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Wildfire Smoke Exposure and Health Impacts for Outdoor Building Construction Workers in California

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Exposure to wildfire-related smoke has serious implications for the health outcomes of outdoor occupational workers. As wildfire season is becoming more prolonged in California, outdoor building construction workers are at great risk of exposure to particulate matter ($PM_{2.5}$) pollution caused by wildfire smoke. Wildfire smoke $PM_{2.5}$ exposure has been shown to result in short-term health impairments, missed workdays, and long-term disease progression. Studies highlighting the exposure of outdoor building construction workers to wildfire-related $PM_{2.5}$ is limited in the existing literature. Using historical wildfires data, employment data of outdoor building construction workers, and air quality data for $PM_{2.5}$ pollution from 2010-2020, this paper investigates the potential exposure of outdoor building construction workers to wildfire smoke $PM_{2.5}$ in California. Counties which experienced wildfire events were identified by intersecting wildfire perimeters with county boundaries using the geospatial analysis software ArcGIS. Monthly employment during wildfire months and the number of days when the $PM_{2.5}$ air quality reached unhealthy levels during those months were evaluated to find the worker smoke exposure days of each county. Results show that outdoor building construction workers in California are vulnerable to wildfire $PM_{2.5}$ exposure and associated health risks, as the typical wildfire season aligns with peak seasonal construction work.

Key Words: Wildfire, Outdoor worker health, Building construction, California

Introduction

Wildfires have been growing in frequency and severity across the Western U.S. over the past two decades. California has been particularly hard hit by recent wildfires, with longer fire seasons engulfing more acres and affecting larger geographical territories within the state annually (S. Li & Banerjee, 2021). For example, in 2021 over 10,000 wildfires burned approximately 2 million acres of land in California and over half of the top 20 largest wildfires in California history occurred in the past decade (CALFIRE, 2022). Wildfires also pose a public health risk due to poor air quality generated by wildfire smoke, especially for people working outdoors (Liu et al., 2021). Wildfire smoke contains multiple hazardous elements such as gaseous pollutants (e.g., carbon monoxide and nitrogen dioxide), hazardous air pollutants (HAPs) (e.g., polycyclic aromatic hydrocarbons),

particulate matter (PM), and other volatile compounds (U.S. Environmental Protection Agency, 2021). In the U.S., wildfires serve as a major source of $PM_{2.5}$ particles (O'Dell et al., 2019), which are fine particulate matter less than 2.5 micrometers in diameter suspended in the air. Wildfire-related $PM_{2.5}$ is considered a major health risk because of its higher toxicity compared to other hazardous pollutants (Yu et al., 2022) and its ability to deeply penetrate human lung tissue and impair the functionality of vital organ systems (Aguilera et al., 2021; Cleland et al., 2021). Annual wildfire $PM_{2.5}$ emissions have been increasing across California with annual emission levels peaking at over 12.1 $\mu g/m^3$ in 2020 – the highest level recorded in the past decade – and higher than the U.S. average annual emissions (7.6 $\mu g/m^3$) and World Health Organization (WHO) recommendations (5.0 $\mu g/m^3$) (California Air Resources Board, 2021). During a wildfire event outdoor workers involved in emergency work (e.g., emergency responders and cleanup crews) and non-emergency work (e.g., construction, utility, and agricultural occupations) are at high risk of wildfire smoke exposure in the workplace (Center for Disease Control and Prevention, 2021).

Outdoor workers comprise about 30% of the total U.S. construction industry labor force (U.S. Bureau of Labor Statistics, 2017). As of the first quarter of 2022, approximately 265,000 outdoor construction workers were employed in California. According to a recent report by the Legislative Analyst's Office of California (LAO, 2022), outdoor construction workers in California are more likely to get exposed to wildfire $PM_{2.5}$, which is associated with health hazards such as asthma, cardiovascular disease, and cognitive impairment. Due to increasing wildfire events and $PM_{2.5}$ exposure for outdoor workers, the California Division of Occupational Safety and Health (Cal/OSHA) passed regulations in 2019 aimed at protecting workers from wildfire smoke particulates (Cal/OSHA, 2021) and applies to workplaces where the Air Quality Index (AQI) for $PM_{2.5}$ exceeds above 150. While some studies have examined wildfire smoke health risks and exposure levels to certain occupations (e.g., farm workers), there are limited studies documenting the exposure of outdoor building construction workers to wildfires.

Literature Review

Occupational exposure to poor outdoor air quality and human health consequences have been discussed in the existing literature. Outdoor workers exposed to any type of $PM_{2.5}$ are at increased risk for Parkinson's disease (Kirrane et al., 2015), reduced lung function (Sehgal et al., 2015), carcinogenic exposure (P. Li et al., 2019), cardiovascular impairment (Zhang & Routledge, 2020), respiratory health disorders (Sundram et al., 2022), and premature mortality (Cleland et al., 2021). Marlier et al. (2022) also found that repeated $PM_{2.5}$ exposure over time led to increased air quality sensitivity. Across all industries, workers spending a greater length of time outdoors are exposed to significantly higher amounts of $PM_{2.5}$ than indoor workers (Tovalin-Ahumada et al., 2007). Negative health impacts from wildfire smoke are more pronounced in populations living in close proximity to wildfire activity, but the effects can be seen in populations miles away from an active wildfire zone (Matz et al., 2020). Stowell et al. (2019) found significant associations between wildfire smoke and acute respiratory outcomes in Colorado. Liu et al. (2021) correlated increases in mortality with increased $PM_{2.5}$ exposure to wildfire smoke during the 2020 Washington wildfires. Sorensen et al. (2021) studied wildfire-related $PM_{2.5}$ exposures in relation to Intensive Care Unit (ICU) admissions in the U.S. and found that a 10 micrograms per cubic meter increase in daily wildfire $PM_{2.5}$ was associated with an over 2.7% increase in ICU admissions five days later.

Outdoor construction workers currently experience a high risk of wildfire smoke exposure, a vulnerability that is expected to increase in the future as wildfire events increase in frequency and severity across the Western U.S. For example, in a study of worker injury claims in Oregon from 2009 to 2018, Evoy et al., (2022) found that wildfire smoke in Oregon led to increased rates of

traumatic injury claims among outdoor workers. Zuidema et al. (2021) studied the exposure of outdoor construction workers to wildfire-related smoke in Washington state and found that increasing patterns of $PM_{2.5}$ during the summer months coincided with the seasonal peak in construction employment during the summer months. Moreover, residential damages resulting from wildfires typically result in heightened demand for construction work (Pradhan & Arneson, 2021) in the aftermath of wildfires. Despite the growing health concern for outdoor construction workers exposed to wildfire smoke, there are limited studies highlighting the exposure and negative health outcomes for particular occupations. Therefore, this study aims to address the following research question: 1) *What are the seasonal exposure trends of outdoor building construction workers to wildfire smoke $PM_{2.5}$ during wildfire events in California?* and 2) *How are the outdoor building construction worker exposure days to wildfire smoke $PM_{2.5}$ spatially distributed across counties in California?*

Research Methods

This study analyzed the seasonal and spatial exposure patterns of outdoor building construction workers to wildfire smoke $PM_{2.5}$ during the months when wildfires hit various counties in California from 2010-2020. The research methods included a multi-step process for: i) collection of wildfire events data, ii) collection of county-level employment data for outdoor building construction workers, iii) collection of $PM_{2.5}$ air quality data, and iv) determining seasonal and spatial $PM_{2.5}$ exposure trends.

Data Collection

Three types of historical data were collected for the state of California from publicly available sources: i) County-level monthly employment for outdoor building construction workers, ii) wildfire perimeters, and iii) daily $PM_{2.5}$ air quality. First, county-level monthly employment data for outdoor building construction workers in California were collected from the Quarterly Census of Employment and Wages conducted by the U.S. Bureau of Labor Statistics (U.S. Bureau of Labor Statistics, 2022). County-level monthly employment data of sector 2381 of the North American Industry Classification System (NAICS) was collected from 2010 to 2020. The NAICS 2381 sector represents the majority of outdoor works involved in building construction and collectively includes trades working in concrete foundation and structure, structural steel and precast concrete, framing, roofing, glass and glazing, masonry, and siding or cladding (Executive Office of the President Office of Management and Budget, 2022). Employment data was limited to 46 of 58 California counties due to availability. Geographic Information System (GIS) data for historical wildfire perimeters was collected from the Fire and Resource Assessment Program (FRAP) under the California Department of Forestry and Fire Protection (CAL FIRE) (FRAP, 2022). The FRAP geodatabase included the timing and geographic location of fire perimeters in California dating back to 1959 and provided information such as the name of the fire, start and contained date, and burned acres. Finally, outdoor air quality data for $PM_{2.5}$ pollutant for the years 2010-2020 was collected from the U.S. Environmental Protection Agency (U.S. Environmental Protection Agency, 2022). The air quality data was collected from all the monitoring sites of the California counties which included daily mean time series of the $PM_{2.5}$ concentration and its corresponding Air Quality Index (AQI). For $PM_{2.5}$ pollutants, an AQI value less than 50 is considered ‘good’, above 50 to 100 is considered ‘moderate’, 101 to 150 is ‘unhealthy for sensitive groups,’ above 150 is ‘unhealthy,’ and above 300 is defined as ‘hazardous’ (AirNow, 2022).

Data Analysis

Data analysis included: i) importing historical fire perimeter geodatabase in GIS software, ii) data filtering, and iii) performing exploratory spatial analysis. ArcGIS Pro Version 2.9 software was used

for processing geospatial data. County-level exposure to the burned area of each wildfire was identified using the historical wildfire perimeters from the FRAP (Aguilera et al., 2021). Historical fire perimeter geodatabase from the FRAP was imported to ArcGIS software and the wildfire events of Class E and above (i.e., 300 acres or more in total burnt area) were extruded out to include in the analysis. Wildfires with a total burnt area of 300 acres or more are considered large fires (National Interagency Fire Center, 2021) with a higher potential for particle pollution (Jaffe et al., 2008). Since the wildfire perimeters were sometimes spread across the county boundary, the wildfire perimeter polygons were intersected over the county boundary to get the wildfire perimeters within each county.

Seasonal exposure patterns of outdoor building construction workers to wildfire-related $PM_{2.5}$ was determined based on the monthly employment of outdoor building construction workers during wildfire months of affected counties and the air quality index (AQI) for $PM_{2.5}$ during those months from 2010-2020. First, wildfire events occurring from 2010 to 2020 for each study county, date of ignition, and date of containment were recorded. The month/s covering the start date to the wildfire containment date was referred to as the *wildfire month/s* for that county and the county-level employment of building exterior workers during those months was tabulated. Second, the number of days when $PM_{2.5}$ AQI index exceeded 100 was determined for each wildfire month using the AQI data. For any county at the study year *i* and month *j*, the outdoor building construction worker exposure days to wildfire smoke $PM_{2.5}$ for AQI>100 was determined by taking the product of monthly employment at *month(i,j)* and the number of days in that month when the AQI exceeded 100 (Zuidema et al., 2021). Finally, the spatial exposure patterns of outdoor building construction workers to $PM_{2.5}$ for AQI greater than 100 was determined based on the monthly employment of outdoor building construction workers during the wildfire events and AQI for $PM_{2.5}$ during those events. For each county, the annual worker exposure days to wildfire smoke $PM_{2.5}$ was calculated by summing up the worker smoke exposure days for every month from January to December and the spatial distribution of mean worker smoke exposure days for the study period was mapped in GIS.

Results and Discussion

From 2010 to 2020, a total of 773 Class E wildfire incidents (burnt area >300 acres) burned over 10.5 million acres of land which added to the $PM_{2.5}$ concentration loading in California. Figure 1 shows the seasonal distribution of employment of outdoor building construction workers during wildfire events along with the mean monthly incidences of wildfire events in California for the study period (2010-2020). The axis on the left denotes the mean monthly employment for the study period and the axis on the right denotes the mean monthly wildfire incidents from 2010-2020. Employment levels reached their peak in September and then declined during the winter months.

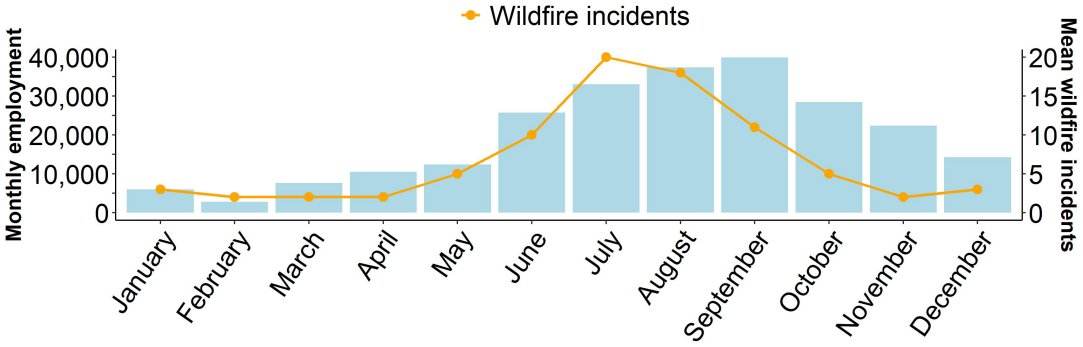

Figure 1. Monthly distribution of employment of outdoor building construction workers and mean monthly wildfire incidences in California during the study period (2010-2020)

Box plots of daily AQI values for $PM_{2.5}$ from January to December recorded by stations across California counties burned by wildfire events from 2010-2020 are shown in Figure 2. $PM_{2.5}$ concentrations reached high values during the months from August to December. This shows that outdoor building construction workers had a greater potential of getting exposed to wildfire smoke $PM_{2.5}$ during those months. The AQI values for $PM_{2.5}$ were relatively high during the month of September when the industry had more outdoor building construction workers gainfully employed.

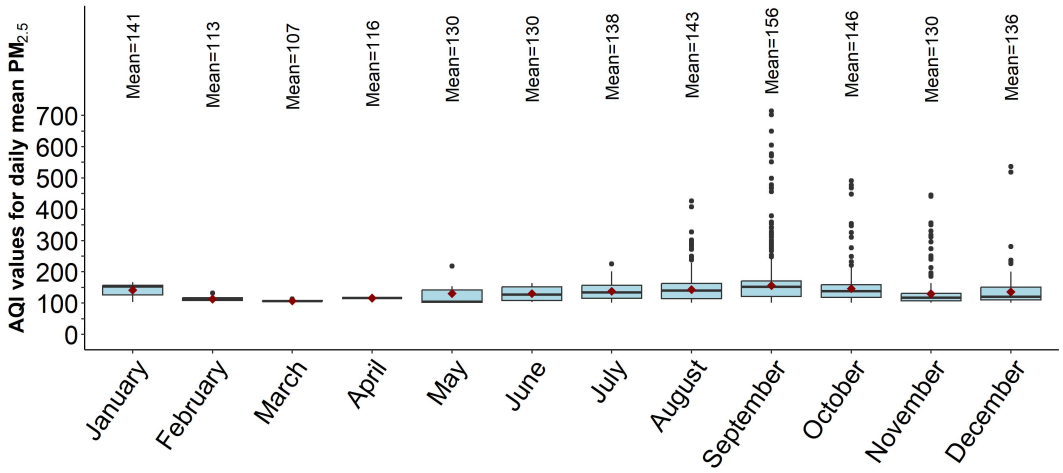

Figure 2. Box plot of AQI values exceeding 100 for daily mean $PM_{2.5}$ (2010-2020)

Figure 3 shows the worker exposure days to wildfire smoke $PM_{2.5}$ during the wildfire seasons which increased starting from July and reached its peak in September. For each month, the total worker smoke exposure days for all the study counties were summed and the mean value of all the wildfire-affected years was plotted. High values of worker smoke exposure days indicated that more workers had the potential of getting exposed to unhealthy air quality and hence more risks of $PM_{2.5}$-related health disorders among outdoor building construction workers.

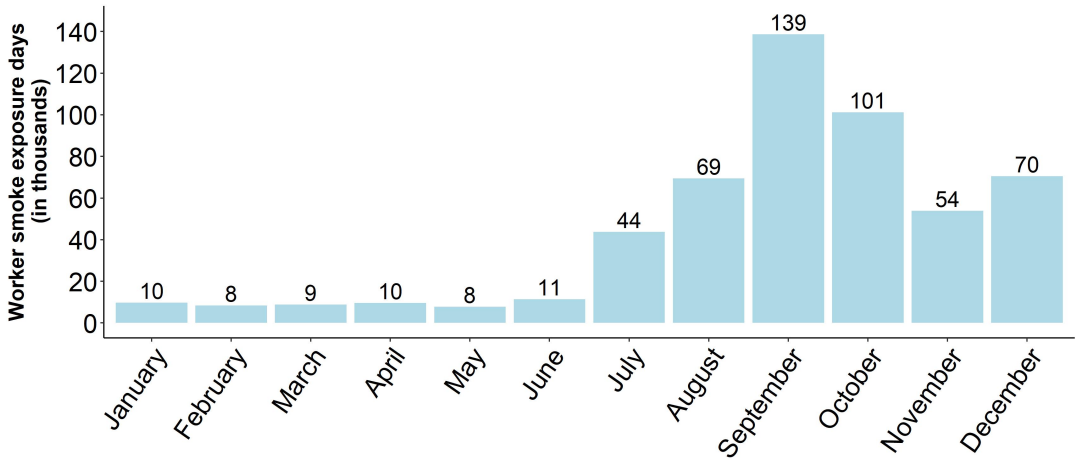

Figure 3. Seasonal distribution of outdoor building construction worker-exposure days to AQI exceeding 100 for $PM_{2.5}$ (2010-2020)

Finally, the spatial distribution of worker smoke exposure days to $PM_{2.5}$ for AQI exceeding 100 during wildfire events was mapped in ArcGIS as shown in Figure 4. For each county, the annual worker smoke exposure days was determined by summing up the monthly worker smoke exposure days and the mean of all the wildfire-affected years in the study period was plotted on the map. The spatial distribution of worker smoke exposure days across California counties showed that counties in Southern California such as Los Angeles, Orange, Riverside, San Bernardino, and San Diego had the highest average worker smoke exposure days during the study period. The monthly employment concentration of outdoor building construction workers in counties like Los Angeles, Orange, and Riverside counties were among the highest in the state. On top of that, counties like Los Angeles, Riverside, and San Bernardino recorded some of the highest numbers of days where AQI for $PM_{2.5}$ exceeded 100 in the past decade. From Northern California, counties such as Santa Clara, Sacramento, Alameda, Fresno, Contra Costa, and Stanislaus had the highest number of worker smoke exposure days. The average monthly number of outdoor building construction workers in those counties were relatively higher than the rest of the counties in Northern California. While counties in Northern California such as Tulare, Butte, Plumas, Madera, and Siskiyou had recorded some of the highest numbers of days when AQI exceeded 100, the worker smoke exposure days were relatively lower because of the lower number of workers employed per month. The total worker smoke exposure days in Southern California counties were found to be higher than those in Northern California which made outdoor building construction workers employed in Southern California counties extremely vulnerable to wildfire smoke exposure.

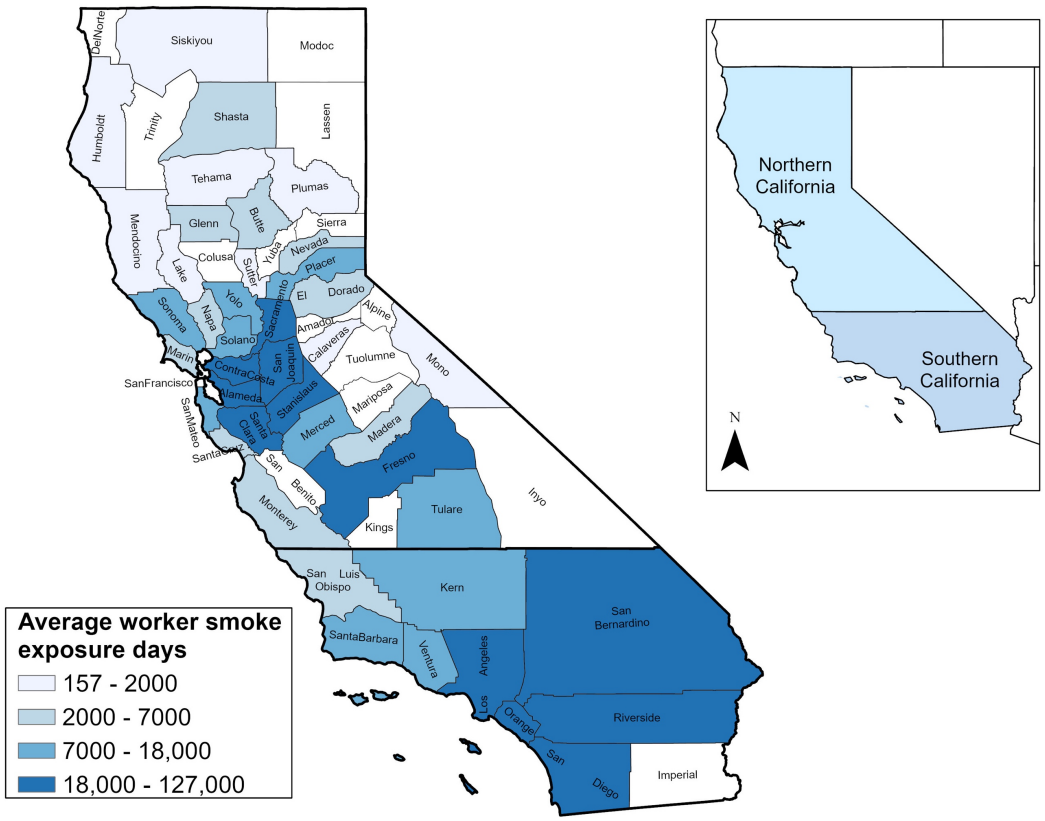

Figure 4. Spatial distribution of average worker smoke exposure days for $PM_{2.5}$ AQI > 100 across counties affected by wildfires in California from 2010-2020

Conclusion

This study reveals new insights about the potential exposure of outdoor building construction workers to wildfire smoke $PM_{2.5}$ in California and its repercussions on the health of workers. Results highlighting the seasonal distribution of employment (Figure 1), variations in air quality during wildfire seasons (Figure 2), seasonal distribution of worker smoke exposure days (Figure 3), and spatial distribution of worker smoke exposure days across California counties (Figure 4) help capture the temporal and spatial trends in outdoor building construction workers' exposure to wildfire smoke $PM_{2.5}$ in California. Historical seasonal patterns of wildfire events show that wildfire season was typically at its peak during the summer months (i.e., June to August) where more incidents of wildfires were recorded during those months. Historical seasonal employment patterns reveal that the summer months had the highest number of outdoor building construction workers in the industry for the entire state of California, coinciding with the period when more wildfire events occurred. Also, the air quality index (AQI) levels for $PM_{2.5}$ during peak wildfire seasons in the summer months were found to be relatively higher. The average monthly building exterior construction workers employed during those summer months was above 25,000, with many workers consistently exposed to dangerous levels of wildfire smoke $PM_{2.5.}$ The findings are consistent with the existing literature that outdoor workers are more vulnerable to wildfire smoke exposure during the summer months (Zuidema et al., 2021) because of the seasonal cycles of employment in the construction industry (Geremew & Gourio, 2018). However, the findings added new insights by highlighting how outdoor building construction workers in the counties of Southern California have more potential for wildfire smoke exposure due to higher employment concentration per county and higher AQI levels induced by frequent wildfires. As a result, outdoor building construction workers can be prone to respiratory illness hospitalizations as result of repeated exposure to wildfire smoke (Aguilera et al., 2021).

Outdoor building construction workers in California are more vulnerable to health disorders due to repeated exposure to wildfire smoke induced $PM_{2.5}$ as shown by the results of this study. Cal/OSHA's recent wildfire smoke regulations mandate employers to take special precautions when AQI exceeds 150. Employers are required to provide some N95 respirators that effectively protect the wearers from inhalation of $PM_{2.5}$, reduce work intensity, provide additional rest periods, and relocate work sites. However, these regulations only compel employers to have N95 respirators available – they do not require employees to actually use any protective masks. Additionally, it is not known to what extent employers are following the new mandate. Repeated exposure to wildfire smoke $PM_{2.5}$ can cause several health disorders in outdoor building construction workers. Contractors should ensure they have enough supplies of N95 masks, especially during the summer months when there is a high probability of wildfire incidences. As future wildfires are getting worse in California, more building construction workers are at risk of getting exposed to wildfire smoke-related health disorders. The findings of this study aim to spread awareness about the risks and health issues caused by exposure to wildfire smoke $PM_{2.5}$. As outdoor building construction workers and contractors become more informed of the serious health risks posed by wildfire smoke $PM_{2.5,}$ perhaps the construction industry and government agencies will require outdoor workers to use protective masks to prevent the negative health effects of repeated exposure to wildfire smoke.

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