estimate changes in human health due to changes in ambient air quality for specific populations and to estimate conventional valuations of these impacts. The valuation process considers the direct and indirect costs of illnesses as well as the willingness to pay (WTP) to avoid premature death. Direct costs include actual medical costs and lost working hours, while indirect costs reflect WTP to avoid pain and suffering.

Changes in air quality provided to BenMAP-CE as inputs were the differences in annual average modeled $PM_{2.5}$ levels with and without residential woodburning emissions. In other words, it is the estimate of annual average $PM_{2.5}$ levels due to emissions from this source sector, Figure B2.2.

B4.2 Application of BenMAP-CE

We downloaded the U.S. EPA's latest released version of BenMAP-CE (released in May 2021, https://www.epa.gov/sites/default/files/2021-04/u.s._epa_approach_for_quantifying_and_valuing_pm_effects_0.zip) and added three health impact functions to the U.S. EPA–recommended set of health impacts functions available in BenMAP-CE to ensure that the premature mortality endpoint in the Bay Area was evaluated rigorously. Two of the added functions are based on California-wide and nationwide analyses of a 1980–2000 cohort (Jerrett et al., 2013). The third added function is a meta-analysis summarizing 53 single studies, 17 of which have been published since 2015 (Vodonos et al., 2018).

We ran BenMAP-CE and aggregated its 1-km grid results to within the District's jurisdiction.

B4.3 BenMAP-CE Results

The aggregated results (Table B4.1) show that annual average $PM_{2.5}$ concentrations from residential woodburning could cause incidence of premature mortality within the District's jurisdiction ranging from 94 to 210 cases per year. (The range reflects different epidemiological studies.) The corresponding valuation[48] (in 2020 U.S. dollars) is 960 to 2,200 million U.S. dollars per year. Among the set of endpoints we evaluated, avoided premature mortality accounts for over 95% of this valuation.

[48] Valuations are not identical to cost savings. Some valuations are based on cost savings, but the most highly valued component (mortality) is based on an estimate of willingness to pay (WTP).

The other health endpoints in the EPA's recommended configuration include selected chronic/severe illnesses, hospital admissions/emergency room visits due to respiratory and cardiovascular diseases, selected minor health effects, and asthma-related effects. The endpoints we evaluated showed annual incidences because of estimated residential woodburning emissions. For example, 10 to 93 non-fatal acute myocardial infarctions (heart attack) could have been caused from residential woodburning emissions in 2022. Again, the range reflects different epidemiological studies. The associated valuation is estimated to be 0.89 to 8.2 million U.S. dollars. Another estimated impacts of residential woodburning emissions is 16,000 lost days of work, valued at 4.4 million U.S. dollars.

Table B4.1: Estimated health impacts of residential woodburning emissions.

Health Impact[49]	Incidences	Valuations in 2020 US Dollars, Million Dollars Per Year
Premature mortality		
All causes[50]	94–210	960–2,200
Chronic/severe illness		
Non-fatal acute myocardial infarction (heart attack)	10–93	0.89–8.2
Hospital admission, neurological[51]	30	0.44
Incidence, out of hospital cardiac arrest	1.8	0.074
Incidence, stroke	6	0.24
Incidence, lung cancer	7.6	0.22
Hospital admissions[52]		
Respiratory[53]	9.2	0.11
Cardiovascular[54]	12	0.22
ER visits		
Respiratory[55]	51	0.051
Cardiovascular[56]	25	0.033
Minor effects		
Minor restricted activity days	95,000	7.7
Work loss days	16,000	4.4
Hay fever/allergic rhinitis	1,800	1.3
Asthma-related effects		
Asthma symptoms/albuterol use	37,000	0.015
Onset of asthma	290	15
Sum		
All health endpoints included	–	990–2,200

[49] Each health impact is associated with one or more unique International Classification of Diseases-9-Clinical Modification (ICD-9-CM) code(s).
[50] Includes all ICD-9 codes.
[51] First hospital admission (cause-specific, to indicate onset of the chronic disease) for dementia, Alzheimer's disease, or Parkinson's disease (ICD-9 codes 290, 331.0, or 332, respectively), and other cardiovascular morbidities.
[52] Hospital admissions due to acute exposure to air pollution are assumed to pass through the emergency room; however, the calculated value of hospital admissions does not account for the cost incurred in the emergency room visit. This strategy avoids double counting.
[53] Includes all respiratory diseases (ICD-9 codes 460–519).
[54] Includes cardio-, cerebro-, and peripheral vascular diseases (ICD-9 codes 410, omitting 410.x2; 410–414; 426–427; 428; 429; 430–438; 440–448).
[55] Includes respiratory diseases (ICD-9 codes 480–486, 491, 492, 496, 460–465, 466, 477, 493, 786.07).
[56] Includes all cardiac outcomes (ICD-9 codes 390–549).

B5 Discussion and Limitations of Modeling Approach

B5.1 Interpreting Maps of Modeled Activity and Emissions

Apparent "hot spots" in maps of modeled activity and emissions (Figures B1.6, B1.7, and B1.9) should be interpreted with caution. These are estimates, not observations or measurements. Maps of modeled estimates will imperfectly reflect true differences for many reasons. Broader spatial patterns are expected to be more reliable than differences within ZIP codes Even so, there can be limitations in the broader patterns as well.

Apart from differences in population density, these maps mainly reflect variation in the surveyed distributions of active devices, typical winter burning frequencies, and typical amounts of wood burned during winter months. Unmeasured or unmodeled factors, such as differences in the predominant types and qualities of wood, could result in additional geographical variation. Also, the trained statistical models are also better able to predict ZIP code level variation across northern counties. These have been more intensively surveyed, and therefore have more data available on a per-household basis.[57] Some areas, particularly dense urban centers such as Oakland or downtown San Francisco, may show higher-than-actual average emissions due to limitations in survey design and precision combined with a high spatial density of occupied households.[58]

Considering wood stove emissions specifically, apparent hot spots may additionally result from the reallocation of wood stove emissions via a spatial surrogate. Because this particular surrogate is based on the relative density of households reporting wood as their primary heating fuel, it will tend to shift emissions from areas where wood burning is more aesthetic or supplemental to areas where it serves fundamental heating needs, often rural areas and smaller towns. Staff evaluated the merits of a more survey-driven approach for wood stoves, but as discussed in the preceding sections, this was impeded by the amount of data available; it was feasible for fireplaces because they are more common. In most areas, PM2.5 emissions from fireplaces dominate those from wood stoves, so maps of total $PM_{2.5}$ emissions are less affected. County-level totals are not affected at all. The surrogate is a refined version of the one provided by CARB, so it is consistent with the practices of CARB and other districts. Future work may improve on the approach.

B5.2 Reliance on Wood for Heat

Staff obtained data from the American Community Survey (ACS) concerning the number and proportion of households in the Bay Area for whom the most-used heating fuel is wood.[59] This was used to create a refined surrogate for wood stove activity and emissions, as described in the

[57] This is for reasons having to do with the STA survey's historical purpose and design. During any given year, a uniform 1/9th of the total sample has been allocated to every county, rather than a slice proportional to the number of households. For more, please see the technical documentation (forthcoming).
[58] When multiplied by a large number of households, a small relative error in a proportion will yield a large absolute error in the resulting quantity.
[59] Table B25117, "Tenure By House Heating Fuel". Question 13 asks, at occupied housing units: "Which FUEL is used MOST for heating this house, apartment, or mobile home?" Available choices are: "Gas: from underground pipes serving the neighborhood"; "Gas: bottled, tank, or LP"; "Electricity"; "Fuel oil, kerosene, etc."; "Coal or coke"; "Wood"; "Solar energy"; "Other fuel"; or "No fuel used".

section B1. It may be taken as an upper bound on the number of "sole source of heat" households, since anyone for whom wood is a sole source of heat should respond to this question by listing it as their primary heating fuel. One may also reasonably expect some correlation between this Census-based measure of "reliance on wood for heat" and the "wood stove and pellet stove activity" measured by the STA survey, although the latter will include more users. Additionally, the downward trend observable in Figure B1.10 appears compatible with the survey-based observations of declining rates of wood stove and pellet stove activity since 2010 (section B1).

Table B1.6: Bay Area households reporting that "wood" serves as their primary heating fuel. Basis: 5-year American Community Survey (ACS), covering the period 2018–2022.

	Wood As Primary Heating Fuel	
County	**Households**	**Fraction**
Alameda	1,182 ± 292	0.20% ± 0.05%
Contra Costa	1,885 ± 480	0.46% ± 0.12%
Marin	1,137 ± 322	1.10% ± 0.31%
Napa	897 ± 229	1.82% ± 0.47%
San Francisco	235 ± 119	0.07% ± 0.03%
San Mateo	828 ± 285	0.31% ± 0.11%
Santa Clara	1,771 ± 452	0.27% ± 0.07%
Solano	1,317 ± 400	0.85% ± 0.26%
Sonoma	6,306 ± 811	3.33% ± 0.43%
	15,558 ± 1,261	0.56% ± 0.05%

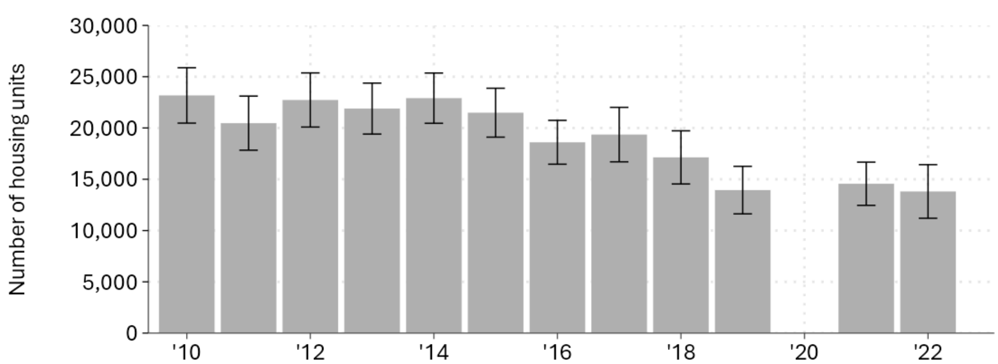


Figure B1.10: Bay Area households reporting that "wood" serves as their primary heating fuel. Basis: 1-year American Community Survey (ACS), showing 95% margins of error. Note: the 2020 wave was not released by the Census, due to issues with response rates.

B5.3 Completeness of Modeled Exposures, Inequities, and Health Impacts

No assessment can accurately reflect all aspects of the real world. For this modeling-based assessment, it is worth noting several limitations of the conceptualization of (a) exposure, (b) inequity, and (c) health impacts. These are traceable to limitations in knowledge, limitations inherent in a modeling-based approach, and limitations in the availability of technical resources, including staff time. It is important to note these limitations, especially insofar as they mean that the set of health impacts modeled is incomplete, and therefore represents at best a lower bound on the true costs of residential wood burning.

Some aspects of exposure, such as peak exposures during wintertime (for example, maximum 24 hour exposures, or number of days exceeding a certain level), can be more challenging to accurately quantify via modeling, and were not modeled here. Direct indoor pathways of exposure were also not modeled—only the population-level impacts from pollution that is vented to the outdoors via a chimney. Finally, some components of woodsmoke emissions, such as toxic air contaminants (TACs), were not modeled. Only annual average exposures to $PM_{2.5}$ were modeled, but actions to reduce wood burning activity would generally stand to reduce these other aspects of woodsmoke exposure as well.

The analysis of inequity has its own limitations. This analysis focused on differences between four major racial/ethnic groups, but did not have sufficient power to examine differences for smaller groups, such as Indigenous residents. Dimensions of inequity and vulnerability other than race and ethnicity could also prove important, but were not examined here due to limited resources. Such dimensions could include, for example: rural/urban status; housing quality; poverty; age; education; language; and so on.

The set of health endpoints modeled is also necessarily incomplete. Multiple forms of scientific evidence support the knowledge that $PM_{2.5}$ exposure contributes to the health endpoints listed in Table B4.1. Weaker (but in many cases, growing) evidence supports relationships with other health endpoints; although those did not yet meet the criteria for inclusion in this analysis, that does not mean the true set of effects is limited to those shown in Table B4.1. The set of estimates in Table B4.1 may therefore be regarded as a lower bound on the true and complete scope of health impacts caused by $PM_{2.5}$ exposure. Finally, as mentioned above, only $PM_{2.5}$ exposure was modeled; therefore, the health burden attributable to other pollutants, such as toxic air contaminants, is also missing from the scope of this analysis.

B6 References

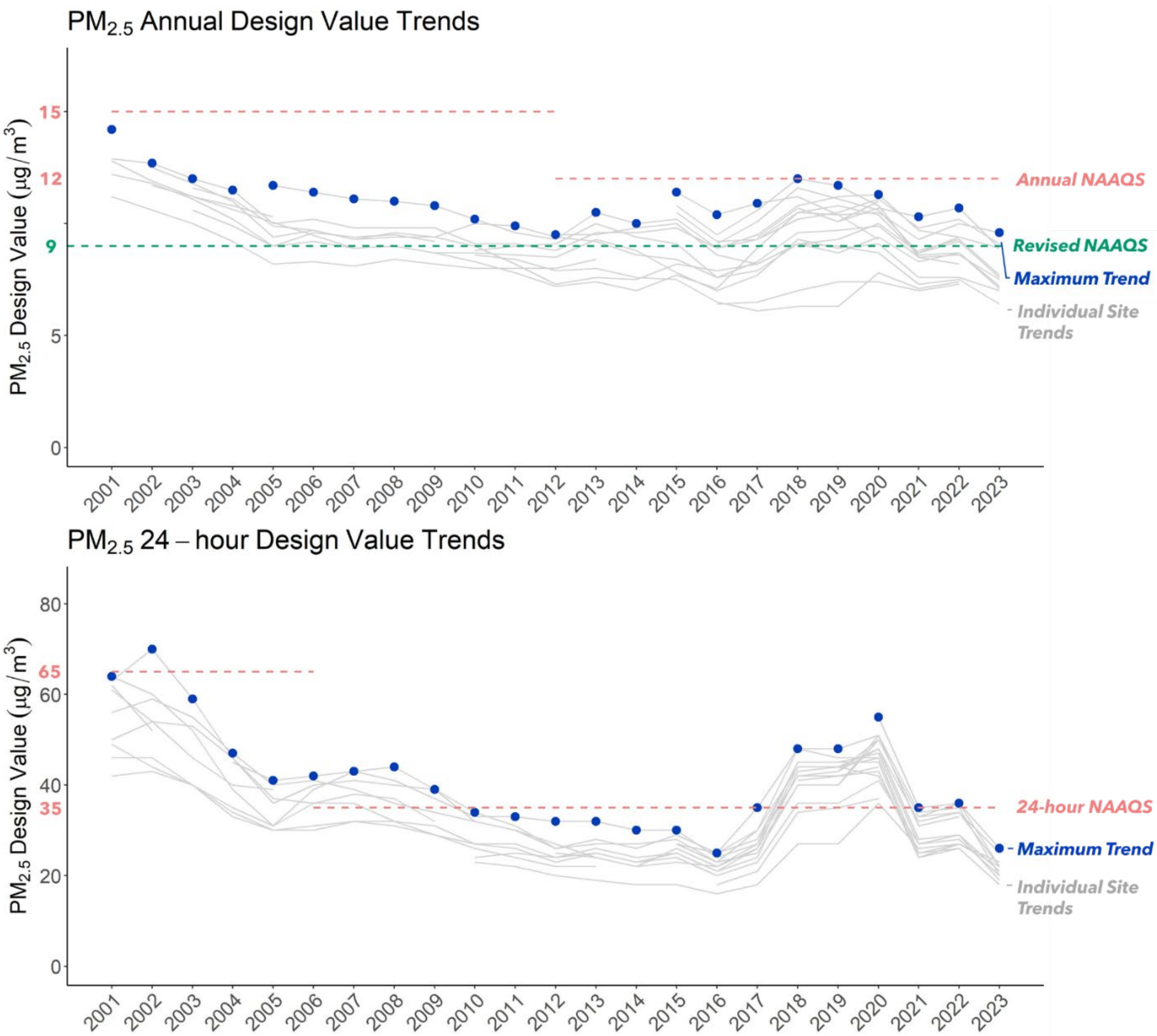
Jerrett, M., Burnett, R.T., Beckerman, B.S., Turner, M.C., Krewski, D., Thurston, G., et al., 2013: Spatial Analysis of Air Pollution and Mortality in California. Am J Respir Crit Care Med 188(5):593-59. https://doi.org/10.1164/rccm.201303-0609OC

Tanrikulu, S., Reid, S., Koo, B., Jia, Y., Cordova, J., Matsuoka, J., and Fang, Y., 2019: Fine Particulate Matter Data Analysis and Regional Modeling in the San Francisco Bay Area to Support AB 617. BAAQMD Air Quality Modeling and Data Analysis Section Publication No: 201901-017-PM.

Vodonos, A., Awad, Y.A., and Schwartz, J., 2018: The Concentration-response between Long-term PM2.5 Exposure and Mortality; A Meta-regression Approach. Environmental Research 166:677-89. https://doi.org/10.1016/j.envres.2018.06.021

Appendix C – Air Monitoring Information

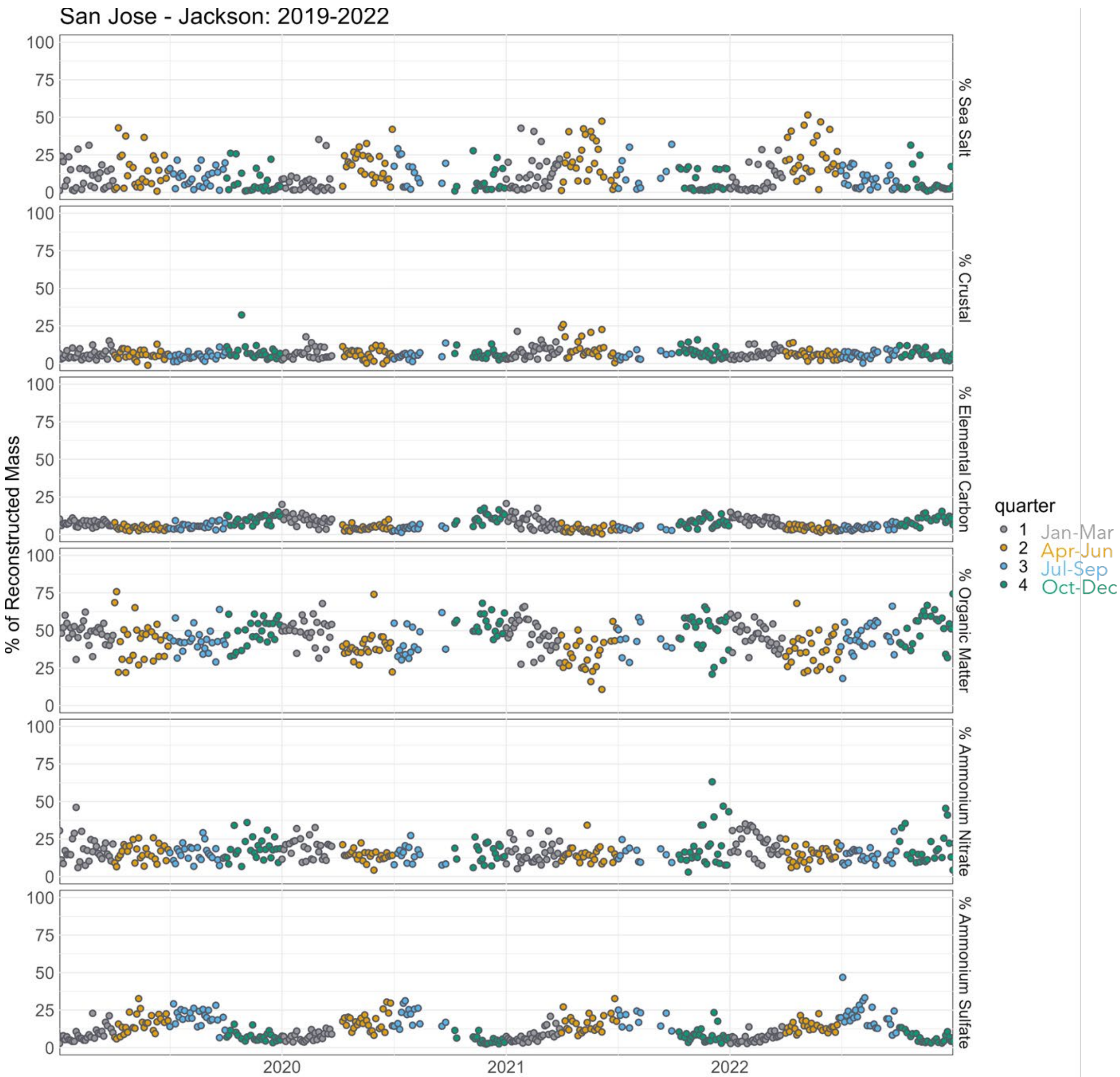
Figure C1. PM2.5 Design Value Trends



Detailed Description*: The plots above show PM2.5 design values for both the annual and 24-hour NAAQS over the last 23 years. Design Values are statistical metrics using three years of data used to compare air monitoring data to the NAAQS. For example, the 2023 design value is an average of data from 2021, 2022, and 2023. The annual design value is a 3-year average of the annual mean, while the 24-hour design value is a 3-year average of the ranked 98th percentile value for each year. Air District began monitoring PM2.5 in 1999, therefore the first valid design value for consideration is 2001. These data include days that may have been affected by wildfire smoke and represent the actual PM2.5 exposure to Bay Area communities and allows comparison of PM2.5 concentrations over time.*

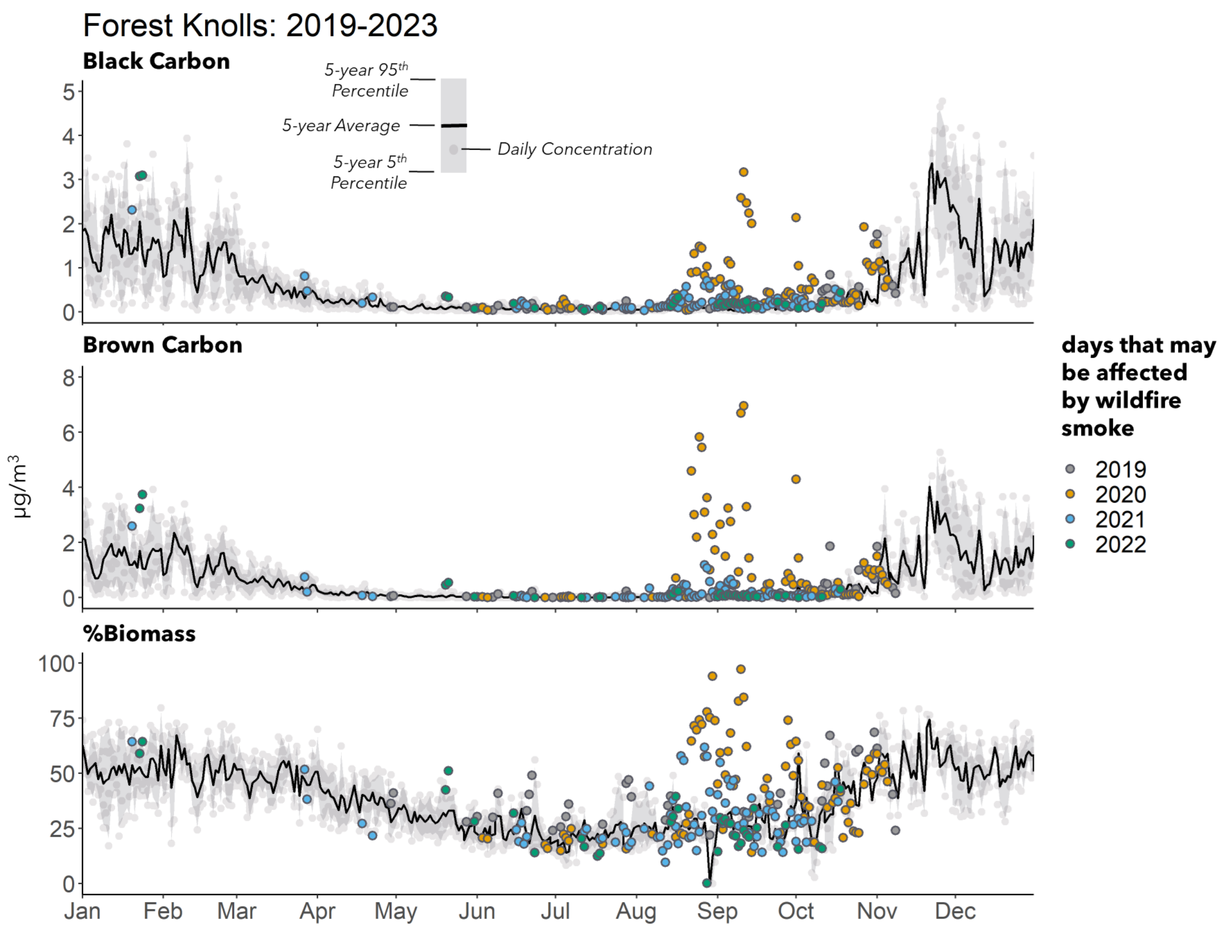
Recent trends in the $PM_{2.5}$ speciation data at San Jose-Jackson do not show a decrease in peak concentrations of major components associated with woodsmoke, suggesting that we do not have evidence that short term woodsmoke impacts are on a declining trend. (Figure C2)

Figure C2. Daily PM2.5 Speciation Trends



Detailed Description*: The plots above show the % of the total reconstructed mass for 24-hour average PM2.5 speciation data from the San Jose – Jackson monitoring site for each of the six major components (sea salt, crustal, elemental carbon, organic matter, ammonium nitrate, and ammonium sulfate). The raw speciation data was used to calculate six major components for the most recently available 4-years of data (2023 speciation data is currently not available yet). The reconstructed mass is the sum of the six major components. The reconstructed mass does not include all the parameters measured in a sample and, therefore, is typically less than the total PM mass measured by Air District PM2.5 Federal Reference Methods (FRMs) and Federal Equivalent Methods (FEMs). The individual % of components were calculated after removing days that may have been affected by wildfire and represent PM2.5 concentrations that are estimated to be largely anthropogenic. Elemental carbon and organic matter are both associated with combustion of fossil fuels and non-fossil fuels, including residential woodsmoke and wildfires. These data are colored by calendar quarter, as identified in the legend, which allows comparison of concentrations from different times of the year over time.*

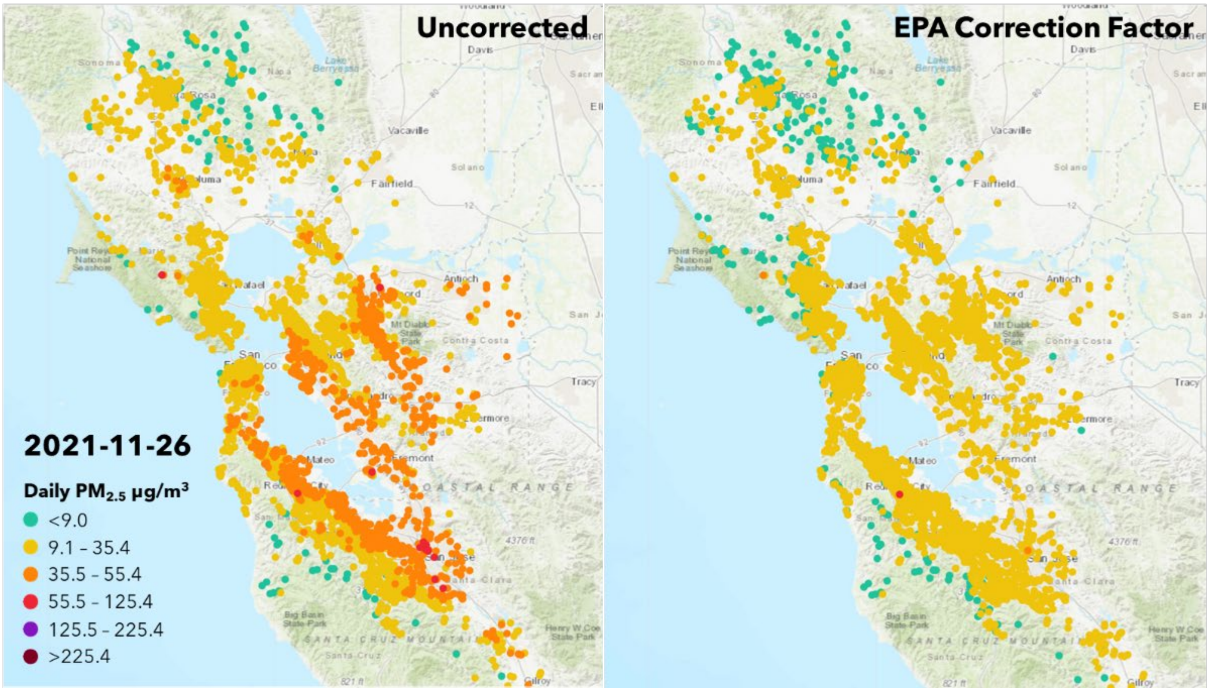
Figure C3. Daily Average Aethalometer Parameters at Forest Knolls

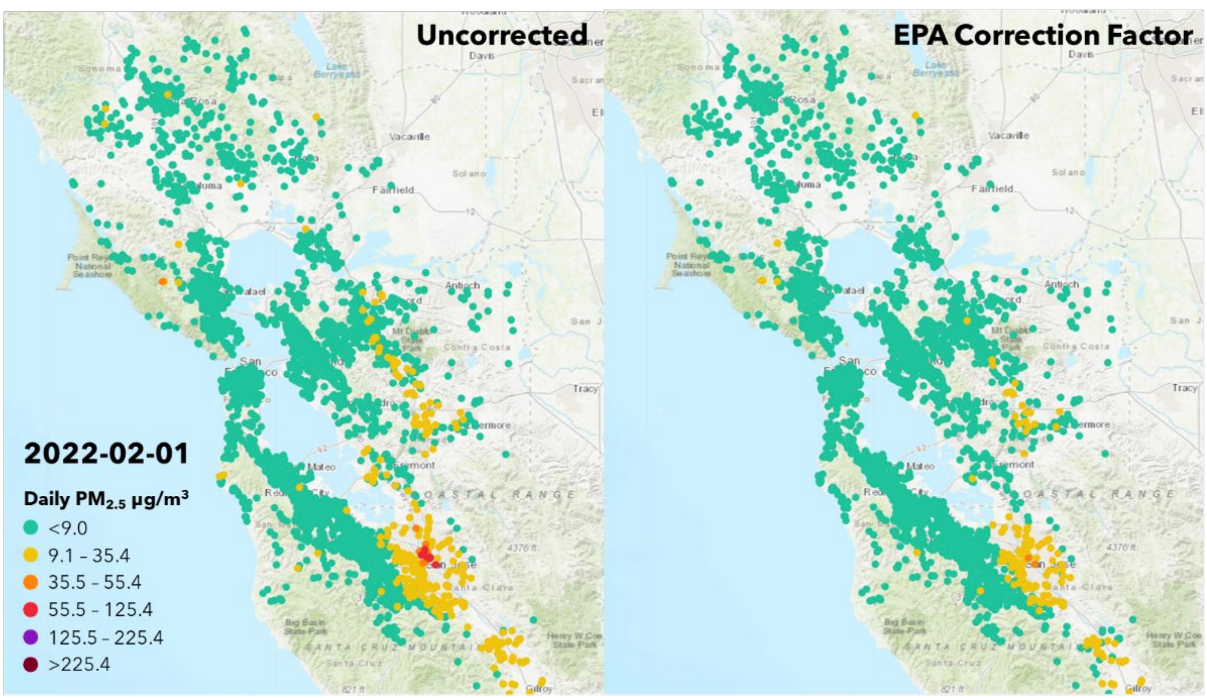


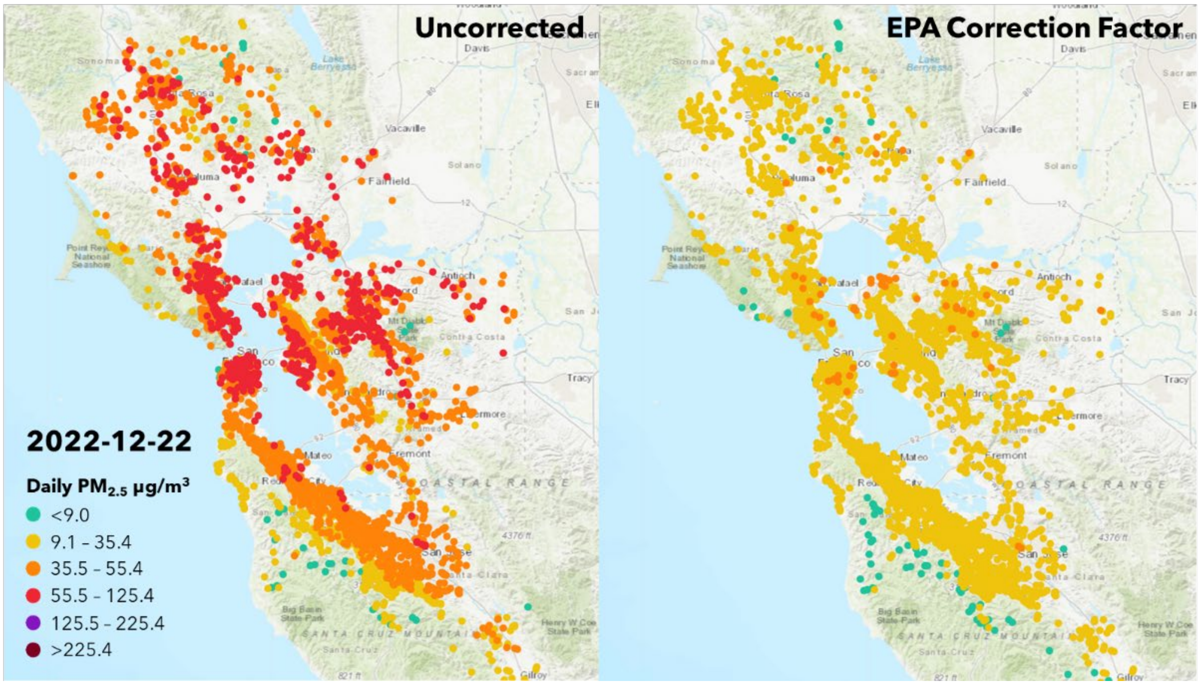
***Detailed Description**: The plots above show 24-hour measurements from a multi-wavelength aethalometer averaged over the last 5-years by Julian date for selected parameters. Black carbon is measured by absorption at 880 nm. Brown carbon is calculated by subtracting the absorption measured at 370 nm from the absorption measured at 880 nm (brown carbon = 880 nm – 370 nm)[60]. %Biomass represents an estimate of how much black carbon is attributable to biomass burning[61]. The averaged data and associated 5th and 95th percentiles shown as black lines and gray shading were calculated after removing data that may have been affected by wildfire and represent black carbon concentrations that are estimated to be largely anthropogenic. The data that may have been affected by wildfire that was removed from those calculations are shown as single points colored by the year (noted as "wildfire year" in the legend), which allows comparison of black and brown carbon concentrations associated with wildfire and those associated with anthropogenic sources of air pollution, including woodsmoke emissions.*

[60] Sparks, T.L., Wagner, J. (2021). Composition of particulate matter during a wildfire smoke episode in an urban area. *Aerosol Science and Technology*, 55:6, 734-747. https://doi.org/10.1080/02786826.2021.1895429
[61] Sandradewei, J, et.al. (2008). Using Aerosol Light Absorption Measurements for the Quantitative Determination of Wood Burning and Traffic Emission Contributions to Particulate Matter. *Environ. Sci. Technol.*, 42, 9, 3316–3323. https://doi.org/10.1021/es702253m

Figure C4. Daily PM2.5 Spatial Patterns







Detailed Description: *The maps above show 24-hour average $PM_{2.5}$ concentrations from publicly available PurpleAir sensors throughout the Bay Area. The "Uncorrected" map on the left includes raw, uncorrected 24-hour average $PM_{2.5}$ concentrations, while the "EPA Correction Factor" map on the right includes 24-hour average $PM_{2.5}$ concentrations that have been adjusted with EPA's national correction factor that was developed for the EPA Fire & Smoke Map that attempts to account for some of the sensor bias due to wildfire smoke and other factors[62]. While the data are binned by the new AQI breakpoints[63] in the PM NAAQS final rule, the absolute concentration levels should be viewed cautiously and in context with other available information. For this specific use-case, the utility of these data is focused on how the sensor concentrations compare to each other from place-to-place to identify spatial patterns and locations where $PM_{2.5}$ is comparatively higher than others. Additionally, since we know that some of the PurpleAir bias comes from how the sensors respond to differences in the optical properties of the particles associated with wildfire smoke, we can look at the raw and adjusted data side-by-side and interpret that some of the difference between these maps may be caused by the presence of woodsmoke (assuming woodsmoke has similar characteristics to wildfire smoke).*

Day-Specific Details:

Date	***Max $PM_{2.5}$ Concentration at Air District Monitoring Site ($\mu g/m^3$)***	***Woodsmoke Indicators***
2021-11-26	*28*	*Black & brown carbon > 5-year, non- wildfire 98th percentile*

[62] Barkjohn, K, et.al. (2021). Development and application of a United States-wide correction for $PM_{2.5}$ data collected with PurpleAir sensor. *Atmos. Meas. Tech., 14, 4617–4637.* https://doi.org/10.5194/amt-14-4617-2021

[63] Reconsideration of the National Ambient Air Quality Standards for Particulate Matter, Final Rule, 89 FR 16404

		Elevated hourly $PM_{2.5}$ during evening and early morning
2022-02-01	*23*	*Black carbon > 5-year, non- wildfire 98^{th} percentile*
		Elevated $PM_{2.5}$/CO enhancement ratios
		Elevated hourly $PM_{2.5}$ during evening and early morning
2022-12-22	*37*	*Black & brown carbon > 5-year, non- wildfire 98^{th} percentile*
		Elevated $PM_{2.5}$/CO enhancement ratios
		Elevated hourly $PM_{2.5}$ during evening and early morning

Table C1. Average Annual Number of Days with 24-hour $PM_{2.5}$ Levels Above Different Thresholds over Five Years (2018-2022) by Monitoring Site and across all sites. The values shown for All Sites are greater than for any individual monitoring site because different monitoring sites may record $PM_{2.5}$ levels above a given threshold on different days.

Monitoring Site	Average annual number of non-fire days with 24-hr $PM_{2.5}$ > 25 µg/m^3 (2018-2022)	Average annual number of non-fire days with 24-hr $PM_{2.5}$ > 35 µg/m^3 (2018-2022)
Sebastopol	0.6	0
Napa	0.4	0
San Rafael	1.4	0.2
Vallejo	3.4	0.2
San Pablo	2.6	0.4
Concord	1.6	0.4
San Francisco	1.8	0.2
Berkeley	1	0
Oakland – West	3.2	0.2
Oakland – Laney	3.2	0.6
Oakland – East	1.2	0
Pleasanton	0.8	0
Livermore	1.2	0.2
Redwood City	0.7	0
San Jose – Jackson	5.4	0.8
San Jose – Knox	4.8	0.6
Gilroy	0	0
All Sites	9.8	1.8

***Detailed Description**: The values in the table above were calculated after removing days that may have been affected by wildfire and represent days when measured $PM_{2.5}$ concentrations were estimated to be largely anthropogenic. Currently, Spare the Air Alerts for $PM_{2.5}$ are issued when 24-hour $PM_{2.5}$ concentrations are forecasted to be above 35 µg/m^3. Days above 35 µg/m^3 now occur infrequently outside wildfire smoke periods (largely due to overall reductions in woodsmoke and other emissions that contribute to $PM_{2.5}$ since the time the rule was first implemented), with an average of only about two days per year across all monitors. Days with $PM_{2.5}$ concentrations above a lower threshold of 25 µg/m^3 were also relatively uncommon, with an average of about 10 days per year. The San Jose – Jackson, San*

Jose – Knox, Vallejo, Oakland – West, Oakland – Laney, and San Pablo monitoring sites recorded more days with relatively higher levels of $PM_{2.5}$ *compared to other monitoring sites. Given the infrequent occurrence of days above the current STA threshold, the efficacy of the rule is limited, and moving to a lower* $PM_{2.5}$ *threshold for initiating burn curtailment would further reduce woodsmoke emissions.*