



The Economic, Fiscal, and Environmental Costs of Wildfires in California

James Paci, Matthew Newman, and Tim Gage

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Contents

Executive Summary

Wildfires have been increasing in intensity and destructiveness in recent years. While other efforts have examined the costs of wildfires in different categories, this report is the first to draw on recent empirical research to estimate wildfires' economic impacts within the State of California and is the first to provide a comprehensive estimate of their fiscal impact on the State's General Fund. This work assesses the net economic, fiscal, and environmental impacts of wildfires in the State of California over the period 2017-2021. However, no comprehensive study has quantified the ongoing costs that wildfires impose on the State of California. This report assesses the net economic, fiscal, and environmental impacts of wildfires in the State of California over the period 2017 - 2021. The total economic value of wildfires' costs in the state includes labor market disruptions, property damage, and losses of life. Over the 2017 – 2021 period, we estimate that average annual losses totaled over $117.4 billion. Of this amount, an estimated $5.0 billion annually was incurred as a fiscal loss by the State of California attributable to reduced tax revenues and increased wildfire response costs.

Our analysis of wildfires' environmental impacts also considers wildfires' contribution to annual greenhouse gas (GHG) emissions. We find that the GHGs released during a typical wildfire season imposes a net cost of $1.2 billion. Table 1, below, summarizes these estimates.

Table 1 – Summary of annual wildfire-related costs in California: 2017 – 2021 average

Annual Losses Due to Wildfire	Cost (in millions)[1]
Total economic loss in California	$117,423
State fiscal loss (subset of total economic loss)	$5,035
Climate impact (global)	$1,168

As with any first-time effort, there may be ways to improve, refine, or clarify aspects of our analysis, as well as the opportunity to expand this methodology to other states and regions. The team welcomes input and commentary on the report, which can be directed to Genevieve Biggs, Program Director, Wildfire Resilience Initiative at the Gordon and Betty Moore Foundation (email: Genny.Biggs@moore.org)

ORGANIZATION OF ANALYSIS AND METHODOLOGY

While growing wildfire severity in recent years has generated greater interest in studying their impacts, few researchers have attempted to fully quantify the costs of wildfires within the state.[2] Though various data sources may establish some of the types of losses attributable to wildfires, there is currently no systematic accounting of wildfires' annual impacts, and no consensus methodology for determining these incidents' more indirect economic and health effects.[3] This analysis combines available research and data on the costs of wildfires to produce a comprehensive analysis of the overall economic, fiscal, and climate effects of wildfires in California.

The analysis of wildfire costs in this report first considers the economic value of all wildfire-related impacts felt by Californians. Within this broad category are both "direct" losses (those primarily attributable to wildfire's flames) and "indirect" losses (those primarily attributable to wildfires' smoke pollution). Within each of these loss categories, we estimate the share of the total loss that is incurred by the State as a fiscal impact. Separately, given the state's GHG emissions reduction targets, we also estimate the net increase in atmospheric GHGs attributable to California's wildfires, estimating the monetary value of these increased emissions using the State's estimate of the "social cost of carbon" (measured in dollars per ton).[4]

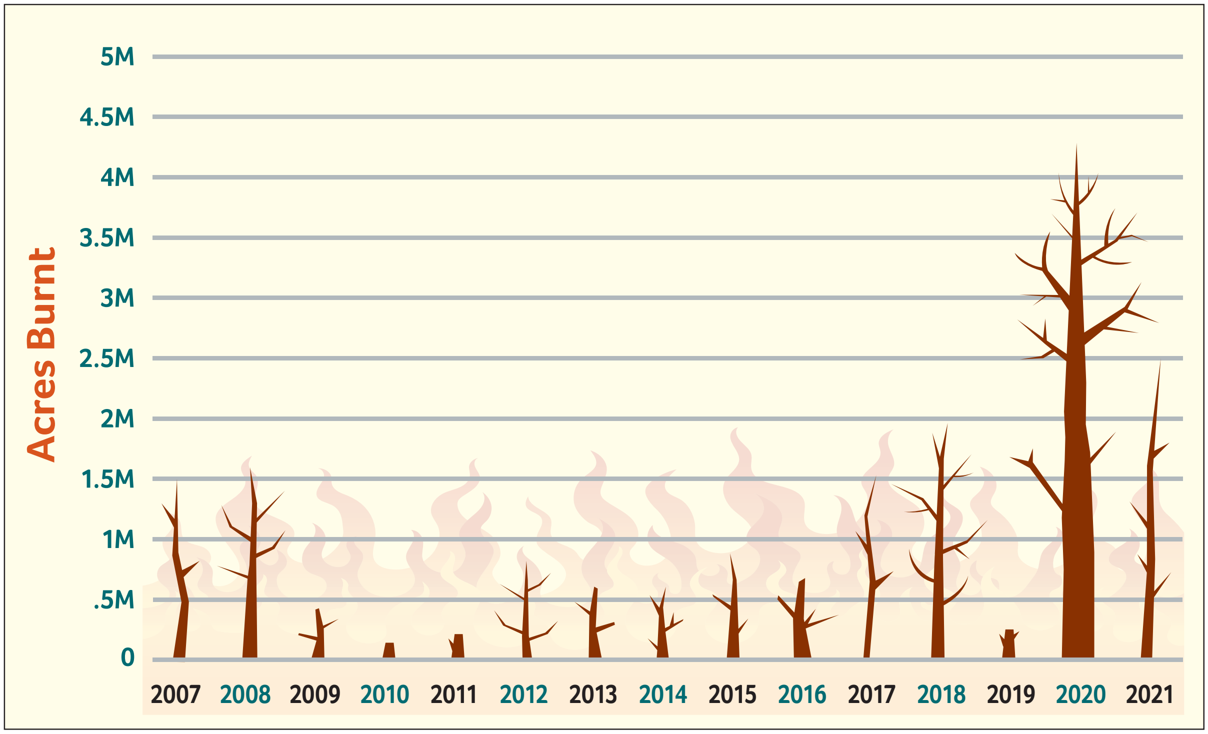
TOTAL HEALTH, ECONOMIC, AND FISCAL IMPACTS OF WILDFIRES IN CALIFORNIA

This analysis identifies all wildfire impacts, categorizing the results as either "direct" or "indirect" losses. "Direct losses" cover the immediate impacts of wildfires, including property losses, fire suppression expenditures, debris clean-up costs, and the monetized value of the lives lost to wildfires, including both civilians and firefighters. Within this category, spending on fire suppression and debris clean-up as well as the value of state property damaged by fires comprise the fiscal impacts on the State of California.

"Indirect losses" include all other adverse economic and health impacts of wildfires, almost exclusively attributable to the health impacts triggered by the fires' smoke plumes. This category includes the monetized value of all premature deaths and other (non-fatal) health impacts resulting from smoke exposure, and the estimated loss of economic output attributable to smoke pollution. These indirect losses also lead to fiscal costs, as the state collects less tax revenue and incurs higher health care costs in paying for the care of the state's Medi-Cal enrollees who suffer adverse health impacts.[5]

For all types of losses, our annual estimates are based on data collected from the five-year period 2017 – 2021. As shown below in Figure 1, however, wildfire intensity – though variable from year to year – has generally increased over time, and researchers expect this trend will continue as the state grows hotter and drier because of climate change.[6]

Figure 1 – Acres Burned Annually in California (2007 – 2021)



Source: CalFIRE Red Books.

ESTIMATION OF DIRECT LOSSES

Estimation of the average annual direct losses from wildfires in California is based on state budget data and CalFIRE's "Red Books," which provide a range of wildfire metrics, including property losses and fatalities, on an annual basis.[7]

Property Losses

Most of the direct property losses from wildfires are borne by the state's residents and private entities. Over the period 2017 – 2021, CalFIRE estimated average annual "dollar damages"[8] of roughly $9.9 billion annually (after adjusting dollar amounts reported for inflation). This amount includes all property destroyed or damaged during fires over this period, regardless of ownership.[9]

Fatalities

In addition to these capital losses, wildfires over the 2017 – 2021 period resulted in nearly 36 direct fatalities annually (2.4 firefighters and 33.4 civilians per year). In monetary terms, utilizing the federal Environmental Protection Agency's (EPA) "value of a statistical life" (VSL)—roughly $10.8 million in 2022 dollars[10]—direct wildfire fatalities impose an additional $386 million in losses annually.

Response and Clean-up Costs

Finally, as detailed further in the section Estimation of Fiscal Impacts, below, while the federal government reimburses roughly 75% of state and local spending on disaster response, the State has still incurred at least $1.13 billion in "emergency" wildfire response and debris clean-up costs annually over the past five fiscal years. This amount excludes "baseline" departmental spending for wildfire suppression and monitoring and only includes variable costs that directly rise and fall based on the intensity of wildfire activity in a given year. Including *federal* response and debris clean-up costs, total estimated losses in this category are roughly $4.5 billion annually.

Summary of Direct Losses

Table 2, below, summarizes all direct losses from wildfire. In total, over the 2017 – 2021 period,[11] California suffered average direct losses of $11.4 billion annually due to wildfires.

Table 2 – Summary of direct losses from wildfires (2017 – 2021 average) (mil $)

Loss Category	Average Annual Losses
Property losses (destroyed and damaged structures)	$9,910
Wildfire casualties (civilians and firefighters)	$386
State response costs (fire suppression; debris clean-up)	$1,130
Total Direct Losses	**$11,426**

Sources: CalFIRE; State of California Budget Details (FY 2017-18 – FY 2021-22).

ESTIMATION OF INDIRECT LOSSES

Despite the severity of wildfires' flames direct harms to life and property, fires' smoke plumes impose health and economic impacts that, while "indirect," are higher still. Wildfire smoke may drift far from the burned area, cover much broader and more densely populated territories, and trigger health impacts that linger long after the fire itself has been extinguished.[12] Reducing the frequency or severity of California's wildfires would reduce the extent of these losses.[13]

Because smoke exposure is the primary determinant of indirect economic losses, the economic estimates in this section rely on previous research into the impacts fine particulate matter ("$PM_{2.5}$") generally—and wildfire-sourced $PM_{2.5}$ in particular—on health and employment. Estimating the monetary value of these harms within California over the relevant period requires applying the findings from this research to estimated levels of smoke exposure across the state.

Economic disruptions from $PM_{2.5}$ Emissions

As discussed in the section "Premature Mortality from $PM_{2.5}$ Emissions," below, researchers have long been aware of the effects of $PM_{2.5}$ emissions on health outcomes. Only recently, however, have studies begun to directly estimate the impacts of wildfire smoke and other pollutants on regional economies, as measured by changes in regional economic output or income levels. As with wildfire fatalities, studies have shown that the *direct* economic impact of wildfires, as discussed above, constitutes only a small share of the total economic impact.

Indirect economic impacts exceed direct impacts for two reasons. First, while property loss estimates reflect the cost of rebuilding the damaged structure, they exclude the value of any economic output lost between the property's destruction and its rehabilitation. For example, if a business' facility is destroyed, or its workers are forced to evacuate, its output cannot return to pre-wildfire levels until the workers return or the building is repaired. The reduction in this business' activity creates upstream and downstream economic effects, as the business' suppliers temporarily lose a customer, and the business' customers temporarily lose a vendor.[14] More significant than any business disruptions resulting from property damage, however, is the impact of smoke pollution on workers' health.

Previous Research on the Economic Impact of Smoke Exposure

The most relevant study on the impact of wildfire smoke on the labor force is Borgschulte et al.,[15] which assessed the relationship between variations in county-level income and "smoke day" data from the National Oceanic and Atmospheric Administration (NOAA)[16] to estimate the impact of wildfire-sourced PM2.5 emissions on the labor market. On average, for every additional smoke day, quarterly income in the county dropped 0.97%. Nationally, because Americans were exposed to an average 20.2 smoke days per year over the 2007 – 2019 period, the researchers concluded that wildfire smoke reduced total U.S. income by roughly 2%.

The magnitude of Borgschulte et al.'s finding aligns with previous studies of pollution's impact on labor market outcomes. The authors note that, under their model, an increase in average quarterly $PM_{2.5}$ concentrations of 1 µg/m3 (roughly a 10% increase above baseline levels[17]) is associated with a 1.81% reduction in quarterly earnings, for an "implied elasticity" of -0.18 (i.e., the 1.81% reduction in earnings divided by the 10% increase in $PM_{2.5}$ concentrations). This finding is well within the range of elasticity findings of previous studies.[18]

Other recent studies not included in Borgschulte, et al.'s literature review come to similar conclusions. Wang et al. relied on a novel "Multi-Regional Disaster Footprint" (MRDF) model to estimate the economic fallout in California over the 2018 wildfire season.[19] The researchers conclude that statewide economic output fell by $42.7 billion—an estimate only $1.4 billion lower than the estimate we derive from the smoke day-based findings from Borgschulte et al. (see Table 4, below).[20]

Jones and McDermott (2021),[21] which assessed only the local effects of "large" wildfires (i.e., those burning more than 100,000 acres) in the United States, found that in the three years immediately following these incidents, incomes in fire-impacted counties declined roughly 2.1% in the first year after; 1.0% in the second; and 0.4% in the third. Thus, despite the short-run stimulative effects of the state and federal spending on suppression and clean-up, wildfires are found to nevertheless reduce net local income.

Finally, evidence of the impacts of $PM_{2.5}$ on labor market outcomes in other countries continues to show similar labor market elasticities.[22]

Applying Borgschulte, et al. to California Smoke Day Data

Because the analysis in Borgschulte et al. concerned the entire United States and examined only the years 2007 – 2019, our estimate of the average annual loss of income in California required a separate analysis of California-specific NOAA smoke day data over the more recent 2017 – 2021 period. In short, our analysis matches NOAA's geospatial smoke day data to California's Census Block Groups (CBG), following the methodology first used by Vargo (2020),[23] to determine the total population in California that was exposed to smoke on each day over the 2017 – 2021 period. This methodology differs slightly from the approach taken by Borgschulte et al., which used entire counties—and not the smaller CBGs—as the relevant population unit. Therefore, to ensure parity between our smoke day measurements and those of Borgschulte et al., we further analyzed national smoke day data over the 2007 – 2019 period, and found that under our approach, the annual average was 23.7 smoke days per year, or 2.5 days per year higher than the Borgschulte et al. finding. Therefore, for purposes of employing Borgschulte et al.'s findings to estimate income loss in California over the 2017 – 2021 period, we have accordingly adjusted our estimates of smoke days for each year in the period.[24]

Table 3 – Estimation of Annual Smoke Days in California (2017 – 2021)

	2017	2018	2019	2020	2021	5-Year Average
Initial Estimated Smoke Days (Vargo methodology) (mil)	1,292	1,516	507	2,715	2,746	**1,755**
Adjusted Smoke Days (Borgschulte et al. methodology) (mil)	1,101	1,292	432	2,314	2,340	**1,496**
Total California Population (mil)	39.33	39.48	39.53	39.54	39.37	**39.45**
Average Smoke Days per Californian	**28.0**	**32.7**	**10.9**	**58.5**	**59.4**	**37.9**

Sources: Borgschulte, et al.; NOAA.

As shown in Table 3, average smoke days per Californian is calculated by dividing the total number of smoke days experienced over a given period by the total state population; over 2017 – 2021, the average Californian experienced 37.9 smoke days per year. As a result, total wage and salary income statewide is estimated to have declined by 3.7% (i.e., a 0.097% decline in income per annual smoke day multiplied by 37.9 smoke days per year) as a result of wildfire smoke. Applying this percentage reduction to the $1.634 trillion of total wage and salary income earned statewide in 2022, it is estimated that this level of smoke exposure resulted in income losses of roughly $60 billion.

Table 4 – Estimation of Statewide Income Losses from Wildfires in California (2017 – 2021)

	2017	2018	2019	2020	2021	5-Year Average
Smoke days	28.0	32.7	10.9	58.5	59.4	**37.9**
Percentage Reduction in wage and salary income	-2.7%	-3.2%	-1.1%	-5.7%	-5.8%	**-3.7%**
Total wages and salary income (statewide, *mil $*, 2022)						**$1,634,244**
Net reduction in wages and salary income (statewide, *mil $*, 2022)						**($60,119)**

Sources: Borgschulte, et al.; NOAA; California Dept. of Finance (2022).

Premature Mortality from $PM_{2.5}$ Emissions

In addition to its disruption of labor markets, we also consider the monetary value of the health impacts of increased air pollutant levels. Estimates of this impact rely on studies employing the EPA's "Environmental Benefits Mapping and Analysis Program" ("BenMAP").[25] In short, BenMAP software takes as inputs the user's selection of pollutant type, the marginal increase in emissions above a pollutant's baseline atmospheric concentration, and the geographic spread of this emissions increase to derive an estimate of excess deaths and other (non-fatality) health costs. The magnitude of the health impact relative to a user-provided marginal increase in emissions is based on a broad survey of academic studies assessing these relationships.[26]

Because the primary pollutant from wildfire smoke is $PM_{2.5}$, use of BenMAP to estimate premature smoke-related fatalities and other health impacts from wildfire smoke requires first estimating the increase in $PM_{2.5}$ concentrations attributable to wildfires. The most recent study to undertake this analysis, Wang, et al., which relied on ground-level $PM_{2.5}$ monitoring data and satellite imagery to estimate levels of wildfire-derived $PM_{2.5}$, found that in 2018 aggregate $PM_{2.5}$ emissions across all fires that year resulted in 3,652 smoke-related deaths statewide. Using the EPA's estimate of the VSL and inflating to 2022 dollars, we estimate that in 2018, the total mortality cost of wildfires given the findings of Wang et al. was $39.3 billion.[27]

While Wang et al. is the only recent study to employ BenMAP to estimate California-specific wildfire mortality impacts, the scale of its mortality finding is well-supported by other analyses of wildfire smoke across the entire United States.[28] In fact, recent research suggests that the use of BenMAP to estimate wildfire smoke-related mortality may in fact understate the actual costs of wildfire smoke. Whereas BenMAP assumes that all $PM_{2.5}$ emissions, regardless of their source, triggers the same health impacts, some recent studies have determined that $PM_{2.5}$ from wildfires may be more harmful than $PM_{2.5}$ from other sources.[29]

Using the Wang et al. statewide fatality estimate for 2018, we rely on NOAA smoke data to separately estimate fatalities for 2017 and for the 2019 – 2021 period, given a constant relationship between smoke days and excess mortality.[30] (For example, since NOAA data shows that there were 79% more smoke days across California in 2020 than in 2018, we estimate that the fatality cost in 2020 exceeds 2018's estimated fatality cost by 79%.)

Under this analysis, we estimate an annual average fatality cost over the entire period of $45.6 billion (see Table 5).

Table 5 – Estimation of Mortality and Health Costs (2017 – 2021)

	2017 (est.)	2018 (Wang)	2019 (est.)	2020 (est.)	2021 (est.)	5-Year Average
Smoke days (mil)	28.0	32.7	10.9	58.5	59.4	**37.9**
Mortality costs (mil $)	$33,663	$39,345	$13,146	$70,349	$71,459	**$45,593**
Other health costs	$211	$247	$82	$441	$448	**$286**
Total	**$33,874**	**$39,592**	**$13,229**	**$70,791**	**$71,908**	**$45,879**

Source: Wang et al. (2020); NOAA.

Non-fatality Health Impacts

Smoke exposure from wildfires also contributes to a range of non-fatal adverse health impacts, primarily cardiovascular and respiratory illnesses such as asthma. These health costs may also be modeled with BenMAP, which generates an expected increase in hospital admissions for a given increase in $PM_{2.5}$ emissions from wildfire smoke.[31] As with the mortality cost estimate above, our analysis relies on Wang et al.'s estimate of California-specific health costs of $210 million in 2018 dollars ($247 million in 2022 dollars) and a constant relationship between smoke days and health costs to derive health cost estimates for 2017 and 2019 – 2021. Over the entire five-year period, we estimate an average annual health cost of $286 million.

Summary of Indirect Losses

Table 6, below, summarizes all indirect losses from wildfire. In total, over the 2017 – 2021 period, in addition to the $11.4 billion of direct losses estimated above (see Table 2), California further suffered an estimated $106 billion of indirect economic losses annually due to wildfires.

Table 6 – Summary of Indirect Losses from Wildfires (2017 – 2021 average) (mil $)

Loss Category	Average Annual Losses
Indirect Economic Impacts (smoke exposure impact on labor market)	**$60,119**
Mortality Costs (deaths from smoke exposure)	**$45,593**
Health Costs (hospital admissions from smoke exposure)	**$286**
Total Indirect Losses	**$105,997**

ESTIMATION OF FISCAL IMPACTS

While the most significant impacts of wildfires are those experienced by Californians generally, these incidents also impose a fiscal drag on the state through lower income tax receipts. In addition, the state must replace damaged state property and facilities, pay wildfire fighting costs, and cover increased health care costs for the state's Medi-Cal population.[32]

Lost Tax Revenue

From a fiscal perspective, by far the largest impact of wildfires is the loss in wage and salary income, estimated above, since this income would have generated personal income tax revenue for the state. This lost income would have been subject to an estimated marginal personal income tax rate of 6.0%, on average, across all affected households.[33] Thus, given an estimated annual loss of $60.1 billion of income statewide over the 2017 – 2021 period, the state has likely lost an average of at least $3.6 billion in income tax revenue annually due to wildfires.

Increased CalFIRE "E-Fund" Expenditures

The growing intensity of the state's wildfires has been accompanied by large increases in state spending on fire suppression. Total funding for CalFire (across all agency programs) rose from less than $1 billion in the 2006-2007 fiscal year to nearly $3.9 billion in FY 2021-2022.[34] Most of this growth is attributable to the agency's base fire protection budget and to the agency's Emergency Fund ("E-Fund"), which covers expenditures made suppressing fires that have not been extinguished within 24 hours.

Table 7 shows total CalFIRE spending across its various programs. Over the five-year period spanning FY 2017-2018 to FY 2021-2022, E-Fund expenditures (net of federal reimbursement) averaged roughly $739 million annually (in 2022 dollars).

Table 7 – CalFIRE expenditures by program (FY 2017-18 – FY 2021-22) (mil $)

CalFIRE Program	FY 2017-18	FY 2018-19	FY 2019-20	FY 2020-21	FY 2021-22	5-Year Average
Fire Control	$743	$901	$988	$982	$1,061	**$935**
E-Fund	$1,079	$687	$507	$539	$886	**$739**
Other Fire Protection	$1,082	$893	$895	$828	$1,059	**$951**
Resource Management	$125	$328	$314	$418	$893	**$416**
Total CalFIRE	**$3,029**	**$2,809**	**$2,704**	**$2,767**	**$3,899**	**$3,042**

Source: State of California Budget Detail (FY 2017-18 – FY 2021-22).

For purposes of this analysis, we have conservatively assumed that annual fluctuations in the frequency or intensity of the state's wildfires would not immediately result in changes in CalFIRE's base fire protection budget. Similarly, expenditures on fire prevention or mitigation, such as prescribed burns, are assumed to hold constant in the near term regardless of annual fluctuations in fire severity. Unlike base fire protection and other CalFIRE programs, however, our estimate treats E-Fund spending as variable, such that a 10% increase in wildfire activity, for example, would increase E-Fund expenditures 10%.

Increased CalOES Clean-up Costs

In addition to fire suppression costs, the state also funds debris clean-up and rehabilitation. These costs are also a function of the wildfire damage suffered each year. While CalOES' budgets generally do not separate wildfire-related expenditures from those responding to other emergencies, their FY 2019-2020 budget provides an overview of expenditures incurred following 2018's Camp and Carr Fires, which triggered total clean-up costs (net of federal reimbursement) of $923 million that year, or $1.07 billion in 2022 dollars.

Given the relationship between property damage and necessary debris clean-up and remediation activities, our estimates of total CalOES clean-up costs for 2017 and the 2019 – 2021 period relies on CalFIRE's "dollar damages" reporting (see Property losses, above). As shown in Table 8, estimated debris clean-up costs for these years are based on the ratio of 2018 dollar damages to 2018 clean-up costs (for example, since 2017 property losses are 41% below property losses in 2018, clean-up costs in 2017 are an estimated 41% below 2018 clean-up costs).

Over the 2017 – 2021 period, we estimate that CalOES incurred roughly $390 million annually in remediation costs in wildfires' aftermaths.

Table 8 – Estimation of CalOES clean-up costs (2017 – 2021) (mil $)

	2017 (est)	2018 (actual)	2019 (est)	2020 (est)	2021 (est)	5-Year Avg.
Property losses	$16,540	$27,134	$582	$4,855	$439	**$9,910**
CalOES clean-up	$652	$1,069	$23	$191	$17	**$390**

Source: State of California Budget Detail (FY 2017-18 – FY 2021-22).

Increased Medi-Cal Costs

To the extent that increases in smoke exposure from wildfires trigger health conditions requiring hospital care, the state also incurs costs attributable to the treatment of Medi-Cal enrollees. Estimation of wildfires' impact on the state's spending on Medi-Cal requires determining total annual health care spending attributable to wildfires; the share of this total spending attributable to the state's Medi-Cal enrollees; and finally, the state's share of total Medi-Cal spending.

Total wildfire-related health care spending: As discussed above (see Table 5), we adopt Wang et al.'s finding of total wildfire-related health care spending in 2018 ($247 million in 2022 dollars) and utilize this finding along with NOAA smoke day data to estimate spending levels in other years (2017 and 2019 – 2021). On average, over this period, we estimate annual total wildfire-related health care spending of $286 million.

Medi-Cal share of total wildfire-related health care spending: As of January 2022, the Medi-Cal program covered 37% of the state's population,[35] though the most recent statewide hospital admissions data shows that enrollees accounted for 35.2% of all hospital admissions in 2021.[36] We therefore estimate that 35.2% of wildfire-related health costs, or $101 million annually over the 2017 – 2021 period, are attributable to Medi-Cal enrollees.

State's share of Medi-Cal costs: While the federal government covers most of the total spending on the state's Medi-Cal enrollees, 21% was covered by the state's General Fund in FY 2021-22, in line with previous years (remaining funding comes from other state and local sources).[37] As shown in Table 9, below, given this state General Fund share, the estimated state-level spending on Medi-Cal attributable to wildfire smoke was an estimated $21 million annually over the 2017 – 2021 period.

Table 9 – Estimation of state's share of increased Medi-Cal spending due to wildfires (2017 – 2021) (mil $)

	2017	2018	2019	2020	2021	5-Year Avg.
Total health spending	$211	$247	$82	$441	$448	$286
Medi-Cal share	$74	$87	$29	$155	$158	$101
State share of Medi-Cal	$15	$18	$6	$32	$33	**$21**

Sources: Authors' analysis of data from Wang et al.; Dept. of Health Care Access and Information (HCAI); Dept. of Health Care Services (DHCS).

Estimating the State's Share of Property Losses

In addition to reduced tax revenues and higher health care costs, the state also incurs direct property losses due to wildfires. To estimate the amount of state property damaged by wildfires, we rely on CalFIRE's "California Land Ownership" database, which shows that the state owns 2.8% of all land statewide.[38] Applying this estimated ownership share to the total property loss amounts reported by CalFIRE over the 2017 – 2021 period (see Table 2, above), we estimate that the state incurs roughly $277 million in property losses due to wildfires each year.

Table 10 – Estimation of state's share of property losses (2017 – 2021) (mil $)

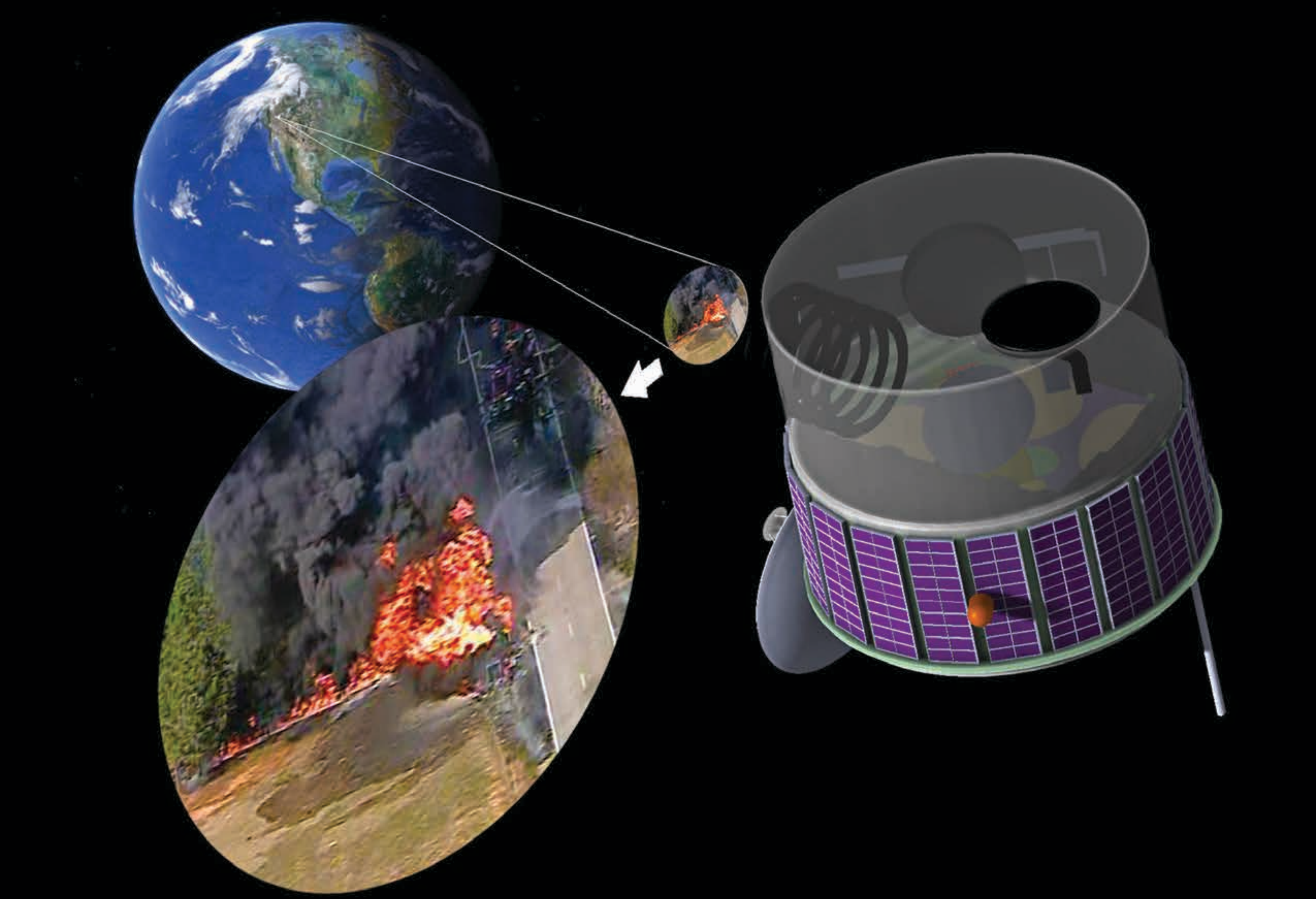
	2017	2018	2019	2020	2021	5-Year Avg.
Property losses	$16,540	$27,134	$582	$4,855	$439	$9,910
State share	$463	$760	$16	$136	$12	**$277**

Summary of Fiscal Impacts

Table 11, below, summarizes all fiscal impacts assessed. In total, over the 2017 – 2021 period, the State of California incurred an estimated $5.0 billion of losses annually due to wildfires.

Table 11 – Summary of fiscal impacts of wildfires (mil $) (FY 2017-18 – FY 2021-22 average)

Fiscal Impact Category	Amount (mil $)
Increases in state expenditures	
CalFIRE – increases in E-Fund spending (net of federal reimbursement)	$739
CalOES – increases in clean-up spending (net of federal reimbursement)	$390
Property losses - state's share of capital stock damaged by fires	$277
Medi-Cal – state's share of costs of hospitalizations	$21
Reductions in state revenue	
Reduction in personal income tax revenue	$3,607
Total Indirect Losses	**$5,035**



CLIMATE IMPACTS

In addition to their short-run impacts on the state's economy and budget, wildfires also release large amounts of greenhouse gases. The California Air Resources Board (CARB) estimates that over the 2017 – 2021 period, wildfires were one of the more significant emissions sources statewide, responsible for the release of 53.4 million metric tons (MMT) of CO_2 per year.[39] By comparison, the entire transportation sector in 2020 emitted roughly 140 MMT of CO_2.[40] Recent trends in California wildfire activity suggest that in future years, wildfires may account for an even higher share of total statewide emissions. For example, the 53.4 MMT of average emissions over the 2017 – 2021 period far exceeded average emissions over the 2012 – 2016 period (14.6 MMT), the 2007 – 2011 period (15.4 MMT), and the 2002 – 2006 period (11.0 MMT).

The net impact of GHGs released by wildfires, however, is not as easily calculated as it is for transportation or industrial emissions, which derive from the combustion of fossil fuels that would have otherwise been permanently sequestered below ground. Wildfires' destruction of forests and their subsequent regrowth, on the other hand, are a natural part of California's ecosystems. In the long run, so long as a wildfire does not permanently alter the types of vegetation that are able to regrow in the impacted area, subsequent vegetation regrowth will eventually sequester the same amount of CO_2 as was emitted during the wildfire. As a result, while CARB's most recent Scoping Plan[42] accounts for net emissions from wildfires in assessing the feasibility of reaching statewide carbon neutrality by various dates, officials caution that "fossil fuel emissions and biomass carbon emissions should be evaluated separately and not be compared to each other."[43]

Estimating wildfires' impact on atmospheric CO_2 levels therefore requires specifying the time scale under consideration and determining likely rates of vegetation regrowth following the average large fire. Recent research suggests that regrowth patterns are highly variable across wildfires. Even under the most optimal regrowth circumstances, research into reforestation practices establishes that it may take decades for new forests to reach full carbon sequestration capacity; some tree species continue to grow for over 100 years.[44]

Many wildfires, however, result in delayed reforestation, with smaller vegetation types, such as shrubs and grass, dominating the region in the years (or decades) following the wildfire.[45] Climate change has exacerbated this challenge, as recent studies have shown that in drier regions, regrowth of the extant forest will not be possible following a future wildfire.[46]

In line with the Scoping Plan, which assesses various paths to achieving statewide carbon neutrality by 2045, our estimate utilizes a 20-year time horizon for purposes of measuring the net carbon emissions impact of an average year of wildfire. In other words, the net carbon emissions estimate is based on the expected amount of CO_2 released during the wildfire, offset by the expected re-sequestration of CO_2 in the acreage burned twenty years into the future.

As shown in Table 12, below, to estimate regrowth at 20 years, we rely on CARB's estimate of average CO_2 emissions per burnt acre over 2017 – 2021 (23.1 tons) along with a separate analysis of typical CO_2 sequestration levels across a variety of plant species in the western US (i.e., shrubland, at 11.0 tons per acre, and forestland, at 36.3 tons per acre).[47] This latter study further estimates that 55% of all forested acres experience delayed reforestation, such that even twenty years post-wildfire, shrubs will predominate. As summarized in the table:

- For 52% of total acreage burned in wildfire, shrubs and smaller vegetation predominated prior to the fire. For these acres, twenty years post-fire, all the CO_2 emitted has been re-sequestered.
- For the 48% of land area that is forested:
  - Shrubs have replaced the forest on just over half of all acres at twenty years post-fire, resulting in a net CO_2 loss of roughly 25.3 tons per acre (i.e., 36.3 tons of sequestered carbon pre-fire less the 11.0 tons sequestered post-fire).
  - For the remaining forested acreage, which benefited from immediate reforestation, younger trees are estimated to sequester half as much carbon (18.2 tons per acre) as the forest had sequestered pre-wildfire. Thus, on average, across all acres with forest cover prior to the wildfire, the average net loss of CO_2 per acre after twenty years is roughly 20 tons per acre.
- Given the above findings, across all acres (including both shrubland and forest), the weighted average loss of CO_2 at twenty years is roughly 10.5 tons per acre.

Table 12 – Carbon emissions estimate over 20-year time horizon

Vegetation Type	Acreage Share	Pre-Fire CO_2 Stock (Tons per Acre)	Year 20 – Post-Fire (Tons per Acre)	Net Loss of CO_2 (Tons per Acre)
Shrubland	52.4%	11.0	11.0	0
Forest	47.6%	36.3	14.2	22.1
Delayed Reforestation	55% (of forest)	36.3	11.0	25.3
Immediate Reforestation	45% (of forest)	36.3	18.2	18.2
Wildland Average		**23.1**	**12.5**	**10.5**

Source: CARB (2021); Spatial Informatics Group (2017).

Given an estimated increase in emissions of 10.5 tons per acre, total CO_2 annual emissions due to wildfires are roughly 22.45 million tons (given that over the 2017 – 2021 period, wildfires burned an average of 2.14 million acres annually). Given CARB's most recent estimate of the social cost of carbon (roughly $52 per ton[47]), we estimate that on average, California's wildfires impose $1.17 billion in global costs annually.

BENEFITS OF FURTHER INVESTMENT IN WILDFIRE DETECTION AND RESPONSE

The extent of these economic, fiscal and environmental costs likely justifies further public and philanthropic investment in preventing, detecting, monitoring, and suppressing wildfire ignitions.

The state and various local governments have responded with a range of new measures, including expanded fire protection budgets, which allow increased hiring and purchases of additional suppression equipment. In addition, firefighting agencies have expanded the practice of prescribed burning, which reduces wildland fuel loads and mitigates the risk of severe wildfire damage.

Emerging technologies can also help officials more quickly detect ignitions and manage wildfire response strategies.[48] The roll-out of wildfire cameras across the state has significantly increased the share of the state's wildlands that are under surveillance, with benefits for both detection speed and monitoring.[49] CalFIRE has also in recent years begun experimenting with the use of unmanned aerial vehicles ("UAVs" or "drones") to more precisely locate detected ignitions and monitor fires' spread.[50] Finally, some entities have begun experimenting with the use of constellations of low-earth orbit (LEO) satellites, which together can provide complete and continuous aerial coverage of wildlands at higher resolutions than previously possible, further helping officials detect and monitor new ignitions.[51]

Few studies have attempted to quantify the effectiveness of investments in new technologies or additional personnel.[52] Still, research consistently shows that reductions in response times (i.e., the duration between initial detection and the arrival of the first suppression crew) are associated with reduced fire severity and a lower likelihood of fires escaping initial attack, thereby reducing acres burned, smoke days, and other fire-related impacts. Specifically, available research suggests that if response times were reduced by 15 minutes, the frequency of large uncontained fires could be reduced between three and seven percent.[53] In other words, a hypothetical investment that helped California fire officials achieve a 15-minute reduction in average response times could be expected to generate $3.5 - $8.2 billion in economic benefits and $150 - $350 million in fiscal benefits (i.e., 3 – 7% of the estimated $117 billion in economic costs and $5 billion in fiscal costs).

Rendering of a low-earth orbit satellite system optimized for wildfire detection and tracking, courtesy of Environmental Defense Fund.

Conclusion

CONCLUSION

Despite the large and increasingly destructive potential of wildfires, no previous research has attempted to produce a comprehensive analysis of the economic, fiscal, and GHG-related impacts of wildfires in California. This study combines available data and research and produces an estimate of the annual impacts of wildfires on the state.

As shown in Table 13, annual economic losses due to wildfires in California over the 2012-2021 period totaled $117.4 billion. During this same period, the State of California of California experienced fiscal losses of more than $5.0 billion annually.

Our analysis of environmental impacts also considers wildfires' contribution to GHG emissions. We find that wildfires result in increased GHG emissions of 10.5 tons per acre, with total CO2 annual emissions due to wildfires of 22.5 million tons. During a typical wildfire season these GHG emissions impose a net cost of $1.2 billion.

Table 13: Average annual impact of wildfires on California (2017 – 2021) (mil $)

Economic Loss Category	Economic Loss	State Fiscal Component	Fiscal Loss
Direct Losses	**($11,426)**	**Direct Losses**	**($1,407)**
Property losses (destroyed structures)	($9,910)	State property losses	($277)
Fire casualties (civilians and firefighters)	($386)	N/A	N/A
Total suppression, clean-up costs	($1,130)	State suppression, clean-up costs	($1,130)
Indirect Losses	**($105,997)**	**Indirect Losses**	**($3,628)**
Increased deaths from smoke exposure	($45,593)	N/A	N/A
Medical costs from smoke exposure	($286)	State share of Medi-Cal expenditures	($21)
Total loss of income	($60,119)	State loss of income tax revenue	($3,607)
TOTAL (Direct + Indirect)	**($117,423)**	**TOTAL (Direct + Indirect)**	**($5,035)**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Reporting Smoke or Fire on the Watershed

End Notes

1 All dollar amounts in this analysis are expressed in 2022 dollars.

2 Wang, et al., "Economic footprint of California wildfires in 2018," Nature Sustainability (2020). Available at: https://www.nature.com/articles/s41893-020-00646-7.

3 "The Costs of Wildfire in California," California Council on Science & Technology (2020). Available at: https://ccst.us/wp-content/uploads/The-Costs-of-Wildfire-in-California-FULL-REPORT.pdf; Grace Gedye, "How much do wildfires really cost California's economy?" CalMatters (October 11, 2021). Available at: https://calmatters.org/economy/2021/10/california-wildfires-economic-impact/.

4 In line with the State's adoption of a social cost of carbon that accounts for all damages felt globally, we estimate the global costs of the state's wildfires.

5 Note that the state may incur other costs as well, including higher health insurance premiums for state workers, but these costs are more minor relative to the loss of tax revenue and the impacts on the Medi-Cal program.

6 See, e.g., Gutierrez et al., "Wildfire response to changing daily temperature extremes in California's Sierra Nevada," Science Advances (2021); Dong et al., "The season for large fires in Southern California is projected to lengthen in a changing climate," Communications Earth and Environment (2022).

7 Data gathered from CalFIRE "Redbooks" for 2017 – 2021. Available at: https://www.fire.ca.gov/stats-events/.

8 CalFIRE defines "dollar damage" as their "[e]stimate of the total property and contents dollar loss in terms of replacement in like kind and quantity. This estimation of the dollar loss includes property and contents damaged by fire, smoke, water, and overhaul. This does not include suppression costs or indirect loss, such as business interruption." See ibid.

9 In 2018, the Red Book acknowledges a deficiency in its reporting: due to a software constraint, damages for the Camp Fire and Carr Fire could not be reported as exceeding $2 billion. For these fires, we have used the estimated dollar damage provided in Wang, et al. (2020) (i.e., $14.6 billion for the Camp Fire and $3.8 billion for the Carr Fire).

10 Environmental Protection Agency, "Mortality Risk Valuation" (updated March 30, 2022). Available at: https://www.epa.gov/environmental-economics/mortality-risk-valuation. The agency "recommends that the central estimate of $7.4 million ($2006), updated to the year of the analysis, be used in all benefits analyses that seek to quantify mortality risk reduction benefits regardless of the age, income, or other population characteristics of the affected population."

11 For state response costs, the five-year period assessed corresponds to fiscal (not calendar) years, i.e., FY 17-18 to FY 21-22.

12 For a map showing annual average smoke coverage across the United States, see National Oceanic and Atmospheric Administration (NOAA), "Hazard Mapping System Fire and Smoke Product" (accessed 12/1/2022). Available at: https://www.ospo.noaa.gov/Products/land/hms.html#stats-smoke.

13 Smoke from prescribed burns may to some extent offset any reductions in smoke damage due to wildfires, but research on prescribed burns suggests that these fires can burn at lower intensities and under more optimal wind conditions, thereby mitigating to some extent the impact of fire smoke. Furthermore, rules dictating the use of prescribed burns in California are designed to minimize health impacts; officials may only conduct prescribed burns if certain meteorological requirements are met, and local air districts will consider air quality and other weather conditions in deciding whether to approve a burn permit. Empirical research conducted in the state suggests that these guidelines are effective at mitigating (if not entirely eliminating) potential harm. See "Can Prescribed Fires Mitigate Health Harm?" PSE Healthy Energy (2022). Available at: https://www.lung.org/getmedia/fd7ff728-56d9-4b33-82eb-abd06f01bc3b/pse_wildfire-and-prescribed-fire-brief_final_2022); CCR Title 17, Subchapter 2, "Smoke Management Guidelines for Agricultural and Prescribed Burning"; Prunicki, et al., "The Impact of Prescribed Fire versus Wildfire on the Immune and Cardiovascular Systems of Children," Allergy (2019).

14 Wang, et al., op. cit. Wang, et al.'s estimate of total indirect economic impacts in 2018 relies, in part, on this type of "input-output" modeling to estimate the net value of the wildfires' business interruptions.

15 Borgschulte, et al., "Air Pollution and the Labor Market: Evidence from Wildfire Smoke," Institute of Labor Economics (2022). Available at: https://docs.iza.org/dp15373.pdf.

16 The "smoke day" frequency estimated by NOAA is based on satellite imagery, with the United States composed of a grid of "smoke polygons." For a given polygon, the total number of annual smoke days is equal to the number of days the polygon was "covered by either light, medium or heavy smoke." See "Hazard Mapping System Fire and Smoke Product," NOAA (2022). Available at: https://www.ospo.noaa.gov/Products/land/hms.html#about.

17 While the study's primary finding is expressed as a change in income per marginal smoke day, the authors rely on data establishing the correlation between smoke levels and PM2.5 concentrations to estimate the change in income as alternatively a function of PM2.5 concentrations.

18 Borgschulte, et al., op cit. at 19. The authors point to four studies that found greater elasticities (ranging from -0.20 to -0.44) and five studies finding lesser elasticities (-0.023 to -0.15).

19 Wang, et al., op. cit.

20 In other words, as shown in Table 4, given a population weighted average of 32.7 smoke days in California in 2018, Borgchulte et al. findings result in an estimated total loss of 3.2% of income statewide, or in 2018 dollars, roughly $44.1 billion.

21 Jones and McDermott, "The Local Labor Market Impacts of US Megafires," Sustainability (2021). Available at: https://www.mdpi.com/2071-1050/13/16/9078/htm.

22 Fan and Grainger, "The Impact of Air Pollution on Labor Supply in China" (2022). Available at: https://ssrn.com/abstract=4003886. Aragon, et al., "Particulate Matter and Labor Supply," Journal of Environmental Economics and Management (2017). Available at: https://openknowledge.worldbank.org/bitstream/handle/10986/27239/j.jeem.2017.02.008.pdf?sequence=1&isAllowed=y. Hoffmann, Bridget y Juan Pablo Rud, "Exposure or Income? The Unequal Effects of Pollution on Daily Labor Supply," RedNIE N°109 (2021). Fan and Grainger (2022) study the labor market impacts of elevated PM2.5 levels in China and find that, on average, a 1 µg / m^3 increase in PM2.5 "reduces an individual's average hours worked by about 14 minutes per week." Aragon et al. (2021) find that in Lima, Peru, the impact of PM2.5 levels on earnings "is concentrated among households with dependents more susceptible to pollution, i.e., small children and elderly adults." The authors report that "an increase in PM2.5 of 10 µg / m3 is associated to a reduction of almost 2 hours worked per week."

23 Jason Vargo, "Time Series of Potential US Wildland Fire Smoke Exposures," Harvard Dataverse (2020). Available at: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/CTWGWE.

24 For instance, our analysis of NOAA data in California in 2020 shows that the average Californian was exposed to 68.7 smoke days that year. We conclude that Borgschulte et al.'s methodology would have resulted in roughly 58.5 smoke days (see Table 4).

25 "Environmental Benefits Mapping and Analysis Program - Community Edition (BenMAP-CE)," Environmental Protection Agency (EPA) (2022). Available at: https://www.epa.gov/benmap.

26 "Technical Support Document - Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors," EPA (2018). Available at: https://www.epa.gov/sites/default/files/2018-02/documents/sourceapportionmentbpttsd_2018.pdf.

27 Wang et al. arrives at a monetary cost of $32.2 billion in 2013 dollars.

28 See, e.g., Thomas et al., "The Costs and Losses of Wildfires," National Institute of Standards and Technology (2017); Chen et al., "Mortality risk attributable to wildfire-related PM 2.5 pollution," The Lancet (2021). Thomas et al. estimated that, based on data from a prior global study of wildfire emissions, from 1997 – 2006 (a period with far less smoke than the 2017 – 2021 period), between 2,940 and 21,095 people across the United States died prematurely due to wildfires. Chen et al. found that within a subset of just 210 American cities accounting for roughly one-fifth of the total U.S. population, wildfire-related PM2.5 was responsible for 3,193 deaths annually from 2000 – 2016. Notably, Chen et al. does not rely on BenMAP to indirectly estimate wildfire-induced mortality effects from an estimated increase in PM2.5 exposure, but instead directly examines the causal impact of wildfire smoke on mortality in the examined cities.

29 Peterson, McCaffrey, and Patel-Weynand, "Wildland Fire Smoke in the United States" US Forest Service Research & Development (2022). Available at: https://www.fs.usda.gov/research/publications/book/wildfiresmoke/wildfiresmokefull.pdf; Aguilera, et al., "Wildfire smoke impacts respiratory health more than fine particles from other sources: observational evidence from Southern California," Nature Communications (2021). Available at: https://www.nature.com/articles/s41467-021-21708-0.

30 NOAA, op. cit.

31 EPA (2018), op. cit.

32 Note that these are the most significant fiscal costs. In addition, the state likely suffers lower sales and property tax receipts and higher costs for health insurance for state workers, among other impacts.

33 Single tax filers (and those who are married but file separately) pay a 6% rate on all taxable income above $34,893; this rate increases to 8% on taxable income above $48,436, and to 9.3% at $61,215. For joint filers, the 6% rate phases in on taxable income above $69,785. As of 2021, according to Census data, the average California household earned $78,672. Though the availability of tax deductions means that average taxable income is somewhat lower, this adjustment does not substantially affect the estimate (the standard deduction for single filers is $4,303 and for joint filers is $9,606 in 2022, according to the state's Franchise Tax Board).

34 Legislative Analyst's Office, "Wildfire and Forest Resilience Package," January 2022. Available at: https://lao.ca.gov/Publications/Report/4495

35 Dept. of Finance, "Slowing State Population Decline Puts Latest Population At 39,185,000," (May 2, 2022), available at: https://dof.ca.gov/wp-content/uploads/Forecasting/Demographics/Documents/E-1_2022PressRelease.pdf; Dept. of Health Care Services, "Medi-Cal Enrollment Update," (November 11, 2022).

36 Dept. of Health Care Access and Information, "Hospital Annual Financial Data," available at: https://data.chhs.ca.gov/dataset/hospital-annual-financial-data-selected-data-pivot-tables.

37 Dept. of Health Care Services, "Medi-Cal May 2022 Local Assistance Estimates," (May 2022), available at: https://www.dhcs.ca.gov/data-andstats/reports/mcestimates/Documents/2022_May_Estimate/M22-Medi-Cal-Local-Assistance-Estimate.pdf.

38 CalFIRE, "California Land Ownership," accessed 12/15/2022, available at: https://gis.data.ca.gov/datasets/f73858e200634ca888b-19ca8c78e3aed_0/explore?location=35.018054%2C-116.716635%2C8.56&showTable=true. This database establishes that the state accounts for 5.4% of all public land statewide. Because public land accounts for 52.1% of all California land, the state's share of total land area is 2.8%. See Laura Treers, "California Public Lands: Past, Present and Future," Berkeley Science Review (December 5, 2020), available at: https://berkeleysciencereview.com/article/2020/12/06/california-public-lands-past-present-and-future. On one hand, this method may overestimate the state's share of property losses because total property value (inclusive of physical structures) is not directly proportional to land area (much state land remains undeveloped). On the other hand, the state's ownership share of land vulnerable to wildfires is likely far higher than 2.8%, given that fires typically ignite in wildlands

39 California Air Resources Board (CARB), "Wildfire Emission Estimates for 2021" (2022), available at: https://ww2.arb.ca.gov/sites/default/files/classic/cc/inventory/Wildfire%20Emission%20Estimates%202000-2021.pdf.

40 CARB, "Current California GHG Emission Inventory Data," (2022). Available at: https://ww2.arb.ca.gov/ghg-inventory-data.

41 CARB, "Draft 2022 Scoping Plan Update" (May 10, 2022). Available at: https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp.pdf.

42 CARB, "Public Comment Draft California's Historical Fire Activity before Modern Fire Suppression," (2021). Given these difference between fossil fuel combustion and the natural release and re-sequestration of forest growth cycles, CARB staff

43 Lefebvre, et al., "Assessing the carbon capture potential of a reforestation project," Scientific Reports (2021). Available at: https://www.nature.com/articles/s41598-021-99395-6#citeas.

44 Korb, et al., "What drives ponderosa pine regeneration following wildfire in the western United States?" Forest Ecology and Management (2019). Available at: https://www.fs.usda.gov/rm/pubs_journals/2019/rmrs_2019_korb_j001.pdf. Stephens et al., "Land ownership impacts post-wildfire forest regeneration in Sierra Nevada mixed-conifer forests," Forest Ecology and Management (2020). Available at: https://bof.fire.ca.gov/media/10078/full-14-c-stephensc-et-al-land-ownership-impacts-post-wildfire-forest-regeneration-in-sierra-nevada.pdf.

45 Stevens-Rumann and Morgan, "Tree regeneration following wildfires in the western US: a review," Fire Ecology (2019). Available at: https://fireecology.springeropen.com/articles/10.1186/s42408-019-0032-1#citeas.

46 Spatial Informatics Group (2017). Available at: https://climateforward.org/wp-content/uploads/2022/07/Buchholz-et-al.-2019--Quantifying-occurrence-and-carbon-emissions-from-d.pdf.

47 CARB relies on the social cost of carbon (SCC) estimate used by the federal Interagency Working Group on the Social Cost of Greenhouse Gases (IWG), which in 2021 updated its SCC estimate to $46.24 in 2020 dollars. We have adjusted this amount to 2022 dollars using growth in California CPI.

48 Fire officials suggest that delays in ignition detection are not typically the primary cause of uncontained wildfires, as most fires are detected quickly (i.e., within 15 minutes of ignition. A study from 2016, which utilizes wildfire data from 2006, suggests that a small number of ignitions may go unreported for an hour or longer. See Koltunov, et al., "The development and first validation of the GOES Early Fire Detection (GOES-EFD) algorithm," Remote Sensing of Environment (2016). Given recent investments in detection technology across the state, the data sample may no longer accurately reflect typical detection times.

49 For example, ALERTCalifornia, a program led by officials at the University of California San Diego, utilizes on a network of over 1,000 monitoring cameras with infrared capabilities. See Caitlin Scully, "ALERTCalifornia Launches to Provide Essential Tools to Understand and Adapt to Wildfires and Natural Disasters in the Golden State," May 3, 2023. Available at: https://alertcalifornia.org/alertcalifornia-launches-to-provide-essential-tools-to-understand-and-adapt-to-wildfires-and-natural-disasters-in-the-golden-state/.

50 Marian Bouchot, "How Cal Fire uses drones to fight wildfires," KESQ, June 15, 2022. Available at: https://kesq.com/news/2022/06/15/how-cal-fire-uses-drones-to-fight-wildfires/.

51 Orora Technologies Press Release, June 1, 2021. Available at: https://ororatech.com/ororatech-successfully-closes-e5-8m-series-a-to-launch-first-satellites-to-tackle-global-wildfire-and-climate-crisis/. Danielle Venton, "Help From on High: Satellites Play Key Role in Fighting California Wildfires," KQED, November 10, 2020. Available at: https://www.kqed.org/science/1970910/help-from-on-high-satellites-play-key-role-in-fighting-california-wildfires.

52 Fire officials devote greater suppression resources to ignitions perceived as more threatening. For example, fire officials may send larger "initial attack" teams, or devote more equipment, to ignitions that are closer to urban area or those which occur on hotter, drier, or windier days. As a result, historical wildfire datasets may show only a weak relationship between, e.g., response times and the probability that a fire escapes containment.

53 Biddle et al., "Measuring the economic impact of early bushfire detection," Australian National University, Centre for Research and Methods (2020); Matt Plucinski, "Factors Affecting Containment Area and Time of Australian Forest

Fires Featuring Aerial Suppression," Forest Science (2012); Arienti et al., "Empirical models of forest fire initial attack success probabilities," Canadian Journal of Forest Research (2006); Collins et al., "Suppression resource decisions are the dominant influence on containment of Australian forest and grass fires," Journal of Environmental Management (2018). Biddle et al. finds that a one-hour reduction in response time would reduce the frequency of large fires by 16%. Plucinksi finds that a one-hour increase in response time leads to a 29% increase in the probability that a given ignition burns more than 20 hectares. Arienti et al. finds that a delay in the average response time from 15 minutes to 65 minutes results in the likelihood of a "response failure" increasing 25%. Collins et al. finds that an increase in response time from 15 minutes to 75 minutes increases the probability of a "containment failure" from 48% to 55%.

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